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TITLE
Nuclear Safety Discussions with AEC - April 21, 1958

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July 10, 1958

NUCLEAR SAFETY DISCUSSIONS WITH AEC-APRIL 21, 1958

Reference: 1) Letter, J.E. Travis to W.E. Johnson, dated March 11, 1958
2) Letter, "Germantown Meeting on Wahluke Slope Problems" J.E. Travis to W.E. Johnson, dated April 18, 1958
3) HW-55756 "Report for Advisory Committee on Reactor Safeguards", R.L. Dickeman, J.W. Healy, R.E. Tomlinson, dated April 16, 1958.
4) Letter, "Report For Advisory Committee on Reactor Safeguards", W.E. Johnson to J.E. Travis, dated April 16, 1958.

INTRODUCTION

Reference (1) requested information on several points to assist the Atomic Energy Commission in reaching a decision on the Wahluke Slope problem; reference (2) posed further matters for discussion and established a meeting in Washington D. C. with division of Production and Division of Licensing and Regulation personnel. The Hanford Atomic Products Operation response to the requests for information is included in references (3) and (4).

Those present in the April 21, 1958 meetings in the Germantown offices of the AEC included the following:

Division of Production:	E. J. Block G. Quinn W. Lindsay
Division of Licensing and Regulation:	C. K. Beck E. Case R. L. Waterfield
AEC:HOO:	R. L. Plum
Hanford Atomic Products Operation:	R. L. Dickeman J. W. Healy R. E. Tomlinson

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SUMMARY

The discussions were devoted to developing the thinking supporting the statements and conclusions reached in references (3) and (4) and amplifying associated points in detailed technology. The discussions were essentially repeated, in more detail in the subsequent meetings with the Advisory Committee on Reactor Safeguards in Washington D. C. on May 9, 1958 and at Hanford June 5 and 6, 1958.

The discussions are summarized as follows:

1. Discussion (A) - Reactor Processes and Hazards - R. L. Dickeman
2. Discussion (B) - Separations Processes and Hazards - R. E. Tomlinson
3. Discussion (C) - Radiological Discussions - J. W. Healy

DISCUSSION

A. Reactor Processes and Hazards - R. L. Dickeman

The reactor hazards discussions concentrated on isolating the types of incidents that could result in release of fission products, the description of the sequence of events necessary for such incidents to occur and a qualitative assessment of the relative probability of the identified types of incidents to occur.

1. Minor to Moderate

Reactor operational incidents are arbitrarily defined as operational experiences in which Process Standards are violated independently of whether damage to the reactor involved results. All such incidents of nuclear safety significance are formally reported to the Commission and the Advisory Committee on Reactor Safeguards. The major fraction of such incidents have involved reactor startup in which the rate of power rise exceeded that specified as permissible in either the low power or high power range. No fission products have been released to the environs in these instances; the only "damage" observed has been an aggravated slug rupture frequency attributed to local overheating of fuel elements or an excessively rapid rate of stress generation.

The minor to moderate class of reactor incident involves the release of fission products from a partial slug to a partial tube loading; releases to date from any cause have not exceeded the inventory from the partial slug level and these have resulted from burning small amounts of uranium during a discharge operation. This class or level of incident would typically encompass burning of reactor fuel elements and loss of cooling to a single reactor tube. The fission product release incidents experienced from the Hanford Reactors to date are summarized below in Table I.

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DISCUSSION (cont'd)

TABLE I
SIFNIFICANT RADIATION RELEASE INCIDENTS - HANFORD REACTORS

Type of Incident	No. of Occurrences	Pertinent Circumstances	Extent & Effects of Release of Fission Products
1. Single tube meltdown	1	Initial Startup of New Reactor	No detectable release of fission products outside of reactor shielding.
2. Reactor Stack Emissions	5	Discharge of ruptured fuel elements. (A fraction of the fission product content of a single fuel element was released in each case. Significant release is usually associated with burning). Exclusion	a) 11/55 (Worst Case)- Material moved southward. Contamination was detected 5 mi from source. Radiation protection (shoe covers, personnel monitoring) were temporarily required outside the 100 Areas. b) 3 instances. Detectable contamination confined to 100 Exlusion Areas. (except in one case 6 "particles" were found in 1,000 sq. ft. surveyed in the adjacent Wahluke Slope). c) 1 instance. No contamination detected outside the 105 building
3. Miscellaneous	1	107 Basin dried out. Wind spread active material	Apr. '57 - Material moved eastward. Detectable to about 5 mi. from sources.

Ref: HW-54636 - Summary of Environmental Contamination Incidents at Hanford 1952-1957, Selby and Soldat.

The slug burning accident results most probably when one or more ruptured fuel elements fail to drop directly into the discharge basin; i.e., lodges in discharge face fittings, becomes overheated, and ignites. Such oxidation is very slow even in the extreme case, in practice is further inhibited by the aluminum cladding which remains essentially intact, and is very unlikely in unruptured elements; in fact, we have never experienced sustained combustion as such. The fire-fighting facilities available at the reactors is sufficient to provide the small quantity of cooling necessary to prevent this type of occurrence from assuming large proportions.

The loss of cooling from a single channel would most likely result from failure of an inlet pigtail. One such failure has been experienced and no damage or release of fission products resulted because of the cooling provided by back-flow from the rear risers which is established under these circumstances. We consider it unlikely that the fission product equivalent from more than one slug or so would be released from this kind of accident except where the Panellit pressure gauge on the stricken channel was also inoperative so that operation of the reactor continued without adquate cooling to a full channel; cooling by backflow under these conditions would be ineffective and in the extreme situation the bulk of the fission products, uranium, and aluminum from the affected

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DISCUSSION (cont'd)

channel would be molten and/or vaporized. However, the probability of complete coolant failure to a single channel is very remote (once in the history of Hanford) and our inspection program would place the chance of an inoperative instrument being on a stricken channel at about one in a thousand.

2. Moderate to Major

The moderate to major accident could involve the loss of cooling from one to several tens of channels; perhaps the most plausible source would be loss of several pigtails concurrently or the failure of an inlet crossheader. In this case, as above, the probability of substantial fission product release cannot be assessed quantitatively although it is certainly much less, perhaps two to three orders of magnitude, than the single channel accident. Cooling by backflow is effective in this case as well unless the failure does not result in a prompt reactor shutdown. However, the several independent instruments act in this case with each having a probability of only about 0.001 of not acting. If the failure of a crossheader were to occur at each end between the check valve and the riser, the check valves would prevent cooling by backflow but the heat transfer to the adjacent lattice should prevent the gross melting of uranium; this selective type of failure is also very improbable - perhaps of the same magnitude as that for the maximum credible accident.

During the discussions it became apparent that the scope, i.e., one to several tens of channels, which was arbitrarily selected as a range of potential fission product volume release, was confusing because the probability of losing coolant to "several tens of channels" is assured to be orders of magnitude less than that from a single tube or even several tubes. Hence it was agreed that greater emphasis would be given probabilities in classifying reactor accidents and loss of coolant from more than a "few" tubes concurrently would be classed as approaching maximum credible in probability of occurrence. It should also be noted that this specifies if single or several tube incidents are not such as to promote propogation of the incident through a larger reactor volume.

3. Major to Maximum Credible

This class of incident is the one treated in detail in many nuclear reactor safety studies and involves the complete, instantaneous loss of coolant pressure from several tens of tubes to the full reactor. In the case of coolant loss from several tens of tubes, perhaps involving the rupture of one or more crossheaders, the cooling obtained from backflow as well as to surrounding tubes with cooling intact would be expected to prevent a gross melt-down, even in the stricken zone, although some melting and fission product release would result. Perhaps the significant point is that the events which could lead to such extensive destruction of primary cooling system piping are probably the type which could cause loss of coolant to the entire reactor with a similar order or probability.

We have determined that a major power excursion will not result from complete loss of coolant but a reactor melt-down is inevitable unless cooling can be restored. There are up to four alternate sources of primary cooling; such an accident would therefore need to involve breaking the supply lines at the reactor or the extremely improbable simultaneous failure of all alternate supplies. In fact, one usually considers earthquake, sabotage, or some form of enemy action to be the most likely causes of complete cooling failure. We do not consider such a failure at Hanford to have other than a "finite" probability of occurring - certainly several orders of magnitude below that of the moderate to major accident class.

