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Documentation for an Environmental Impact Statement: the Pantex Plant

Radiation Monitoring and Radiological Assessment of Routine Releases

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Supplementary Documentation for an Environmental Impact Statement Regarding the Pantex Plant

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RADIATION MONITORING AND RADIOLOGICAL ASSESSMENT OF ROUTINE RELEASES

by

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ABSTRACT

This report documents work performed in support of the preparation of an Environmental Impact Statement (EIS) regarding the Department of Energy's Pantex Plant near Amarillo, Texas. Results of environmental measurements performed for the EIS are described. Descriptions are presented of existing radiological conditions at the Pantex Plant and the two alternate sites, the Iowa Army Ammunition Plant near Burlington, Iowa, and the Hanford Site in Washington. Radiological impacts on these three sites by the proposed options and alternatives considered in the EIS are evaluated. Only impacts from routine operations are considered; impacts from accidents are treated in other reports.

I. INTRODUCTION

This report documents work performed in support of the preparation of an Environmental Impact Statement (EIS) regarding the Department of Energy's Pantex Plant near Amarillo, Texas. That EIS addresses continuing nuclear weapons operations at Pantex and construction of additional facilities to house those operations. The EIS was prepared in accordance with current regulations under the National Environmental Policy Act. Regulations of the Council on Environmental Quality (40 CFR 1500) require agencies to prepare EISs with less than 300 pages for complex projects. This report was prepared by Los Alamos National Laboratory to document details of work performed and supplementary information considered during preparation of the Draft EIS.

This report describes the environmental sampling and radiological assessment performed by Los Alamos National Laboratory to evaluate

environmental radiation at the Pantex Plant and at the two alternate sites, the Iowa Army Ammunition Plant (IAAP) near Burlington, Iowa, and the Hanford Site in Washington. Measurements included determination of external radiation at Pantex and IAAP, air and foodstuff sampling at Pantex, and soil sampling at Pantex and IAAP. This sampling regime complements the foodstuff, soil, sediment, and water sampling programs at Pantex performed by other Laboratory personnel (Purtymun 1982, Wenzel 1982B). Environmental radiation measurements were not performed at Hanford because this area is extensively monitored in an ongoing program by Pacific Northwest Laboratory (Sula 1982).

Radiation doses* to the public were estimated for current operations at each site, as well as for the proposed operations and facilities. Doses were calculated using atmospheric dispersion modeling and pathway analysis. The pathways that were considered included exposures through inhalation of airborne radioactive material and consumption of food affected by released material. Doses from current and proposed facility operations were compared with those incurred from natural background radiation. Only radiological impacts from routine operations were considered. Impacts from accidents have been treated by Elder (1982).

Current operations at Pantex that involve the release of radioactive material are tests using depleted uranium, burning high explosives attached to depleted uranium, and operations with tritium. Other releases occur from the resuspension of soil from test zones.

Some offsite releases at IAAP may also occur because of wind resuspension of soil in the test area that was formerly used for depleted uranium tests. Because operations by the Atomic Energy Commission terminated in 1974 at IAAP, there are no other current emissions of radioactive materials.

Releases of radioactive material at Hanford are described in the 1981 Hanford environmental surveillance report (Sula 1982).

The options and alternatives for Pantex presented in the EIS include three proposed operations that are expected to have routine emissions of radioactive material. These operations would occur at whichever site is chosen to continue the Pantex program, so the impact of these operations was evaluated at all three sites. These operations are (1) continuation of the dynamic testing program with depleted uranium, (2) continued work with tritium, and (3) use of a coal-fired power plant for production of energy. At Pantex the termination option was also considered to estimate the radiological impacts at Pantex if operations there were relocated to either IAAP or Hanford.

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*Dose in this report refers to dose equivalent, measured in rem or mrem.

II. RADIOLOGICAL ASSESSMENT

A. Introduction

Radiation doses to the public were estimated for current and proposed routine operations at Pantex, IAAP, and Hanford and for natural background radiation. All doses from current operations were estimated for 1981, and those from proposed operations were estimated for 1990. Potential health risks associated with these doses were calculated using the procedures recommended by the Committee on the Biological Effects of Ionizing Radiations of the National Academy of Sciences (the BEIR Committee) (BEIR III 1980).

Estimates of the radiation doses from current operations were based, as much as possible, on environmental monitoring data. However, as can be seen from the data presented in Section III and from data taken by other authors (Purtymun 1982, Sula 1982, Wenzel 1982B), concentrations of radioactive materials in environmental media and associated doses resulting from facility operations were usually so small that they were indistinguishable from background levels. In these cases, doses were estimated by environmental dose assessment models. In addition to doses from current operations, doses caused by routine releases from proposed operations at each site were estimated with models.

Doses from continuous releases, such as from the proposed coal power plant, were calculated using the computer code AIRDOS-EPA (Moore 1979). This code uses standard Gaussian dispersion meteorological methods, a dose calculation procedure based on the US Nuclear Regulatory Commission's (USNRC) Regulatory Guide 1.109 (USNRC 1977A), and site-specific meteorological, agricultural, and demographic data. (See Appendix D.)

Radiation doses from instantaneous releases of depleted uranium during test shots were calculated using a modified version of AIRDOS-EPA. A description of the procedure that was used is in Appendix D.

Pantex and IAAP have no discharges to ground and surface waters of liquid effluents containing above-background radioactive material concentrations. Similarly, no such liquid effluents are expected from proposed activities being considered in the Pantex EIS. Therefore, doses due to water transport of radioactive material were considered to be negligible at Pantex and IAAP and for the proposed activities at all three sites. This conclusion is supported by environmental sampling of ground water, surface water, soils, and sediments that was performed for the Pantex EIS (see Section III.F and Purtymun 1982). No statistically significant differences were found in any of these media between samples taken from areas that could be potentially affected by plant operations and samples from control areas (Purtymun 1982).

All doses estimated by these models are 50-year dose commitments. Many radionuclides of concern have very long clearance times in organs such as bone and liver; therefore, irradiation of these organs can occur long after actual exposure. Use of the 50-year dose commitment accounts for this. This dose commitment is the total dose that a particular organ receives from an intake of a radionuclide during the 50 years following that intake.

An alternative interpretation of the 50-year dose commitment is also useful. The 50-year dose commitment can be viewed as the maximum annual dose that one would receive in 50 years if annual radioactive material intake remained the same during those 50 years. The basis for this interpretation is that the dose that an individual receives from inhaled or ingested radioactive material during the 50 years following an intake (the 50-year dose commitment) is numerically equal to the dose he would receive in the 50th year of continuous intake. Under continuous intake, annual radiation dose would either remain essentially constant in time or increase with time. For continuous intake of radioactive materials with short physical or biological half-lives, all annual doses would be approximately the same. For radionuclides with long physical and biological half-lives (such as ^{238}U, ^{235}U, and ^{234}U, which are considered in this report), the 50th-year dose would be appreciably larger than the 1st-year dose, and larger than any dose in any of the years before the 50th.

The dose calculational method used here follows the recommendations of the International Commission on Radiological Protection (ICRP) in that the entire dose commitment is charged against the year in which the intake or exposure occurs (ICRP 1977).

Doses were calculated using a quality factor of 20 for alpha radiation (ICRP 1977). A relative damage factor of 5 was used in calculating the bone dose from a chain having thorium as parent isotope. Following the ICRP, we considered the long-lived isotopes of uranium, radium, polonium, and lead uniformly distributed in the bone (ICRP 1979, ICRP 1980). A relative damage factor of 1 was used to calculate bone dose from chains whose parent isotope was one of these radionuclides.