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DISCUSSION (cont'd)

B. Separations Potential For Off-site Contamination Via The Atmosphere - R. E. Tomlinson

1. General

The release of biologically hazardous materials to the atmosphere from the separations areas can be postulated to result from enemy action or from a failure of process or equipment. The probability of enemy action is outside our ability to evaluate, and is not considered in the subsequent discussions. Based on the more detailed discussion which follows, we believe that, from a separations viewpoint only, the Wahluke slope is no more subject to inadvertent contamination than is other uncontrolled areas, including Richland. While no quantitative statement is proferred concerning the desirability of controlling more land, some idea of the author's feeling can be inferred from the fact that he purchased a home and lives with his family in Richland. Short of enemy action, we believe the probability of significantly contaminating off-site areas via the atmosphere to be very small.

The potential release of fission products from the separations facilities to the atmosphere may be categorized by possible mechanisms of release as follows:

1) The release of fission products associated with particulate matter from the Redox, Purex, or 234-5 facility.

2) The selective release of iodine-131 from the Redox or Purex plant.

3) The selective release of ruthenium from the Redox plant.

4) The release of contaminated particulate matter from the waste storage tanks.

The above possibilities are discussed separately below. The plant in which uranium nitrate is calcined to the oxide contains virtually no fission products and is not considered further.

2. Particulate Matter

Particulate matter, such as dust, rust, mists, etc., is removed from the ventilation exhaust by filters of sand (Redox) or glass wool (Purex, 234-5). Normally, the contaminated particulate matter which escapes the plants and settles in the environment is not distinguishable from debris from bomb tests. In 1954, particulate ammonium nitrate was found to be settling in the vicinity of the Redox stack. This salt was the product of a gas-phase reaction between water, ammonia from the jacket removal step, and nitrogen oxides from the uranium dissolution step. The emission problem was alleviated by installing spray rings in the stack which permitted the stack liner to be flushed. The stack liners of both plants are now washed down periodically, and ammonium nitrate deposition is no longer a problem.

A major emission of particulate contamination is believed to be possible only through a rapid release of energy in the processing equipment. This energy release could take the form of a nuclear incident or an abnormal chemical reaction. A nuclear incident has not been experienced in a separations plant, but is believed to have about the same energy potential as a chemical reaction. Chemical reactions involving hexone-air, hexone-nitric acid, and unstable silver compounds have been experienced several times. In no case has contamination

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DISCUSSION (cont'd)

escaped the immediate confines of the plant. The principle which is relied upon to prevent contamination spread from the canyon buildings is the concept of "defense in depth". The processing equipment itself is not expected to contain the material in which the energy is released. The cells and building shell will, however, effectively contain the contaminated materials. The cells which contain the process equipment occupy a much larger volume than any piece of processing equipment, and the pressures developed in the larger volumes are considerably reduced. Each cell vents in turn to a much larger volume area, thereby reducing the probability of breaching the building shell to essentially zero. The ventilation filters are connected with the process cells and equipment through long lines and/or ducts which effectively snub any pressure wave thereby minimizing any impact on the filter units. This concept is equally applicable to the 234-5 facility, sustituting hoods and rooms for cells and canyons.

The in-process inventory runs about 20,000,000 curies of fission products in Purex, and 10,000,000 curies in Redox. About 1/2 to 2/3 of the inventory is in the dissolver and feed make-up portion of the plant and the balance in the waste handling portion of the plant. About 0.1% of the inventory is distributed in the process equipment in the rest of the plant. We believe that the probability of a significant emission of particulate matter from a process building is very small.

3. Iodine

We are currently releasing about 10 curies of iodine-131 per week to the atmosphere. The range of release rate is generally between 2 and 20 curies per week. Iodine deposition in vegetation in the environment is detectable in an irregular strip about 4-6 miles wide extending generally in a south-easterly direction toward Richland. Off-site contamination is well below the level believed to be safe for continued ingestion by sheep, and for continued ingestion by humans of garden produce and milk produced in such environment.

In 1944, several hundred curies of iodine-131 were purposely released in one emission so that the Army could determine the dispersion and transport characteristics of the atmosphere. This was a one-shot experiment.

Iodine-131 is handled at a rate of several hundred curies per day. About half of the iodine is volatilized during dissolution, and is absorbed on silver reactors. These units are 2 to 3 feet in diameter by about 10 feet high, filled with a porous packing material which has been impregnated with silver nitrate. The unit is operated at about 200°C for optimum efficiency. These units remove up to 99.9% of the iodine evolved when in good operating condition, but periodic breakthroughs occur through depletion of silver nitrate or failure of temperature control. During the last year, electric heaters were installed in Purex to improve the efficiency of the silver reactors. Back up facilities were placed in operation in both plants for the dual purpose of recovering nitric acid previously routed to the atmosphere and assuring that iodine releases are minimized.

In the Purex process, an average of perhaps ten to fifty curies of iodine per day are volatilized from the processing equipment subsequent to the dissolving step. A steam heated silver reactor is provided to retain this iodine. The gaseous effluent from this unit does not pass through the back-up facilities.

DISCUSSION (cont'd)

Generally speaking, about half of the iodine being released to the atmosphere escapes via the dissolver off-gas, and half via the process off-gases.

4. Ruthenium

About 200 curies of ruthenium were released to the atmosphere from the Redox plant in two incidents in January, 1954. Off-site contamination was limited to a narrow strip of land extending toward Spokane (See HW-54636, Summary of Environmental Contamination Incidents at Hanford, 1952-1957, by J. M. Selby and J. K. Soldat, January 25, 1958). The level of off-site contamination was low, and decayed within six months such that it was indistinguishable from debris from nuclear weapons tests. No subsequent emissions of ruthenium have been experienced.

In the original flow pattern, ruthenium was oxidized to the volatile RuO_4 form and removed from the off-gas stream in a caustic scrubber. The off-gas was then passed through a glass wool filter for removal of particulate matter, and discharged through the 200 foot stack to the atmosphere. The releases of ruthenium were occasioned by the failure of the recirculating pump in the caustic scrubber coincidentally with an instrument failure which permitted the pump failure to be undetected. Since that time, a second caustic scrubber has been installed in series with the original scrubber, and the off-gas has been routed through the sand filter which handles the building ventilation exhaust. The extended surface of the sand filter is an efficient reducing-absorber for the removal of the gaseous tetroxide, and the filter also removes the activity present as particulate matter. The probability of a significant emission of ruthenium is judged to be vanishingly small.

5. Waste Storage

The fission products which have been separated from the uranium and plutonium products are stored in underground tanks of reinforced concrete. The wastes are stored as alkaline slurries, with the bulk of the fission products associated with precipitates of hydrous oxides of iron and aluminum. The cesium remains in solution. We see virtually no chance of contaminating the atmosphere to a significant extent off-site, short of a direct hit by a bomb.

C. Radiological Considerations - J. W. Healy

The following discussion treats the topics discussed in the April 21, 1958 meeting at Washington D. C. Some supporting detail is provided for which available time did not permit detailed development at that meeting. This same material was discussed in the May 9, 1958 and June 5 and 6, 1958 meeting with the Advisory Committee on Reactor Safeguards.

1. Radiological Consequences of Past Incidents

Five stuck emissions have been recorded for the reactor areas as a result of ruptured or burning fuel elements. In addition several spreads of contamination have occurred from dried out effluent basins and wind pickup of the debris. Several of these incidents which are representative of the patterns encountered are described along with contamination incidents in the Separations Areas.

Figure 1 illustratrates the results of a burning element at the 100 Areas in May of 1955. This incident occurred about 7:00 a.m. in the morning during a

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DISCUSSION (cont'd)

period of inversion conditions although the inversion broke shortly after the material was emitted. The winds were variable with speeds on the order of two to four miles per hour generally from the west although they varied from southwest to north between the period of 5:30 to 8:30 a.m. The area represented by the figure consists of the 100-H Area and indicates the deposition pattern of particles resulting from the stack emission. The particle activity distribution of those measured is represented by the small table in the upper right hand corner of the figure. Here it is seen that one per cent of the particles were greater than 2 uc per particle.

The second incident occurred at 100-H in November of 1955 and the deposition pattern is represented by Figure 2. Here detectable particles were found four to five miles south of the stack with the heaviest deposition occurring at the gatehouse approximately one mile from the stack. It was estimated from stack filters that about 0.8 curies were emitted. The incident occurred about two o'clock in the afternoon with winds northeast to north-northeast at one mile per hour until 2:30 p.m. and four miles per hour at 3:30 p.m. The atmosphere was unstable during the emission. As a result of this emission it was necessary to decontaminate automobiles parked at the entrance of the gatehouse and to reroute traffic into the 100-H Area until the contamination was cleaned. Again, the particle activity distribution is given on the figure with one per cent of the measured particles greater than 1.3 uc.

The latest incident is illustrated in Figure 3. This incident occurred at 100-K when an estimated 0.05 uc were emitted. The contamination pattern caused no particular difficulty although one per cent of the particles were greater than 4.5 uc in this particular case.

Figure 4 illustrates the type of contamination pattern which results from the drying out of a retention basin and blowing of the particles in the vicinity. The 107-C basin was allowed to dry in early April, 1957, so that repair work could be completed. The overall contamination pattern is on the order of one mile in extent with particle activities generally less than has been noted in other surveys with one per cent being greater than 1.7 uc.

Figure 5 illustrates the results of an emission of about 230 curies of ruthenium from the Redox plant stack early in January, 1954. Here, the incident occurred during the night hours with winds from the southwest at twenty to thirty miles per hour until 4:30 a.m. At 4:30 a.m. the wind shifted to five miles per hour from the south, and at 5:30 a.m. four miles per hour from the west. The conditions were close to neutral, perhaps slightly unstable, with wind gusts up to forty miles per hour until 4:00 p.m. It is estimated that this emission occurred over a several hour period. The shape of the plume indicated a relatively constant and invariant wind direction over the time of emission and travel, with the width not greatly different from that expected from Sutton's equations. It is impossible to give fine detail on the resulting concentrations on the slope since the survey measurements in this area were not detailed. This ruthenium apparently came out as a fine aerosol with relatively uniform deposition on the vegetation. The concentrations on the slope were on the order of 0.1 to 0.01 uc per gram of vegetation. If we examine these concentrations in view of the present maximum permissible limits for ruthenium and assume that an individual could eat as much as 250 grams per day, it is indicated that these concentrations are between 10 and 100 times the maximum permissible limits for continuous occupancy. At the time of the incident, however, the maximum permissible limit for ruthenium was about 100 times that now accepted. In addition, the narrow

DISCUSSION (cont'd)

character of the plume in this region indicates that very few people would have access to as much as 250 grams of vegetation per day from the area of maximum concentration.

In May, 1954, an estimated 40 curies of ruthenium were again emitted from the 200 West stack with the pattern indicated in Figure 6. The time of this emission has not been definitely fixed. The Redox stack sample removed May 24 was found to contain unusually large amounts of radioactive materials. Surveys immediately outside of the Redox area revealed small white flakes at a frequency of 30 to 300 per 100 square feet. The maximum particles found at various locations are listed in the upper right hand corner of the figure and indicate a general decrease as one moves away from the area. The offshoot to the east in this figure is believed to be due to a pattern existing prior to this emission. In this survey one per cent of the particles were found to be greater than 3.5 uc.

Figure 7 indicates the general ground contamination pattern for the Hanford reservation during the period of September and October, 1954. It was during the summer of 1954 that the particle problem with ruthenium particles occurred. It is believed that the emissions in January caused deposition of ruthenium on the stack and duct walls with later flaking of this material to produce the small, intensely radioactive particles which were found. The activity distribution shown on this figure is reasonably typical of the problems encountered. Here it is seen that 50 per cent of the particles were greater than about 0.2 uc per particle, ten per cent were greater than one uc per particle and one per cent were greater than about five uc per particle. The maximum particle found in the environs was on the order of one millicurie, although its physical size was about one millimeter. Since the hazards from such small discrete radiation sources are not well understood, programs to develop information on the probability of contact and the effects of such particles were started. Survey techniques consisted of reading the particles in a known area with a conventional radiation measuring instrument and converting the meter deflection in units of rads per hour to the estimated quantity of radioactive materials in the particle. In measurement of the dimensions of the particles and the quantity of radioactive material it was found that there was no strong correlation between the quantity of radioactive material in the particle and the physical size, although it was noted that none of the particles were larger than a size proportional to the square of the maximum particle dimension. The ruthenium content of 36 particles was computed from the activity measurements and compared with the weight of the particle. Values ranging from less than 0.01 per cent to 31 per cent were found. Over 50 per cent of those measured had less than one per cent ruthenium dioxide, although a second group of 30 per cent of the total had between two and four per cent ruthenium dioxide. Studies of the effects of these particles on the skin of animals were started and are presently being continued for the possible long range effects.

Studies of the dosimetry of point sources of this material and the possibility of pick up by winds and impaction on humans were carried out in order to provide some basis for the estimation of possible hazards. In addition, studies of the possible transfer of contamination from the ground to people working in the area and the probability of particle pickup from driving or working on contaminated vehicles were made. As a result of these studies it was indicated that the probability of a hazard existing in public areas was remote. However, the various roads on the project were cleaned by spraying and in some cases by hand removal of individual particles and the secondary roads were blocked to non-essential traffic. A survey station was established at the 300 Area and a station for decontamination of vehicles at the 200 Area. Survey stations for

DISCUSSION (cont'd)

personnel were installed in the badge houses in order to detect individuals possibly leaving with radioactive particles on their person. In general, a remarkably few particles were found on people in the course of the survey procedures and no indication of damage or over-exposure to any individual as a result of this emission was noted.

2. Predicted Consequences of Accidents

a. Calculation Procedures

The estimations of consequences of a reactor accident are extremely sensitive to the initial assumptions made as to the course of the accident, the dilution downwind and the limits at which damage is assumed to occur. We are in process of reviewing and revising these calculations in order to take into account the advances in several fields over the past few years and to indicate the variability which may occur under different conditions. The present estimates are a mixture of the new results applied to many of the older limits. The basis of the present estimates will be reviewed to be certain that the procedures are clear before discussion of the results.

(1) Fission Product Burden of Reactors

Figure 1 indicates the calculated quantities of fission products present in a reactor operating at a power level of one megawatt for the time indicated[1] For comparison, the present irradiation time in the Hanford reactors is about 50 - 100 days.

It is interesting to note that the total quantity of fission products is fairly independent of the time of operation in the period immediately following shutdown. At long times after shutdown, however, the quantities of fission products are strongly dependent upon the time that the fuel is in the reactor. As a first approximation, the total quantities of fission products after shutdown is proportional to the power level, while at long times they are proportional to the exposure. Thus, effects in the environs which depend upon radiation exposures soon after shutdown may be expected to depend largely upon the power level while those which depend upon the lingering nature of the contamination will be more dependent upon the exposure.

(2) Quantities Released

One of the large uncertainties in the prediction of consequences is the quantitative estimate of quantities of fission products released under the stimulus of the accident. Parker and Creek[2] have studied the volatilization of fission products from aluminum and zirconium alloys with the following tentative conclusions:

(1) The fraction released from the molten fuel is proportional to the temperature.
(2) The fraction released is strongly affected by the degree of oxidation, the burnout of the fuel, and the type of fuel.
(3) There is some indication that the time of heating is important. Their general data on volatility during heating are given in Table I:

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DISCUSSION (cont'd)

Table I

GENERALIZED BEHAVIOR OF FISSION PRODUCTS ON MELTING

Elements	Release %	Remarks
Xe, Kr, I, Br, Cs	10 - 100	High volatility
Te, Se, Mo, Tc, Ba, Sr	1 - 10	Moderate volatility Volatile in vacuum Non-volatile in air
Y, La, Ce, Pr, Nd, PM	0.1%	Low volatility, form refractory compounds
Zr, Nb, Ru, Rh	0.1%	Low volatility - form alloys and refractory compounds

An overall release of 25 per cent of the fission products, fractionated as:

100% of the noble gases
70% of the halogens
10% of the remainder

has been adopted for these calculations. It may be noted that this predicts a low release for cesium and perhaps tellurium but a high release for strontium, zirconium, and the rare earths although even these results may be dependent upon the physical conditions (i.e., oxygen content, water vapor content, etc.) in the reactor.

Once the fission products are released from the fuel element they must still escape from the reactor structure and the building. To escape from the reactor, the heated gases must pass either along the tube and out the broken end or through the gas system of the reactor which consists of rather small channels in the graphite. In either case there will be considerable deposition of the particulates on the walls of the channel with possible further fractionation of the material. As the gases leave the reactor and expand into the reactor building, it is to be expected that the expansion and subsequent condensation will again result in the removal of fission products from the cloud. These factors have not been well evaluated although meager data are available on the deposition of particles in tubes[3] and it is planned to attempt to apply some of these data to the particular conditions of the reactors.

(3) Delution and Deposition

The travel of the material in the atmosphere will be dependent upon the meteorological conditions existent at the time. The problem of diffusion in the atmosphere has received a considerable amount of effort with reasonable solutions now available for the condition in which the movement is during invariant meteorological conditions. Unfortunately, the characteristics of the atmosphere and the possibility of changes in wind direction and velocity during the period of emission have not, as yet, been well characterized. We do have considerable information on the climatological and average meteorological conditions in the area; however, we have not yet adequately characterized the possibility of encountering variable wind conditions for given periods of time and given meteorological conditions.