B. Existing Radiological Conditions

1. Background Radiation. Background radiation doses were based on environmental measurements (see Section III of this report) (Sula 1982, Miller 1978) and on values published in reports by the National Council on Radiation Protection and Measurements (NCRP) and the US Environmental Protection Agency (EPA) (NCRP 1975, Klement 1972).

External penetrating radiation exposure levels were measured at Pantex by Pantex (MHSM 1982), EG&G, Inc. (Boyns 1981), and Los Alamos National Laboratory (Section III); in the Burlington area (IAAP) by a nearby nuclear

power plant (EIC 1980) and by aerial flyovers by EG&G, Inc. (Burson 1974); and at Hanford by Pacific Northwest Laboratory staff (Sula 1982).

External radiation levels at any location are variable for many reasons. Cosmic radiation is influenced by the 11-year solar cycle. During 1980-1981 the solar cycle was near an 11-year maximum, which corresponds to a period of reduced cosmic radiation because of increased shielding from the solar magnetic fields. The amount of soil moisture and snow cover can affect dose rates from terrestrial external radiation, providing another source of variability.

Because of this variability in external radiation levels, typical background doses were estimated from the cosmic ray exposure versus altitude graphs published by the NCRP (NCRP 1975) and from terrestrial dose rates as determined by in situ spectroscopy (described below and in Section III.B.2). These estimates represented long-term average doses typical of the three areas under consideration.

Doses from cosmic radiation in Table I were estimated for the altitudes of Pantex, IAAP, and Hanford from NCRP Report 45 (NCRP 1975). These doses include the component from neutron exposure, as well as the components from charged particles (principally muons and electrons) and photons. The cosmic radiation doses in Table I were reduced by 10% from the values given for outdoor dose rates in NCRP Report 45 to account for shielding by buildings.

The components of natural background external radiation dose caused by terrestrial radioactivity were estimated for all three sites. At Pantex and IAAP, soil concentrations and external radiation levels of both naturally occurring and worldwide fallout gamma-emitting radionuclides were measured using in situ gamma-ray spectroscopy (Section III.B.2). Gamma spectra were taken at 14 selected field locations around Pantex and 10 sites around IAAP to determine radionuclide soil concentrations. Radionuclide soil concentrations at Hanford were taken from Miller (1978). From these soil concentrations, external radiation levels were estimated using conversion factors from the NCRP (1975) and Beck (1972) (Section III.B.2).

Results of the external terrestrial dose rate measurements are in Table I. Two corrections were applied to the measured radiation levels to obtain these doses: a 20% reduction in dose caused by shielding from buildings and a 20% reduction from self-shielding by the body (NCRP 1975).

TABLE I

ANNUAL BACKGROUND RADIATION DOSES

Estimates of Current Background Radiation Doses (mrem) per Year of Exposure to a Hypothetical Individual

	Whole body	Lung	Bone	Gonads
Pantex				
Cosmic	37	37	37	37
External terrestrial	38	38	38	38
Internal	31	231*	216	36
Total	106	306	291	111
IAAP				
Cosmic	28	28	28	28
External terrestrial	26	26	26	26
Internal	31	231*	216	36
Total	85	285	270	90
Hanford				
Cosmic	27	27	27	27
External terrestrial	24	24	24	24
Internal	31	231*	216	36
Total	82	282	267	87

Population Doses (person-rem) in the 80-km Assessment Area Around Each Site from Natural Background During 1981

Pantex	27 200	78 600	74 700	28 500
IAAP	31 600	106 000	100 000	33 500
Hanford	27 000	93 200	88 200	28 700

Population Doses (person-rem) in the 80-km Assessment Area Around Each Site from Natural Background During 1990

Pantex	30 600	88 400	84 100	32 100
IAAP	32 600	109 000	104 000	34 500
Hanford	31 900	110 000	104 000	33 800

*Exposure to bronchial epithelium is 0.2 WLM/yr.

Internal background radiation was taken to be 31 mrem/yr (whole body), 216 mrem/yr (bone), 231 mrem/yr (lung),* and 36 mrem/yr (gonads). These doses were based on doses in NCRP Report 45 (NCRP 1975) and Klement (1972), modified for a quality factor of 20 for alpha radiation. In calculating the background bone dose, long-lived radioisotopes of uranium, radium, polonium, and lead were assumed to be distributed uniformly throughout the bone (ICRP 1979, ICRP 1980). A relative damage factor of 1 was used for chains that have one of these radionuclides as parent isotope. Bone doses were calculated using the effective energies and radionuclide concentrations in bone presented in NCRP Report 45 (NCRP 1975). A description of the calculation of these background doses is in Appendix D.

Population doses caused by background radiation were calculated by multiplying the individual natural background dose in Table I by the 1981 and 1990 populations of the area within 80 km of each facility. These doses are also in Table I.

2. Doses in 1981 from Facility Operations.

a. Pantex. Sampling of air, water, foodstuffs, and soil and sediment and measurements of external radiation levels were performed in offsite areas that could have been affected by Pantex operations and in control areas that were beyond the influence of Pantex operations (Section III) (Purtymun 1982). No statistically significant difference was found between samples taken from potentially affected areas and control areas.

Radiation doses resulting from Pantex operations could not be estimated from sampling results because effects of operations were less than measurement detection limits. Consequently, radiation doses were calculated using a published computer model (Moore 1979), radionuclide release rates, and local demography and meteorology.

Routine operations at Pantex result in the release of depleted uranium and tritium. Other radioactive materials (plutonium, enriched uranium, cobalt-60) present at Pantex are totally contained in sealed sources so that no release of these materials occurs.

Depleted uranium is principally released during high-explosive tests. Table II lists the amount of depleted uranium that was involved in the tests

*Background exposure to the bronchial epithelium from short-lived radon decay products is taken as 0.2 WLM/yr, a result based on the work of George and Breslin (George 1978). A working level (WL) is any combination of short-lived radon decay product (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po) concentrations in 1 ℓ of air that produces 1.3×10^5 MeV of alpha energy in decaying to ^{210}Pb. A working level month (WLM) is exposure to one WL for one working month (170 h).

each year since 1963. A depleted uranium source term was calculated from these data and from results of a study performed by Pantex personnel, showing that approximately 95% of the uranium in a test shot can be accounted for at the test site (USERDA 1976B). No tests releasing depleted uranium occurred

TABLE II

DYNAMIC TESTS INVOLVING DEPLETED URANIUM

Test Shots Involving Depleted Uranium at Pantex

Year	Kilograms of Depleted Uranium
1963	112
1964	123
1965	316
1966	303
1967	206
1968	210
1969	2418
1970	3589
1971	3379
1972	2421
1973	832
1974	896
1975	626
1976	416
1977	138
1978	419
1979	74
1980	12
1981	0

Test Shots Involving Depleted Uranium at the IAAP

Year	Kilograms of Depleted Uranium
1965-1969	2610
1970	2024
1971	3542
1972	2593
1973	696
1974	316

during 1981. Average annual depleted uranium emissions from 1963 to 1979 were 16.1 mCi/yr of ^{238}U, 6.0 mCi/yr of ^{234}U, and 0.3 mCi/yr of ^{235}U. During 1980, 0.201 mCi of ^{238}U, 0.075 mCi of ^{234}U, and 0.004 mCi of ^{235}U were released.

Additional smaller emissions of depleted uranium may have occurred during periodic operations when a high explosive was burned with material attached to depleted uranium. This operation was performed during the summer of 1981 at Pantex. For at least the 5 years before 1981, no burning of materials attached to depleted uranium took place at Pantex. Measurements of emission rates that were made by Pantex personnel indicated that some 0.14 µCi of depleted uranium (0.10 µCi of ^{238}U, 0.04 µCi of ^{234}U, and 0.002 µCi of ^{235}U) was released by this mechanism during 1981 (see Appendix D).