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DISCUSSION (cont'd)

The dilution of the radioactive material was calculated in the neutral and unstable case by the use of Sutton's equations for wind speeds of 1, 5, and 10 meters per second. The release was also considered to occur from ground level and from a 200 foot stack.(4) In the actual incident it is not certain as to whether the release would be from the stack or from crevices in the building. In practice it may well occur by both methods and the final result will be a summation of the two. Dilutions in the stable case were calculated from the recent equations derived from Hanford work for an elevated plume. For the ground release condition it is necessary to assume that the constants in the equations were the same as for an elevated plume.

In each case the dilution was calculated for a puff or instantaneous emission and the results expressed in units of integrated exposure at a distance. For a slow release of the material the primary difference in results will be the spreading of the plume due to the wind shifts which occur during the period of emission and the radioactive decay in the time before emission. Thus the distances calculated from an instantaneous emission should be maximum since additional dilution caused by the wind meander will tend to decrease these distances. In general, the integrated exposure at any point along the cloud axis will be decreased by this wind meander although the width of the cloud will be increased. Methods for estimating the effect of such wind meander depend upon a statistical knowledge of wind shifts during various meteorological conditions. Data presently available would indicate that this decrease in concentration and increase in width would amount to something on the order of a factor of three for many of the wind conditions although it must be realized that relatively invariant winds over periods of several hours have been noted.

The deposition of the radioactive materials from the cloud was calculated from the velocity of deposition of the radioactive material. This was taken as 2.7 cm per second for the halogens and about 0.1 cm per second for the particulate materials in neutral atmospheres with wind speeds of 5 meters per second. It was assumed that this deposition velocity was controlled by the meteorological conditions and the deposition velocity was taken as directly proportional to the wind speed. An arbitrary allowance was incorporated for the change in deposition velocity with stability of the atmosphere. The calculations were performed assuming that the halogens were emitted in the vapor phase. If they occur adsorbed on particulate materials then the resulting calculated deposition of the halogens is high in the vicinity of the plant and low at longer distances from the plant.

The calculations were all performed for invariant conditions which were assumed to last over the entire period of cloud travel. This is an extremely unrealistic assumption and was made simply to indicate differences caused by changes in the meteorological conditions. It is extremely dangerous, however, to interpret these results, particularly in the inversion condition, as true indications of the distances and perhaps areas which would be covered in an actual incident.

b. Conditions on Slope

In applying these calculations to the Wahluke Slope it must be remembered that the terrain slopes upward from the reactors so that the elevated release, in particular, poses problems in the effects of terrain which have

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DISCUSSION (cont'd)

not been completely solved. In general, it is believed that the concentrations under these conditions will be higher than calculated for a flat plane, at least at distances where the plume has not yet diffused to the ground, but they may well not be as high as would be predicted by an imaginary plane intersecting the plume at this elevation above the hypothetical plane at the base of the stack.

(1) Calculated Conditions

A full meltdown of a reactor would release on the order of 1000 to 2000 megacuries of fission products which would decay to about 500 - 1000 megacuries at one day after reactor shutdown. A single tube at 1.5 megawatts would release on the order of one megacurie which would decay to about 0.5 megacuries at one day.

The maximum distances at which various actions would be required have been summarized in Table II for both the ground and elevated release case.

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Table II

MAXIMUM DISTANCES
(miles)

	Strong Inversion	Moderate Inversion	Neutral	Unstable
Ground Level Release Case				
Full Release				
Lethal		15 - 30	2 - 6	
Long Evacuation	100 - 250	200 - 300	30 - 40	20 - 25
Temporary Evacuation	-	-	100 - 150	70 - 90
Halogens	5 - 10	15 - 30	40	20 - 30
Crops	300 - 600	600 - >1000	300 - 600	250 - 350
Halogens	5 - 10	30 - 100	>1000	>1000
200 Foot Release Case				
Full Release				
Lethal		0 - 180	3 - 8	
Long Evacuation	0 - 500	250 - 300	30 - 40	15 - 25
Temporary Evacuation	200 - 700	>1000	100 - 160	70 - 80
Halogens	600 - 800	120	50 - 70	30 - 40
Crops	>1000	>1000	400 - 600	250 - 300
Halogens	>1000	300 - 800	>1000	>1000
Ground Level Release Case				
Single Tube				
Long Evacuation	5 - 6	3 - 4	<1	<1
Temporary Evacuation	20 - 25	10 - 20	2 - 3	1 - 2
Halogens	2 - 3	1 - 3	1	~0.5
Crops	50 - 80	60 - 70	7 - 9	4 - 5
Halogens	5 - 10	20 - 50	100	60 - 70
200 Foot Release Case				
Single Tube				
Long Evacuation	-	-	-	-
Temporary Evacuation	<1	<1	2 - 3	1 - 2
Halogens	-	-	1 - 2	~0.8
Crops	<1	0 - 40	6 - 10	4 - 6
Halogens	900 - 1000	150 - 200	150 - 200	70 - 80

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DISCUSSION (cont'd)

It should be noted that for an elevated release into a stable atmosphere, the plume may pass completely over the slope area and cause damage elsewhere or the elevated terrain may cause higher ground concentrations on the slope than indicated with consequent greater damage at these close approaches and less at large distances. The crop distance for the single tube incident is derived primarily from the halogens and represents a seasonal type of damage. The more lingering contamination of crops from the particulates would be in the range of perhaps five to ten miles for the unstable conditions.

For a prolonged release period the distances may be reduced as explained earlier by wind shifts. For example, meander which increases the plume width by a factor of two, decreases the distances by a factor of about 1.5; while meander which increases the width by a factor of four decreases the distances by a factor of about two. In field tests in the stable case, the average plume width was on the order of 1.5 to 2.0 times that which was used in thse estimates when emission was over a 30 to 60 minute period. In the recent diffusion experiments over the Wahluke Slope from a ground source in slightly unstable conditions, the average plume width over a two-hour period was 3.2 times the short period width. For releases over periods of several hours, then, it appears reasonable to assume that the wind meander will lower the average concentration by a factor of perhaps three to four and simultaneously increase the width of the plume. This would have the effect of decreasing the distances estimated above by a factor of perhaps two. It should be noted, however, that conditions of relatively stable wind direction do occur over periods of several hours so that the possibility of reaching these maximum distances still exists.

Under these conditions the property damage category in the full meltdown case reaches far beyond the slope area with the slope itself comprising a small part of the damage. The estimated lethal distances are of the same range as the dimensions of the slope so that the bulk of the immediately lethal section will be in this vicinity if the wind is in the direction of the slope. No damage criteria was included in the table because of the uncertain nature of the damages resulting and the possible late effects on people at some distance.

For the single tube incident, lethality is not expected outside of the immediate plant area and the attention shifts to property damages. Here the range of evacuation distances under unfavorable release conditions are on the order of the slope dimensions although under more favorable conditions evacuation would not be necessary. Prolonged control of crops from the particulates is estimated to be on the order of eight to nine miles maximum under neutral or unstable conditions and up to 60 to 70 miles under stable conditions. Temporary restrictions on milk and some crops may be necessary from the iodine-131 content at larger distances, although this will depend upon the width of the plume (i.e., the fraction of the total food consumed by families that is grown in the plume) and the makeup of the local population affected (i.e., the number who derive their food supplies from their own land).

For general information the estimated areas involved are listed in Table III.

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Table III

AREAS
(miles^2)

	Strong Inversion	Moderate Inversion	Neutral	Unstable
Full Release				
Ground Level Release Case				
Lethal		10 - 100	0.2 - 2	
Long Evacuation	300 - 700	800 - 1200	40 - 60	20 - 30
Temporary Evacuation	> 1000	>1000	500 - 700	200 - 300
Halogens	1 - 6	5 - 20	60 - 70	40 - 50
Crops	> 1000	>1000	>1000	>1000
Halogens	5 - 10	50 - 600	>1000	>1000
200 Foot Release Case				
Lethal		0 - 200	0.3 - 3	
Long Evacuation	0 - 100	>1000	30 - 40	20 - 30
Temporary Evacuation	>1000	>1000	300 - 400	300 - 400
Halogens	>1000	250 - 300	130 - 170	90 - 100
Crops	>1000	>1000	>1000	>1000
Halogens	>1000	>1000	>1000	>1000
Single Tube				
Ground Level Release Case				
Long Evacuation	1 - 2	<1	<1	<1
Temporary Evacuation	8 - 10	4 - 8	<1	<1
Halogens	<1	<1	<1	<1
Crops	70 - 80	60 - 80	2 - 4	1 - 2
Halogens	3 - 10	10 - 70	300 - 400	200 - 300
200 Foot Release Case				
Long Evacuation	<1	<1	<1	<1
Temporary Evacuation	<1	<1	<1	<1
Halogens	<1	<1	<1	<1
Crops	<1	<1 - 9	2 - 3	1 - 2
Halogens	>1000	>1000	800 - 1000	500 - 600

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DISCUSSION (cont'd)

These areas are much less sensitive to wind shifts than the distance since meander which results in a smaller distance will also result in a wider plume with the damage occurring closer to the reactor but about the same areas covered. Again, in the single tube case, the crop damage is primarily from iodine-131 deposition. Long term damage from the particulates is generally confined to areas on the order of one to ten square miles except in the ground release during inversion conditions when areas up to 80 square miles are involved.