A third source of depleted uranium emissions is resuspension of soil contaminated by the test shots and burning materials. An upper limit for this release rate from wind erosion was estimated from onsite soil samples using an area source term estimation procedure developed by Travis and modified by the USNRC (Travis 1975, USNRC 1980). Using soil typical of the Amarillo area as reported by Unger (1981), wind speed distribution for Amarillo given in Section III.C, and conservative assumptions about the size of the contaminated area and magnitude of the contamination, we estimated that approximately 110 µCi of ^{238}U, 40 µCi of ^{234}U, and 2 µCi of ^{235}U were resuspended from the firing site during 1981 (Appendix D). We estimated that approximately 26 µCi of ^{238}U, 10 µCi of ^{234}U, and 0.5 µCi of ^{235}U were released during 1981 from resuspension from the burning grounds.

Mechanical resuspension of the soil was also considered. Releases from mechanical resuspension due to the depleted uranium test shots have been included in the source term for the test shot itself (see Appendix D). Other possible sources of mechanical resuspension were the other high-explosive test shots not involving depleted uranium that took place in 1981 and vehicular traffic.

No significant mechanical resuspension of contaminated soil is expected from the other high-explosive test shots because all occurred at firing sites other than the firing site (FS5) used for the depleted uranium test shots. The aerial gamma radiation survey performed by EG&G, Inc., (Boyns 1981) detected no depleted uranium in soil at any firing site except FS4 and FS5. Firing site FS4 was infrequently used in the past for test shots involving depleted uranium, and FS5 is the site where almost all such tests have been performed. The EG&G, Inc., survey found gamma count rates at FS4 only slightly increased over background and much less than were the rates at FS5, indicating low levels of depleted uranium in the soil. Depleted uranium released by mechanical resuspension from high explosive tests at FS4 was estimated to be approximately 4% of the total release from Pantex. This

release was considered negligible compared with other releases in 1981 (see Appendix D).

This conclusion is supported by results of continuous air sampling performed in 1981. As will be discussed in Section III.A, uranium air concentrations in air measured by onsite air samplers placed downwind from the firing sites (samplers PA-AR-01 and PA-AR-03, see Fig. 1) were indistinguishable from concentrations measured in background locations. (Also see MHSM 1982, where parallel air monitoring by Pantex supports the same conclusion.)

Mechanical resuspension of contaminated soil due to vehicular traffic was assumed to be negligible because traffic is light in the remote area of Pantex where the tests take place. In addition, the roads in that area are paved, which would further reduce dusting.

Small quantities of tritium are released occasionally when shipping drums are opened. Residual tritium is sometimes present in air in packaging drums and inadvertently enters the atmosphere. A second source of tritium is the quality assurance section of the plant, where components containing tritium are tested. Estimates of tritium releases during 1981, based on measurements made by Pantex personnel, were approximately 95 mCi (MHSM 1982).

Exposures during 1981 resulting from test shots before 1980 (through inhalation of resuspended soil and consumption of foodstuffs grown on the soil) were estimated assuming a continuous release of depleted uranium equal to the average annual emissions from 1963 to 1979. Doses due to radionuclide intakes in 1981 from the five tests occurring during 1980 were calculated individually.

Doses to the surrounding population were estimated using the above release rates (Table D-II) and meteorological data presented in Section III.C. All doses were calculated using the computer code AIRDOS-EPA (Moore 1979) with modifications as described in Appendix D. This computer code uses the Gaussian atmospheric dispersion model and radionuclide release rates to estimate radionuclide concentrations in air and deposition rates in the surrounding area.

Doses were calculated both for inhalation and ingestion of radioactive materials released to the air by the plant. Ingestion doses include those received from consumption of vegetables, meat, and milk affected by airborne plant releases. External radiation doses due to cloud submersion and ground deposition were considered but proved to be negligible (<1%) compared to critical organ doses from other pathways.

Pantex has no discharge of liquid effluents to offsite ground and surface waters. Waste water is released to a playa located within Plant boundaries. No above-background radionuclide concentrations are expected in this waste water, a fact confirmed by sampling sediments and ground and surface water at Pantex (Purtymun 1982).

In a study of the geohydrology of the Pantex area performed for the Pantex EIS, Purtymun et al. concluded that both onsite and offsite ground and surface water samples reflected only naturally occurring uranium concentrations. The ^{137}Cs, ^{238}Pu, ^{239}Pu, and ^{3}H concentrations were at or below the measurement limits of detection. Similarly, sediment samples taken from surface water run-off and collection areas showed no evidence of Pantex activities. Uranium concentrations in the sediments were typical of natural background, and levels of ^{90}Sr, ^{137}Cs, ^{238}Pu, and ^{239}Pu were typical of worldwide fallout (Purtymun 1982). Consequently, doses resulting from waterborne transport of radioactive material released by the plant were considered negligible.

Calculated 50-year dose commitments to the maximum exposed individual for bone, lung (the two organs receiving the largest dose), whole body, and gonads are shown in Table III. These doses are estimated for 1981, the base year used in the EIS.

The dose that was the largest fraction of the Department of Energy's Radiation Protection Standard (RPS) was 0.078 mrem to bone. This dose is 0.005% of the 1500 mrem/yr RPS for dose to bone for the public (USDOE 1980) and 0.03% of the 291 mrem/yr bone dose from background radiation.

Over 99% of this bone dose is due to consumption of vegetables containing depleted uranium. In estimating this maximum dose, we assumed that an individual obtained his entire 1981 supply of produce from his garden, which was located in the direct path of the aerosol cloud released by a dynamic test shot containing depleted uranium. Of the five 1980 test shots, the September test gave the highest dose because it occurred during harvest season, minimizing the time available for removal of depleted uranium deposited on plant surfaces by wind and rain. A relatively high vegetable consumption rate of 584 kg/yr, three times that of a typical adult, was also used in determining this maximum dose. This is the produce consumption rate recommended by the USNRC for the maximum exposed individual (USNRC 1977A).

The 50-year population dose commitments to persons living within 80 km of Pantex, estimated for 1981, are in Table III for bone, lung, whole body, and gonads. The highest population dose is 0.16 person-rem to bone, approximately 0.0002% of the annual population dose to bone from background radiation.

TABLE III

ESTIMATED RADIATION DOSES DURING 1981 DUE TO PANTEX OPERATIONS

Maximum Exposed Individual	Lung	Bone	Whole Body	Gonads
Dose (mrem)* from Pantex operations	<0.01	0.078	<0.01	<0.01
Natural background radiation (mrem)	306	291	106	111
% of natural background radiation	0.002	0.03	0.005	<0.001
Radiation Protection Standard (mrem)	1500	1500	500	500
% of Radiation Protection Standard	<0.001	0.005	0.001	<0.001
Population Dose				
Dose (person-rem)* from Pantex operations	0.051	0.16	0.012	0.00030
Natural background radiation (person-rem)	78 600	74 700	27 200	28 500
% of natural background radiation	<0.001	<0.001	<0.001	<0.001

*50-year dose commitments.

b. Iowa Army Ammunition Plant (IAAP). Operations involving the release of radioactive materials have not occurred at IAAP since 1974, when the Atomic Energy Commission discontinued its programs at IAAP. However, small releases of depleted uranium may occur from resuspension of dust at the firing site once used for dynamic tests involving depleted uranium.

Samples of water, soil, and sediments and in situ measurements of external gamma spectra detected no above-background radionuclide concentrations in offsite areas that could be associated with IAAP operations or releases (Section III.F). Above-background concentrations of depleted uranium were found in soil at the firing site, at an isolated location near Line One, and in sediment from the Long Lake spillway (located onsite).

Because no radionuclide concentrations could be detected offsite above background, radiation doses resulting from IAAP releases were less than detection limits. As in the case of Pantex (Section II.A.2.a), doses were calculated using a computer model (Moore 1979), estimated radionuclide release rates, and local demography and meteorology.