All of the above computations assume that the halogens are emitted as vapors and the particulates as aerosols. Halogen patterns will be greatly changed if the vapors adsorb on particles of other materials such as apparently occurred at Windscale. Although these specific calculations have not yet been carried out, it is believed that such an emission would tend to decrease the areas of iodine contamination. The emission of large particles, such as apparently occurs in some of the minor emissions, would completely invalidate these calculations since the deposition mechanisms and thus the patterns would be changed. An accident leading to the consequences postulated, however, would be expected to produce aerosols of type envisioned.

(2) Comparison with Diffusion Experiments

The diffusion experiments with ground level sources of fluorescent pigment which have been conducted over the Wahluke Slope area have been described earlier. In general, these experiments consisted of three runs eastward from 100-H, 100-D, and White Bluffs and three runs northward from 100-B. The release was made for periods of two to three hours and samples were taken along lines perpendicular to the wind direction. Conditions of slightly unstable atmosphere with brisk winds were chosen to maximize the probability of striking the sampling line.

Unfortunately the data are still not detailed enough to permit the detailed assessment of the effects of terrain and local influences on the diffusion. These experiments have a built-in correction for deposition which has not yet been evaluated for this pigment although it should be close to that assumed for particulate fission products. Additional long range studies will be needed to assess the full impact of these variables.

These experiements have given the opportunity to assess the possible inaccuracies of the analyses of accident consequences calculations using conventional diffusion equations. We have compared the ratio of the maximum concentration as calculated by Sutton to the maximum measured calculation for these conditions.

These results are given in Table IV:

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DISCUSSION (cont'd)

Table IV

COMPARISON OF CALCULATED AND MEASURED PEAK CONCENTRATIONS

Exp.	Distance (miles)	Wind Speed (m/sec)	Ratio, Calculated/Measured
1	3	10	6
2	2	10.3	3.8
	8		1.6
3	2	8	21
	8		5.4
4	1.2	5.4	36
	4.5		13.6
5	1.7	5.8	100
	4.2		84
6	2.2	12	27
	8.6		18

This ratio includes the effects of both the terrain and wind meander during the two to three hour collection period. The first item of interest is the generally lower ratio at the greater distance. This is a consequence of the lower slope of the concentration versus distance curve and additional points will be required to see if this trend is continued. Experiments one and two give ratios consistent with those expected from wind meander during this period while the others all appear high, indicating stronger meander, terrain effects, or inadequacy of Sutton's equations. In experiment four, a measure of the standard deviation of the plume width for short time periods over a two hour total period was obtained at a distance of 4.5 miles. This analysis indicated a standard deviation of 880 meters for the short-term width as compared to a calculated width of 600 meters from Sutton. The average concentration at the center of the short term plume was 3.2 times the average concentration at the center of the plume averaged over two hours. If the ratio of 13.6 given in the table for this point is corrected for these factors the measured concentration is still low by about a factor of three.

In general, then, these experiments indicate that, while the equations used in the analysis are capable of predicing the concentrations at the distances of concern reasonably well when allowance is made for wind meander (i.e. experiments one and two) it is probable that, in the general case, they overestimate the concentration. The flat gradient in concentration downwind from the source is of interest particularly when extrapolations to long distances are required.

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(3) Evacuation Times Available

Minimum evacuation times have been previously estimated for a complete reactor meltdown.[5] These times were calculated from the moment of complete water loss and resulting meltdown using the estimated rates of emission given by Rogers. These indicate no emission in the first 15 minutes; a linear increase from zero to 200 curies per second during the period from 15 minutes to one hour and a uniform emission rate of 200

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DISCUSSION (cont'd)

curies per second from one hour to 30 hours. The criterion of injury was chosen as an integrated exposure believed to be roughly equivalent to 50 to 75 r of whole body exposure.

The total time available before this exposure is reached is compounded of three parts.
(a) The delay in emission (taken here pessimistically as 15 minutes).
(b) The travel time which is inversely proportional to the average wind velocity in the absence of strong plume meander, and
(c) The time to build the dose to injurious levels.

For each distance there is a wind speed which provides a minimum evacuation time. For wind speeds less than this the travel time predominates as the controlling factor while for speeds greater than this the time of build-up of the dose predominates due to the greater dilution of the plume. These wind speeds, for minimum time, range from three miles per hour at one mile to four to five miles per hour at 20 miles. The minimum evacuation times then range from 0.88 hours at one mile to ten hours at 20 miles with a reasonably linear relationship between distance and time. Thus, the minimum evacuation times in hours approximate one-half of the distance in miles. For other wind speeds the evacuation times are longer ranging up to 2.5 times as long at 20 miles per hour winds and 1.5 to two times as long at one mile per hour winds.

These evacuation times will probably not be much shorter than given but could well be several hours longer due to additional delays in emission and plume meander. The values can be regarded as little more than order of magnitude although they do indicate probable zones which may require warning before the plant emergency plan is completely in action.

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2. Parker, G. W., Creek, G. E., The Volatilization of Fission Products by Melting of Reactor Fuel Plates, CF-57-6-87, July 15, 1957.

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4. Healy, J. W., Calculations on Environmental Consequences of Reactor Accidents, Interim Report, HW-54128, December 11, 1957.

5. Dickeman, R. L., et. al., Report for Advisory Committee on Reactor Safeguards, HW-55756, April 16, 1958.

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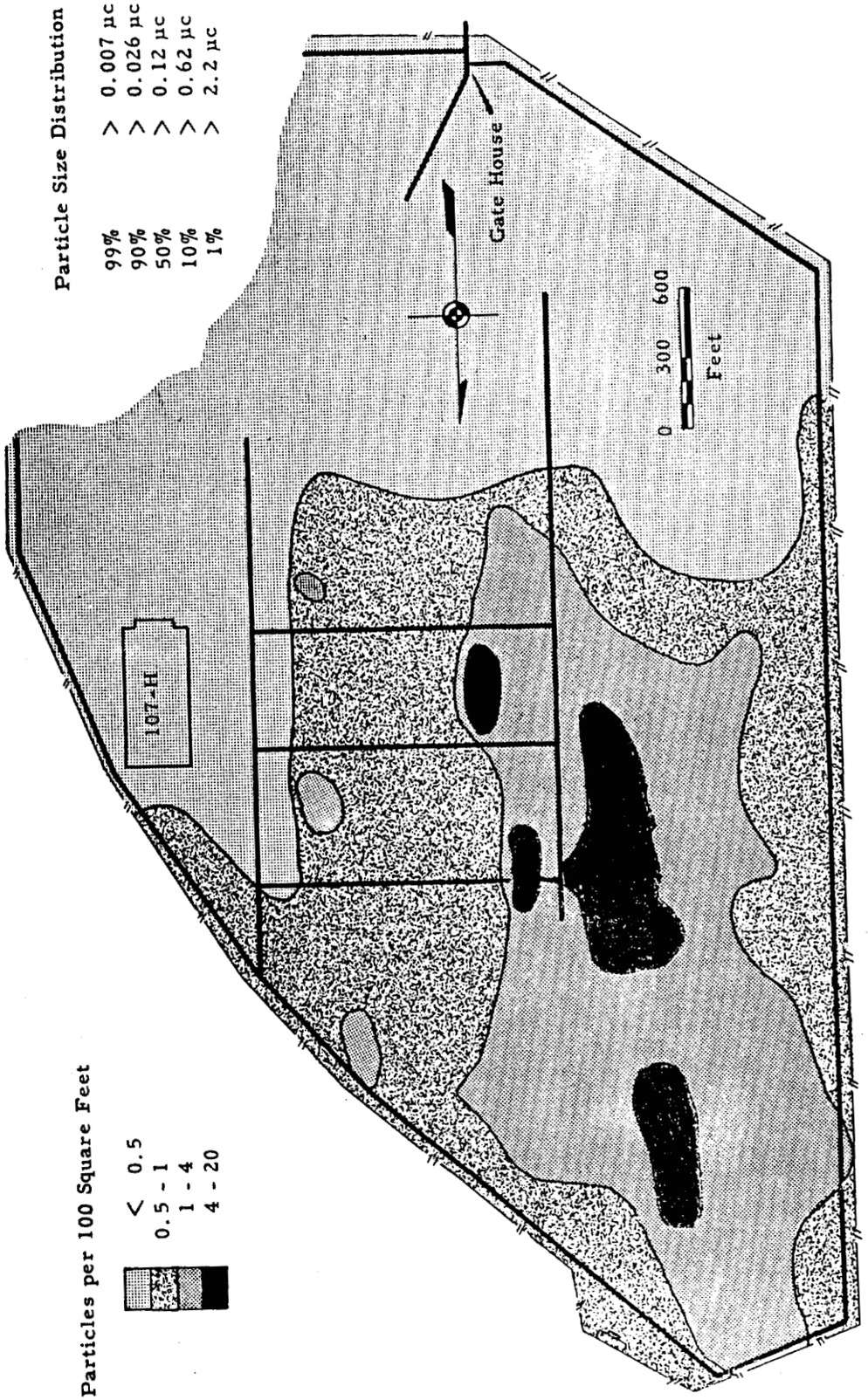