Resuspension of contaminated soil at the IAAP is expected to be minor. After the Atomic Energy Commission discontinued its testing program at IAAP in 1974, the firing site used for test shots containing depleted uranium was decommissioned. The most heavily contaminated soil was removed from the site and replaced with clean fill dirt and gravel. In addition, other areas at the site are grass covered, which would reduce erosion.

Releases of depleted uranium from resuspension of contaminated soil from the firing site area were estimated using the same procedures as for resuspension at Pantex (Appendix D and Section II.A.2.a). Annual releases were calculated to be 2.2 μCi of ^{238}U, 0.8 μCi of ^{234}U, and 0.04 μCi of ^{235}U.

Doses from 1981 exposure to depleted uranium deposited offsite from test shots occurring during 1965 to 1974 were estimated assuming a continuous release rate of depleted uranium during those years equal to the annual average of the 1965 to 1974 emissions. The amounts of depleted uranium involved in these tests are in Table II. Emission rates are in Table D-II of Appendix D.

The maximum exposed individual 50-year dose commitments for lung, bone, whole body, and gonads are in Table IV. All organ doses are less than 0.01 mrem for the maximum exposed individual, are less than 0.001% of the RPS for a member of the public (USDOE 1980), and are less than 0.001% of the natural background doses. The highest 50-year population dose commitment estimated for persons living within 80 km of the IAAP is 0.0015 person-rem to lung, some 1×10^{-6}% of the annual population dose to lung from natural background.

c. Hanford. Radiation doses to members of the public due to operations at Hanford during 1981 were estimated by Sula (1982). Doses were based on environmental sampling and measurements, as well as on dose modeling using computer codes (Sula 1982). Doses to the maximum exposed individual were 1.3 mrem (bone), 0.4 mrem (whole body), and 0.6 mrem (infant's thyroid). These doses are 0.09%, 0.08%, and 0.04% of the RPSs for bone, whole body, and thyroid, respectively (USDOE 1980). The 50-year population dose commitments to the population living within 80 km of the site are 4 person-rem (whole body), 3 person-rem (lung), 6 person-rem (bone), and 4 person-rem (thyroid) (Sula 1982). These population doses are all less than 0.02% of the doses to these organs from natural background radiation.

TABLE IV

ESTIMATED RADIATION DOSES DURING 1981 DUE TO RELEASES AT THE IAAP

	Lung	Bone	Whole Body	Gonads
Maximum Exposed Individual				
Dose (mrem)* from IAAP operations	<0.01	<0.01	<0.01	<0.01
Natural background radiation (mrem)	285	270	85	90
% of natural background radiation	<0.001	<0.001	<0.001	<0.001
Radiation Protection Standard (mrem)	1500	1500	500	500
% of Radiation Protection Standard	<0.001	<0.001	<0.001	<0.001
Population Dose				
Dose (person-rem)* from IAAP operations	1.5×10^{-3}	1.1×10^{-3}	1.2×10^{-4}	2.5×10^{-5}
Natural background radiation (person-rem)	106 000	100 000	31 600	33 500
% of natural background radiation	<0.001	<0.001	<0.001	<0.001

*50-year dose commitments.

Doses to the organs of interest for this report--bone, lung, whole body, and gonads---have been taken from Sula et al. and are in Table V.

C. Radiological Impact of Proposed Operations

Radiation doses were calculated for those future operations or facilities proposed for Pantex, IAAP, and Hanford that would have radiological impact through routine releases. These releases occur from continued testing involving depleted uranium, routine operations involving tritium, and operation of the proposed coal-fired power plant.

TABLE V

ESTIMATED RADIATION DOSES DURING 1981 DUE TO HANFORD OPERATIONS*

	Lung	Bone	Whole Body	Thyroid	
				Infant	Adult
Maximum Exposed Individual					
Dose (mrem)** from Hanford operations	0.02	1.3	0.4	0.6	0.1
Natural background radiation (mrem)	282	267	82	82	82
% of natural background radiation	0.01	0.5	0.5	0.7	0.1
Radiation Protection Standard	1500	1500	500	1500	1500
% of Radiation Protection Standard	0.001	0.09	0.08	0.04	0.007
Population Dose					
Dose (person-rem)** from Hanford operations	3	6	4	4	
Natural background radiation (person-rem)	93 200	88 200	27 000	28 700	
% of natural background radiation	0.003	0.007	0.01	0.01	

*Taken from Sula (1982).
**50-year dose commitments.

Doses were calculated for 1990 at all three sites using the procedures described in Appendix D. Dose estimates are based on source terms described below and demographic data projected for 1990.

Test shots are expected to occur at a maximum rate of one test per year. No more than 10 kg of depleted uranium would be involved in each test (Appendix D). Using a 0.05 aerosolization fraction (USERDA 1976B), we would expect 167 μCi of ^{238}U, 62 μCi of ^{234}U, and 3 μCi of ^{235}U to be released.

Based on past experience, tritium releases are projected to be 100 mCi/yr.

The release rates of naturally occurring radioactivity from the coal-fired power plant were based on preliminary design characteristics for the plant (United Engineers 1979, USDOE 1982). These characteristics include using coal with a 5% ash content, a 25:75 fly ash to bottom ash ratio, and a 99% efficient filtration system. Enrichment factors in the fly ash for more volatile radionuclides were taken into account (Appendix D). Release rates are in Table D-2 of Appendix D.

TABLE VI

ESTIMATED RADIATION DOSES* IN 1990 FROM PROPOSED OPERATIONS AT PANTEX

Maximum Exposed Individual	Dose (mrem)			
	Lung	Bone	Whole Body	Gonads
Coal-fired power plant**	0.015	0.015	<0.01	<0.01
Test shots	0.68	3.1	0.23	<0.01
Tritium releases	<0.01	<0.01	<0.01	<0.01
Termination of operations***	<0.01	<0.01	<0.01	<0.01
Maximum dose	0.68	3.1	0.23	<0.01
Natural background	306	291	106	111
Radiation Protection Standard	1500	1500	500	500

Population Dose	Dose (person-rem)			
Coal-fired power plant**	0.073	0.19	0.014	0.0032
Test shots	0.53	2.6	0.19	0.0050
Tritium releases	4.2×10^{-5}	4.2×10^{-5}	4.2×10^{-5}	4.2×10^{-5}
Termination of operations***	0.019	0.047	0.0036	9.2×10^{-5}
Natural background (1990)	88 400	84 100	30 600	32 100

*50-year dose commitments.

**Maximum individual and population exposure to the bronchial epithelium are 3×10^{-8} WLM and 1×10^{-4} person - WLM, respectively.

***Fifty-year dose commitments at Pantex if operations are relocated to either IAAP or Hanford.

Calculated 50-year dose commitments for the maximum exposed individual and for the surrounding population from these proposed operations are in Tables VI, VII, and VIII for Pantex, IAAP, and Hanford, respectively. As seen in the tables, the highest individual dose is 3.1 mrem to bone, 0.2% of the RPS and 1% of the background dose. The highest population dose is 2.6 person-rem to bone, 0.003% of the background population dose to bone.

The maximum exposed individual dose at each site was primarily due to exposures to depleted uranium released by the dynamic testing. Many conservative assumptions were made in defining the release scenarios that would make these dose estimates higher than what would probably occur in practice. These assumptions include:

- using conservative wind speed and stability class categories so that radionuclide concentrations in air would be relatively high and using conservative wind direction so that the cloud centerline would pass over the nearest resident. All clouds from the test shots occurring from 1983 to 1990 were assigned the same wind direction so that material from each test would be deposited at the location of the maximum exposed individual. Centerline concentrations, rather than sector-averaged concentrations, were used in the calculation.

- assuming that the test shot occurred in September of each year during crop harvest so that no removal by wind and rain of depleted uranium deposited on plant surfaces would occur.

- assuming that the maximum exposed individual obtained his entire year's supply of produce from the affected garden.

TABLE VII

ESTIMATED RADIATION DOSES* IN 1990 FROM PROPOSED OPERATIONS AT THE IAAP

Maximum Exposed Individual	Dose (mrem)			
	Lung	Bone	Whole Body	Gonads
Coal-fired power plant**	0.019	0.018	<0.01	<0.01
Test shots	0.56	2.5	0.19	<0.01
Tritium releases	<0.01	<0.01	<0.01	<0.01
Maximum dose	0.56	2.5	0.19	<0.01
Natural background	285	270	85	90
Radiation Protection Standard	1500	1500	500	500
Population Dose	**Dose (person-rem)**			
Coal-fired power plant**	0.17	0.18	0.012	0.0023
Dynamic tests	0.26	0.76	0.058	0.0015
Tritium releases	1.9×10^{-4}	1.9×10^{-4}	1.9×10^{-4}	1.9×10^{-4}
Natural background (1990)	109 000	104 000	32 600	34 500

*50-year dose commitments.

**Maximum individual and population exposure to the bronchial epithelium are 4×10^{-8} WLM and 3×10^{-4} person - WLM, respectively.

TABLE VIII

ESTIMATED RADIATION DOSES* IN 1990 FROM PROPOSED OPERATIONS AT HANFORD

Maximum Exposed Individual	Dose (mrem)			
	Lung	Bone	Whole Body	Gonads
Coal-fired power plant**	<0.01	<0.01	<0.01	<0.01
Test shots	0.078	0.35	0.027	<0.01
Tritium releases	<0.01	<0.01	<0.01	<0.01
Maximum dose	0.078	0.35	0.027	<0.01
Natural background	282	267	82	87
Radiation Protection Standard	1500	1500	500	500
Population Dose	**Dose (person-rem)**			
Coal-fired power plant**	0.14	0.11	0.0071	0.0012
Test shots	0.011	0.29	0.021	0.00056
Tritium releases	5.1×10^{-9}	5.1×10^{-9}	5.1×10^{-9}	5.1×10^{-9}
Natural background (1990)	110 000	104 000	31 900	33 800

*50-year dose commitments.

**Maximum individual and population exposure to the bronchial epithelium are 5×10^{-9} WLM and 3×10^{-4} person - WLM, respectively.

The produce consumption rate of the maximum exposed individual was 584 kg/yr, three times higher than the typical adult consumption rate of produce of 194 kg/yr. Consumption rates of milk and meat were higher by factors of 2.8 and 1.2, respectively. The foodstuff consumption rates for both the maximum exposed and average exposed individual were taken from values recommended by the USNRC (USNRC 1977A).

These assumptions cause the estimated dose to be from a factor of 3 to a factor several orders of magnitude higher than what would be estimated using more typical assumptions.

Population doses were also calculated for test shots occurring each September from 1983 to 1990. Assumptions similar to those given above were used with the exception that sector-averaged concentrations rather than

centerline concentrations and typical adult food consumption rates were employed. To estimate the maximum population dose, population doses were calculated for depleted uranium releases into each of the 16 compass directions at each site. The highest calculated population doses are reported in Tables VI, VII, and VIII.

D. Health Risks from Estimated Radiation Exposures

Risks of dying from cancer and of having genetic disorders in offspring as a result of the radiation exposures discussed in Sections II.A and II.B were estimated using risk factors taken from the 1980 report of the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiations (BEIR III 1980) and Evans (1981). The risk factors used in these calculations are in Appendix E.

Average doses to the population living within 80 km of each of the three sites were calculated by dividing the population dose by the population of the 80-km assessment area. These average doses were multiplied by the risk coefficients in Table E-II to obtain either the lifetime risk of having a fatal cancer, or the risk of genetic disorder in offspring in all subsequent generations, as a result of the 1-year radiation exposure. Risks from 1-year exposure to background radiation are presented for comparison.

The estimated risks are in Table IX. Risks from routine releases of radioactive material from current and proposed operations are on the order of, or less than, 10^{-9}, or one chance in a billion of an adverse effect occurring.

Incremental risks of dying of cancer from exposure to depleted uranium from test shots, resuspended contaminated soil, or naturally occurring radionuclides released by coal combustion were calculated assuming that lung and bone cancer would constitute the major risk. Doses to other internal organs, such as red bone marrow, liver, and kidney, were routinely calculated (Appendix D). These doses were smaller than the bone and lung doses, and the risk of cancer associated with irradiation of these other organs ranged from 2% (for resuspension of depleted uranium from soil) to 10% (for the coal-fired power plant) of the total risk of cancer.

The number of fatal cancer cases due to this incremental risk from 1 year of exposure to radiation in either 1981 or 1990 was obtained by multiplying the risk by the population in the assessment area. The largest number of expected fatal cases of cancer from 1 year of radiation exposure due to facility operations was 0.0006 cases. Because this number is much less than one, this indicates that, within the limits of the risk factors and dose model, no cases of fatal cancer are expected due to the radiation doses. All other estimated cases of fatal cancer, calculated for the other risks

TABLE IX

ESTIMATE OF HEALTH RISKS TO THE POPULATION IN EACH ASSESSMENT AREA DUE TO EXPOSURE TO IONIZING RADIATION IN 1981 AND 1990

	Lifetime Risk of Cancer Mortality	Range of Risk of Genetic Disorder in All Subsequent Offspring
I. Pantex		
Natural background	3.3×10^{-5}	$(1.1 - 20) \times 10^{-5}$
Pantex operations, 1981	$<10^{-9}$	$<10^{-9}$
Proposed options and alternatives		
Coal-fired power plant, 1990	$<10^{-9}$	$<10^{-9}$
Test shots, 1990	$<10^{-9}$	$<10^{-9}$
Tritium operations, 1990	$<10^{-9}$	$<10^{-9}$
Termination	$<10^{-9}$	$<10^{-9}$
II. IAAP		
Natural background	3.0×10^{-5}	$(8.7 - 160) \times 10^{-6}$
IAAP releases, 1981	$<10^{-9}$	$<10^{-9}$
Proposed options and alternatives		
Coal-fired power plant, 1990	$<10^{-9}$	$<10^{-9}$
Test shots, 1990	$<10^{-9}$	$<10^{-9}$
Tritium operations, 1990	$<10^{-9}$	$<10^{-9}$
III. Hanford		
Natural background	3.0×10^{-5}	$(8.4 - 150) \times 10^{-6}$
Hanford operations, 1981	1.9×10^{-9}	$(1.2 - 22) \times 10^{-9}$
Proposed options and alternatives		
Coal-fired power plant, 1990	$<10^{-9}$	$<10^{-9}$
Test shots, 1990	$<10^{-9}$	$<10^{-9}$
Tritium operations, 1990	$<10^{-9}$	$<10^{-9}$

from radiation doses due to facility operations, were less than 0.0006 cases.

This result agrees with the epidemiological study being conducted for the Pantex EIS by Wiggs (1982), who found no abnormal mortality from any type of cancer in any of the six counties surrounding Pantex. Their results are still tentative, because latent periods for many cancers being considered are on the order of 10 years or longer and the final results would not be available for several decades. However, testing at Pantex involving depleted uranium began almost 20 years ago so that the epidemiological study is entering the expression period for cancer cases that may have resulted from the earlier tests. This includes the period when increased testing began in the late 1960s (see Table II). Since depleted uranium release rates were higher during this period than during the 1980-1981 period (the period which would most affect doses calculated for 1981), the observed absence of increased cancer mortality tends to support the conclusion of negligible impact of Pantex operations on local cancer mortality rates.