Figure 1
GROUND CONTAMINATION PATTERN
100-H
MAY 26, 1955

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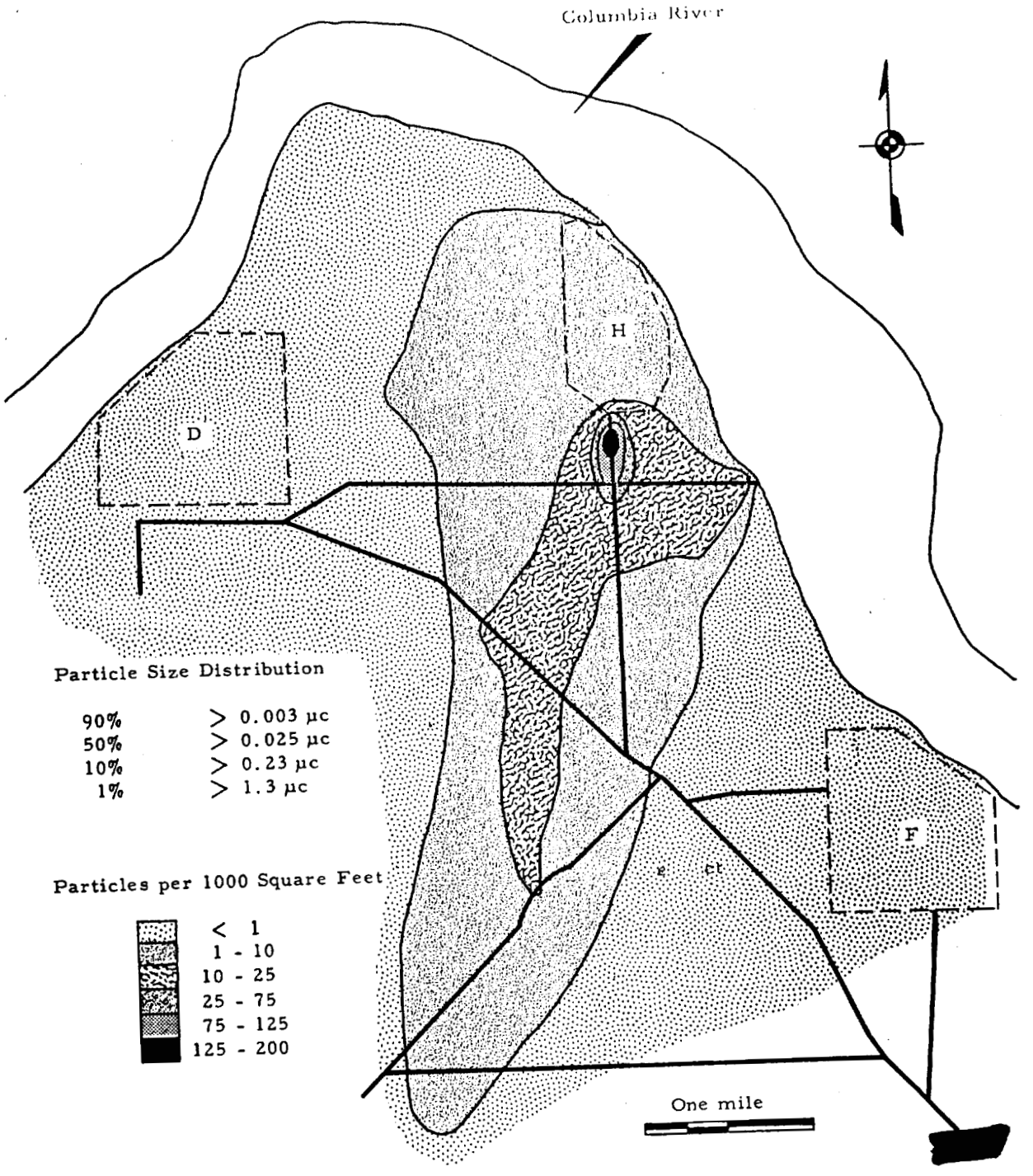

Figure 2

GROUND CONTAMINATION PATTERN
100-H AND VICINITY
NOVEMBER 1-5, 1955

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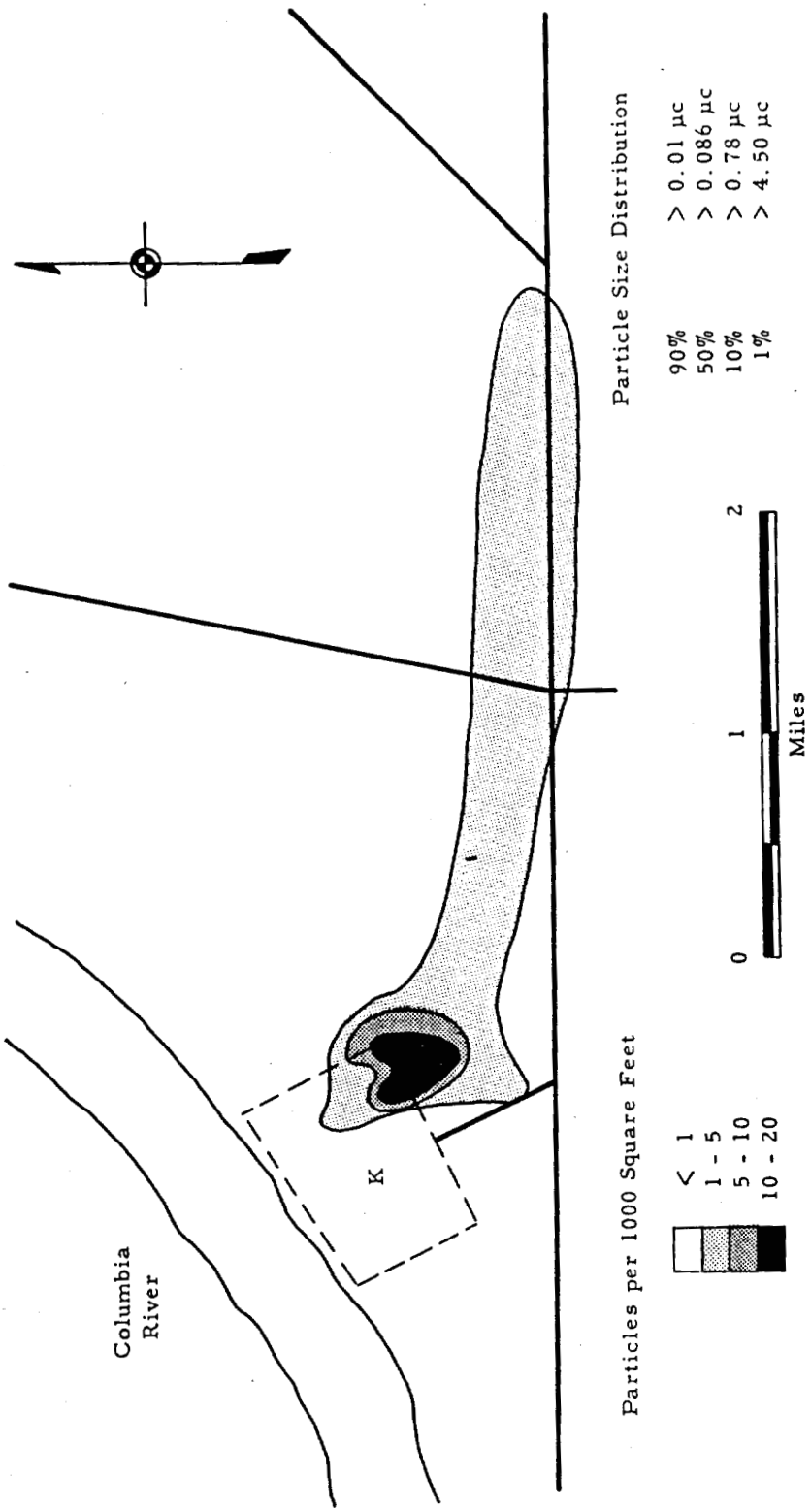