For comparison with the estimate of a maximum of 0.0006 cancer cases from releases from facility operations, the estimated number of fatal cases of cancer from background radiation at Pantex, IAAP, and Hanford is 8, 11, and 10, respectively, in 1981. These estimates become 10, 12, and 12, respectively, for background radiation in 1990, where the slight increase is due to the increase in the area populations from 1981 to 1990.

The lifetime risks of fatal cancer for the maximally exposed individual (as opposed to the average individual dose discussed above) from doses in 1981 resulting from operations at any of the three sites were calculated to be on the order of or less than 5×10^{-8}. The estimate of the risk of genetic disorders in all subsequent offspring from the maximum individual dose in 1981 ranged from 4×10^{-8} to 7×10^{-7}. The highest cancer risk at any of the three sites to the maximally exposed individual from proposed operations in 1990 was estimated to be 3×10^{-8}, and the corresponding risk of genetic disorder in offspring ranged from 2×10^{-9} to 3×10^{-8}. All other risks to the maximally exposed individuals at the three sites for doses in 1981 or 1990 were less than these reported risks. These risks are more than two orders of magnitude less than the risks of 10^{-5} to 10^{-6} that were used by the ICRP as the annual risk levels acceptable to the general public (ICRP 1977). They are a factor of 200 or more less than the risks of dying from cancer or of having a genetic disorder in offspring resulting from a 1-year exposure to natural background radiation in each assessment area (see Table IX).

III. FIELD DATA COLLECTED TO CHARACTERIZE CURRENT RADIOLOGICAL CONDITIONS

A. Monitoring of Airborne Radioactivity at Pantex

1. Continuous Air Monitoring.

a. Introduction. For a 12-month period (4 February 1981 through 4 February 1982), a special ambient air sampling program for radioactivity was conducted at the Pantex Plant by Los Alamos National Laboratory's Environmental Surveillance Group. This sampling program complemented the existing radiological air surveillance done by Pantex personnel (MHSM 1982). The air sampling by Los Alamos was done to independently evaluate any possible impact Pantex Plant operations could have on radiological air quality in the vicinity of the plant.

b. Description of Radiological Ambient Air Sampling Program. Air particulates were collected on filters at 14 continuously operating air samplers. Of these 14 samplers, 5 were onsite (Fig. 1), 8 were at perimeter locations on an 8-km radius from the Pantex Plant, and 1 regional (background) sampler was in Bushland, Texas, which is about 13 km west of

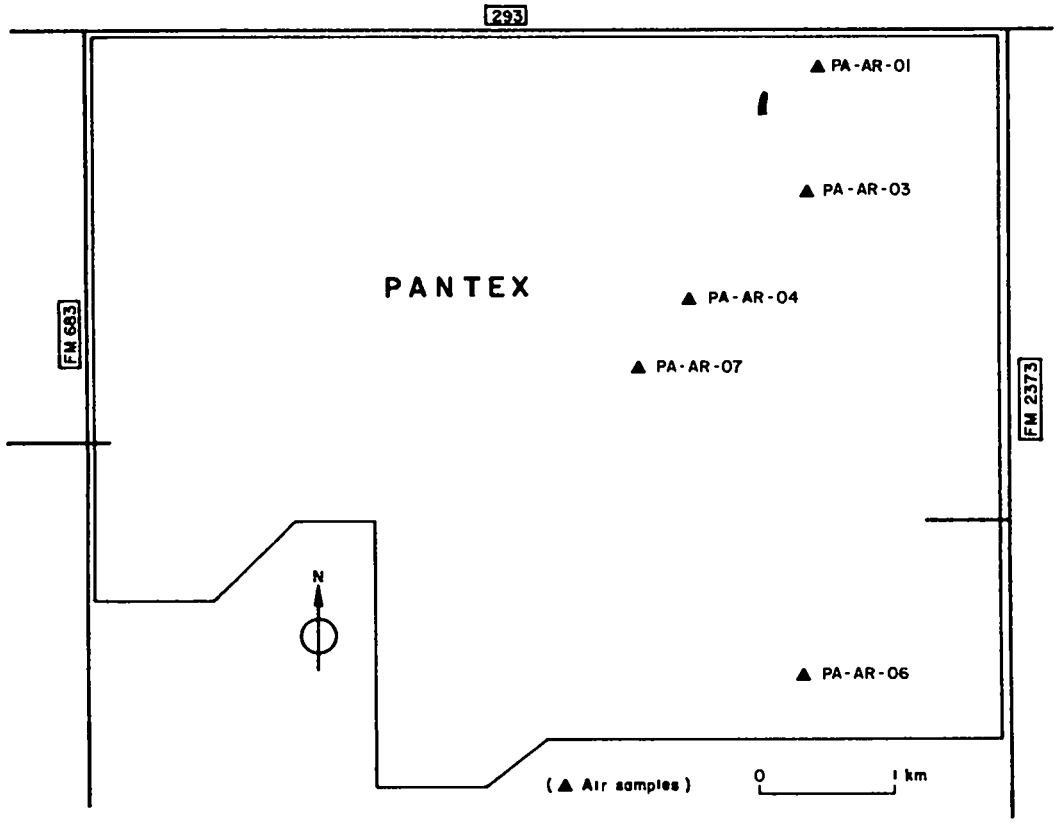

Fig. 1. Onsite air sampling locations.

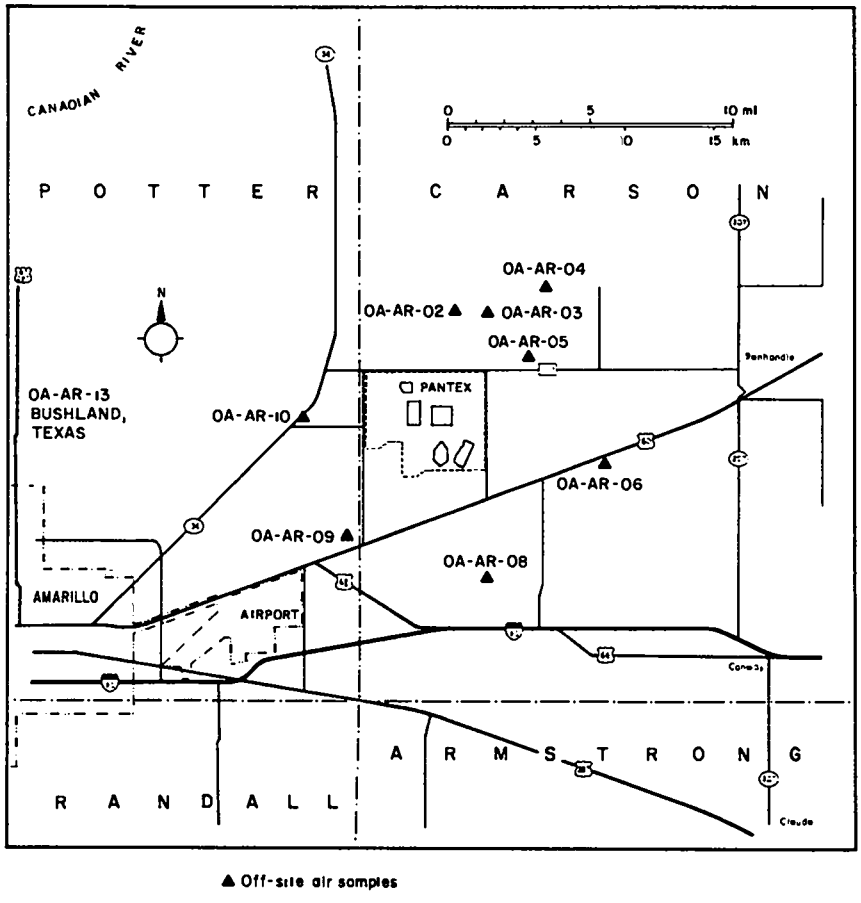

Fig. 2. Pantex environmental air sampling network around an 8-km radius.