Figure 3

GROUND CONTAMINATION PATTERN
100-K AND VICINITY
APRIL 14, 1958

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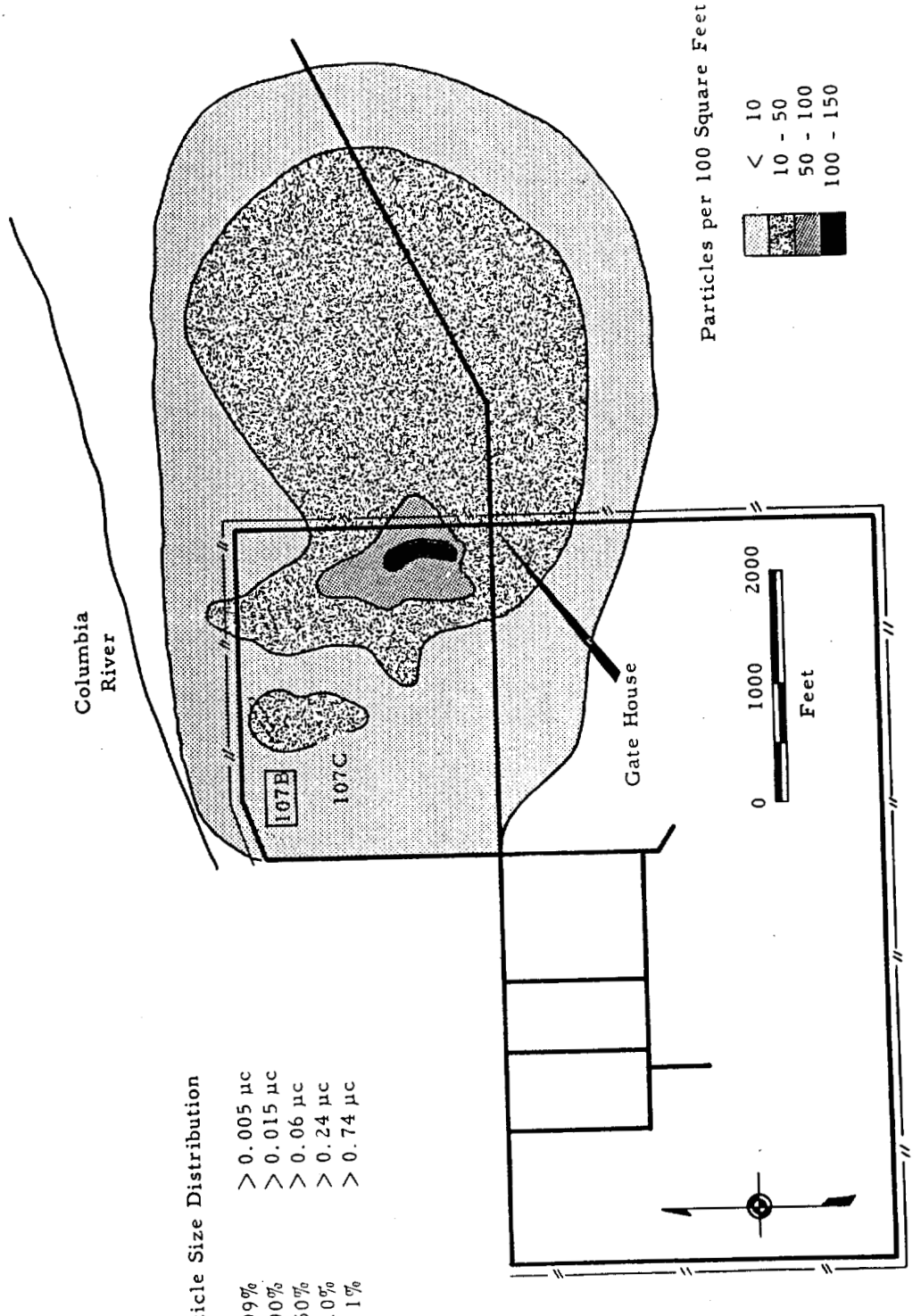

Figure 4
GROUND CONTAMINATION PATTERN
100-B
May 3 - 10, 1957

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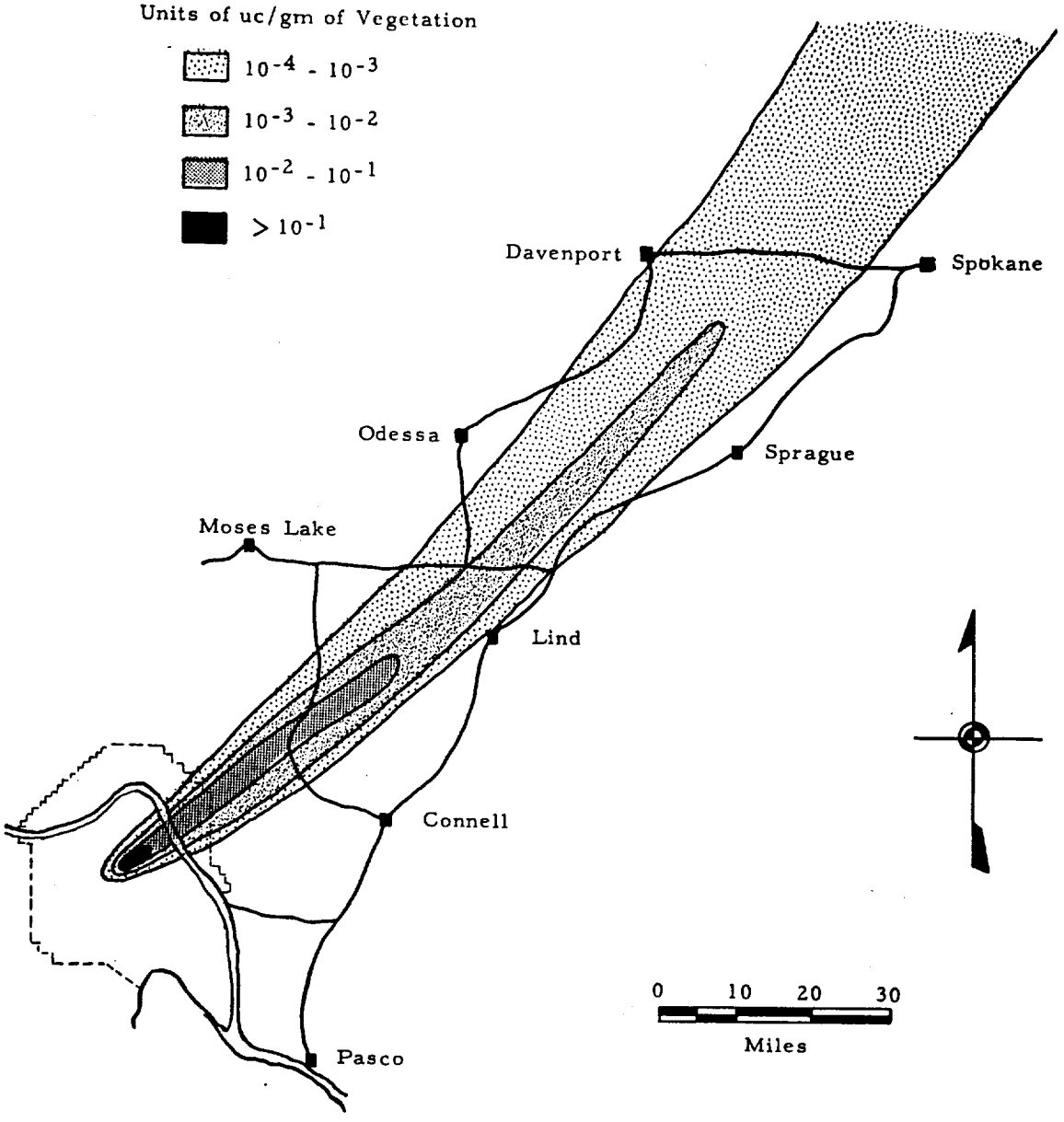