Amarillo (Fig. 2). Onsite samplers PA-AR-01 and PA-AR-03 are located near the firing sites; samplers PA-AR-04, PA-AR-06, and PA-AR-07 are located near other areas where radioactive materials are handled.

The air filters were collected weekly and analyzed for gross alpha and gross beta activities. Atmospheric gross alpha and gross beta concentrations serve as indicators of overall radioactivity levels. The filters were composited on a monthly basis and analyzed for ^{238}Pu, $^{239-240}Pu$, and uranium. These analyses were done because plutonium is handled in Pantex operations (although no measurable amounts are released) and small amounts of depleted uranium are released to the atmosphere during test shots. Atmospheric tritium was not sampled because an insignificant amount (<0.1 Ci/yr) is released by Pantex. More details of the sampling and analytical procedures are in Appendix B.

c. Air Sampling Results.

(1) Introduction. Detailed data tables in Appendix C show air sampling results for gross alpha, gross beta, ^{238}Pu, $^{239-240}Pu$, and uranium analyses. Annual maximums, minimums, and means are listed. The annual means are compared to standards, known as Concentration Guides, that are established by the Department of Energy (Appendix A). The Concentration Guides are concentrations of radioactivity in air that, if breathed continuously over 50 years, would result in whole body or organ doses equal to the RPSs in the 50th year [standards for external or internal exposure to radioactivity (Appendix A)]. Concentration Guides are of two types. Controlled Area Concentration Guides cover any laboratory or plant area to which access is controlled to protect individuals from exposure to radiation and radioactive materials. Uncontrolled Area Concentration Guides cover an area beyond the boundaries of a Controlled Area to which the public has access. Controlled Area Concentration Guides are less stringent than Uncontrolled Area Concentration Guides.

(2) Discussion of Results. When interpreting data from this air sampling program, one must first be aware of natural and fallout radioactivity levels and their fluctuations. Worldwide background atmospheric radioactivity is largely composed of fallout from atmospheric nuclear weapons tests, natural radioactive constituents in dust from the decay chains of ^{232}Th and ^{238}U, and materials resulting from interactions with cosmic radiation (such as tritiated water vapor). Background radioactivity concentrations are summarized in Table C-I and are useful in interpreting the air sampling data.

Because airborne particulates are mostly from soil resuspension, there are large temporal fluctuations in airborne radioactivity as a result of changing meteorological conditions. Periods of high winds result in relatively high suspended particulate concentrations, whereas periods of heavy precipitation remove many airborne particles. Spatial variations are dependent on these same factors.

For gross alpha, gross beta, ^{238}Pu, $^{239-240}Pu$, and uranium analyses, the annual means of the regional, perimeter, and onsite sampling locations were indistinguishable from one another at the 95% confidence level. All annual means and maximums were a few per cent or less of the relevant Concentration Guides.

2. Monitoring of a Test Shot. On January 26, 1982, a test shot was conducted at Pantex involving release of depleted uranium. Six portable air samplers were placed downwind from the test: two on an arc approximately 275 m from the firing site and four on an arc approximately 640 m from the firing site. Both arcs were about 75° in angular width, centered on the firing

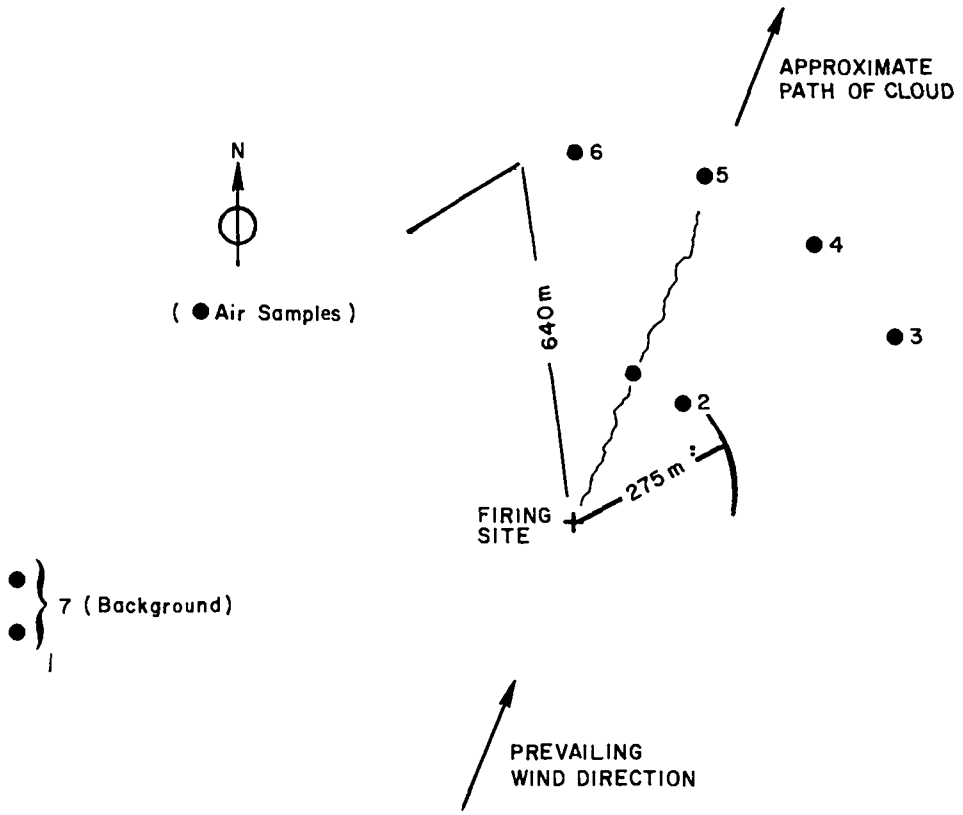

Fig. 3. Air sampling grid used in monitoring test shots.

site. Two additional samplers were run at a background location. A diagram of the air monitoring grid is in Fig. 3.

Photographs were taken of the passage of the cloud to provide a record of the cloud path. The samplers at Positions 1 and 5 were submerged in the cloud as it passed (Fig. 3). Unfortunately, the portable electric generators driving samplers at Positions 1 and 6 had mechanical problems so that no samples were available at these locations. A sample was taken at Position 5 as well as the other positions.

Winds at the time of the test shot were out of the south-southwest (approximately 200° off north) at a speed of 13-14 m/s, with gusts up to 18 m/s, and with D stability. While D stability is typical of daytime meteorological conditions at Pantex, the wind speeds at the time of the test shot were higher than the 6-7 m/s wind speed observed under more typical daytime conditions. The air concentrations that were measured at the monitored locations were estimated to be approximately 50% lower than were

those that would have been measured under more typical conditions resulting from less dilution with the lower wind speed. Since, as will be shown below, the measured air concentrations were roughly two orders of magnitude below the Concentration Guide, this factor of 2 would not significantly alter the conclusions drawn from these measurements.

The filters were analyzed for total uranium. Air concentrations measured at these locations are in Table X. As can be seen from data in the table, only one sampler had a uranium concentration greater than detection limits. The highest air sample was 57 ± 28 ng/m^3. All other samplers had less than 28 ng/m^3, measured over an approximately 40-min sampling time.

In comparison, the Concentration Guide for depleted uranium is 10 000 ng/m^3 (Appendix A) for uncontrolled areas, some 175 times higher than the highest sample measured here. In addition, the Concentration Guide is applied to an annual average air concentration. Averaging the uranium collected by this 40-min sample over an entire year would greatly reduce the uranium concentration, so that it would be much smaller than a factor of 175 below the Concentration Guide.