Figure 5
CONTAMINATION ON VEGETATION
EASTERN WASHINGTON
JANUARY, 1954

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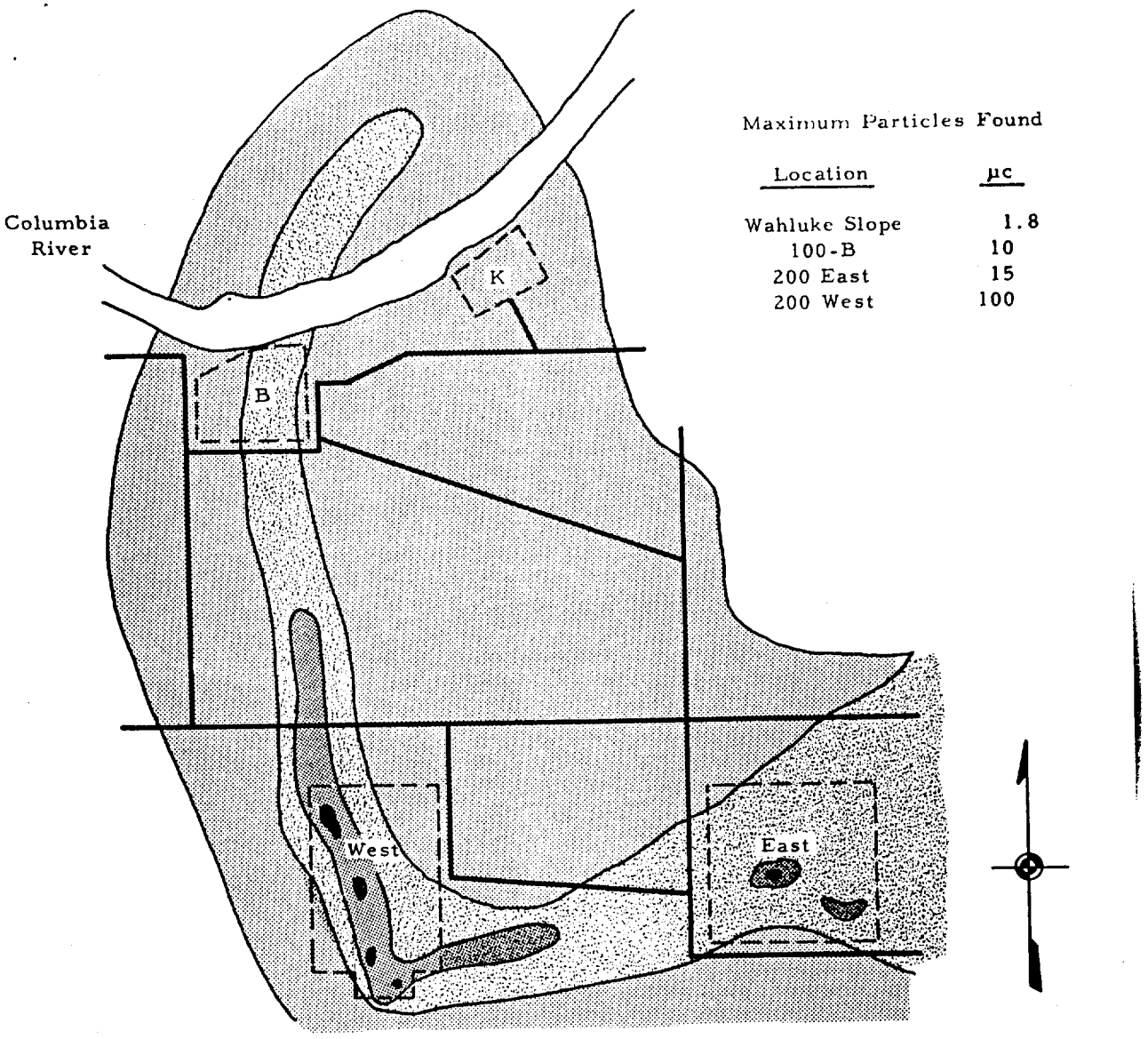

Maximum Particles Found

Location	µc
Wahluke Slope	1.8
100-B	10
200 East	15
200 West	100

Particles per 1000 Square Feet

- <10
- 10 - 100
- 100 - 250
- >250

Average uc per Particle

- < 0.18
- 0.18 - 0.7
- 0.7 - 3.5
- > 3.5

0 1 2
Miles

Figure
GROUND CONTAMINATION PATTERN
200 WEST, 200 EAST & 100-B
MAY 25 TO JUNE 10, 1954

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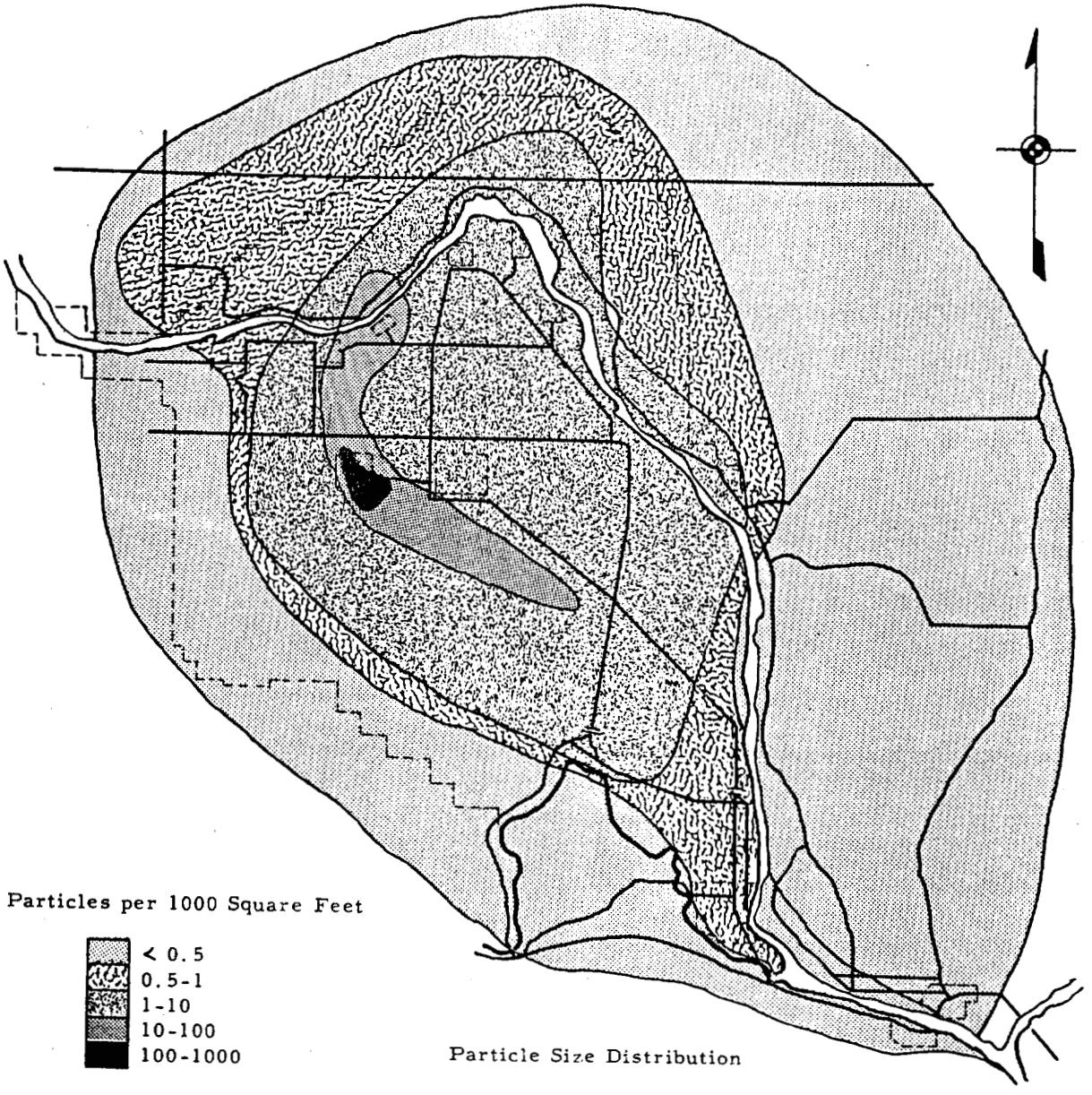
Figure 7
GROUND CONTAMINATION PATTERN
HANFORD AND VICINITY
SEPTEMBER - OCTOBER, 1954



Particle Size Distribution

99%	> 0.009 μc
90%	> 0.03 μc
50%	> 0.18 μc
10%	> 1.1 μc
1%	> 4.8 μc

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