B. Measurement of External Radiation

1. Continuous Monitoring with TLDs at Pantex. Levels of penetrating radiation--including x and gamma rays and charged particle contributions from cosmic, terrestrial, and manmade sources--were measured with thermoluminescent dosimeters (TLDs) during calendar year 1981 at 24 locations in and around the Pantex facility. Sampling procedures and statistical treatment of TLD data have been summarized previously (ESG 1982, Wenzel

TABLE X

RESULTS OF AIR SAMPLES TAKEN DURING A TEST SHOT INVOLVING DEPLETED URANIUM

Station Number (see Fig. 3)	Uranium Concentration in Air (ng/m^3)
1	No sample
2	57 ± 28
3	<28
4	<28
5	<28
6	No sample
7	<28

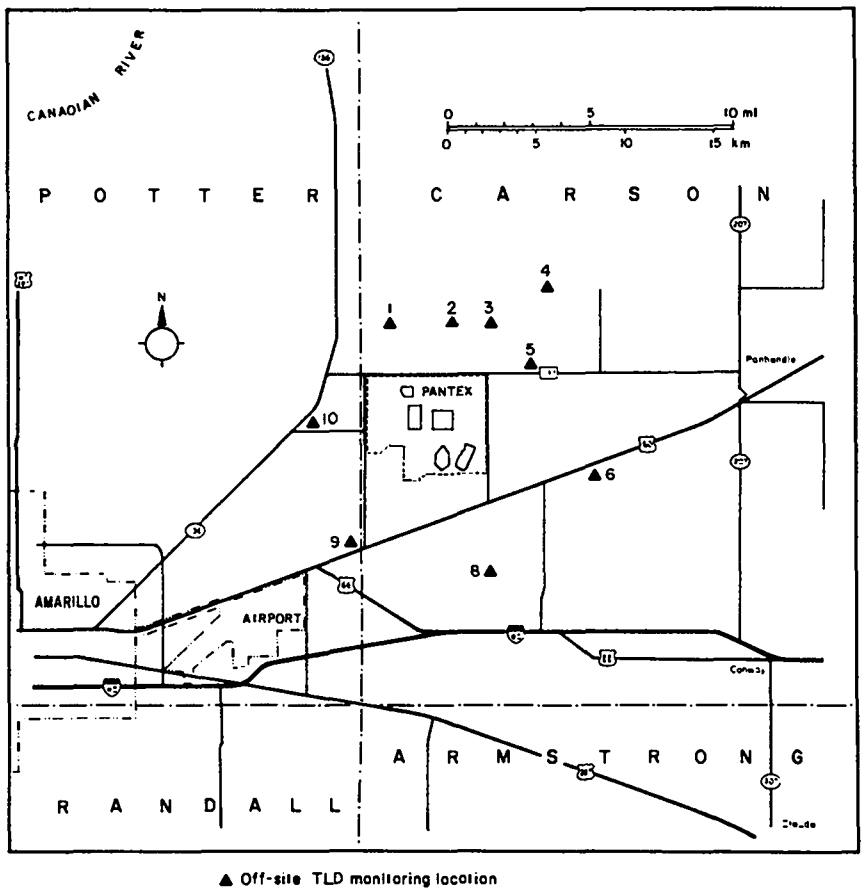

Fig. 4. Pantex environmental thermoluminescent dosimeter network around an 8-km radius.

1982A). Nine of these locations were offsite and describe a roughly circular array, centered on Area 12, with a diameter of about 15 km (Fig. 4). Five locations were on the perimeter fence and 10 were onsite (Fig. 5).

Tables XI and C-VII summarize the annual total doses for the offsite, perimeter, and onsite groups for 1981. The average doses for the three groups are statistically indistinguishable at the 95% confidence level. The highest exposure onsite, near a known source of radiation, is nearly 80% more than the average for the other nine in its group. This is the only location in the TLD network that has an exposure level above background.

2. In Situ Gamma Spectra on Soils. To help identify external radiation that might not be associated with background radiation, in situ gamma-ray spectra were taken at field sites around the Pantex and IAAP plants. At all offsite locations, only naturally occurring radionuclides or radionuclides asssociated with worldwide fallout were detected.

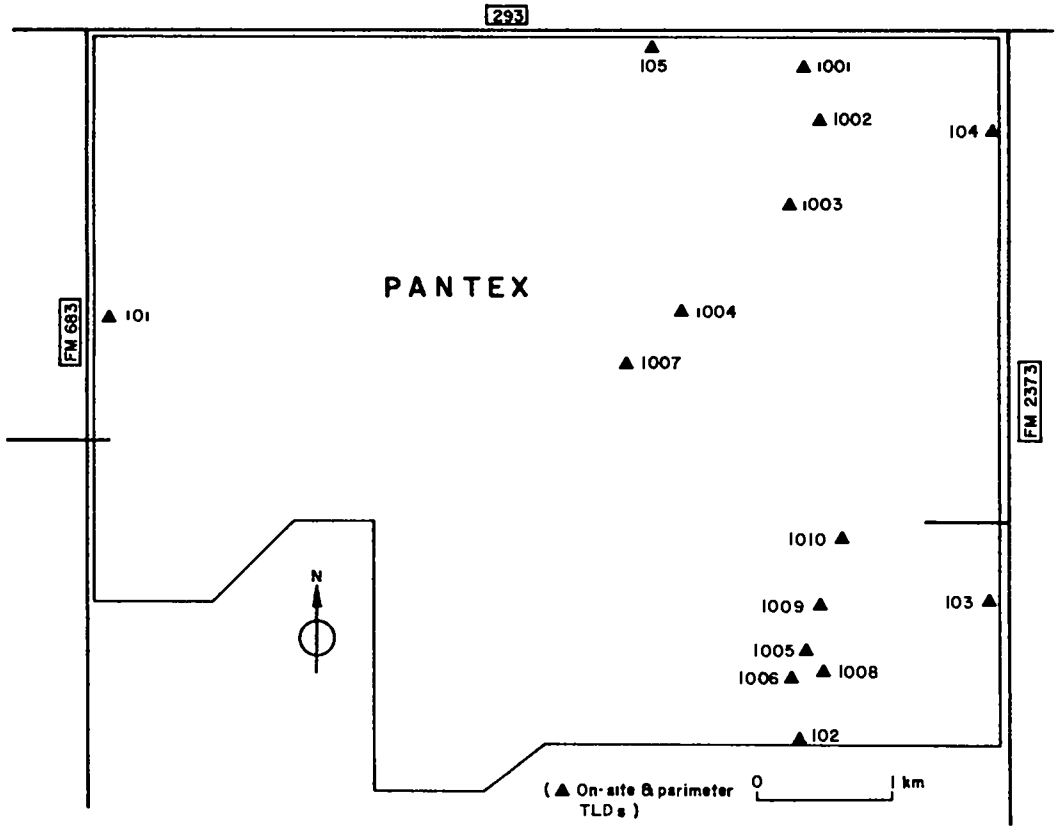

Fig. 5. Onsite and perimeter thermoluminescent dosimeter network at Pantex.

TABLE XI

EXTERNAL PENETRATING RADIATION AT PANTEX DURING 1981

Group	Dose (mrem-95% Confidence Level)		
	High	Low	Average
Offsite	80 ± 5	68 ± 5	72 ± 5
Perimeter	84 ± 5	76 ± 5	81 ± 5
Onsite	132 ± 5	64 ± 5	80 ± 5

External terrestrial radiation spectra were measured in the field at 14 sites at Pantex and 10 sites at IAAP, using a high-purity intrinsic germanium detector (Figs. 6 and 7). This instrument was carried by a specially designed environmental surveillance van, equipped with a multichannel analyzer and power generator. The van also carried phoswich detectors

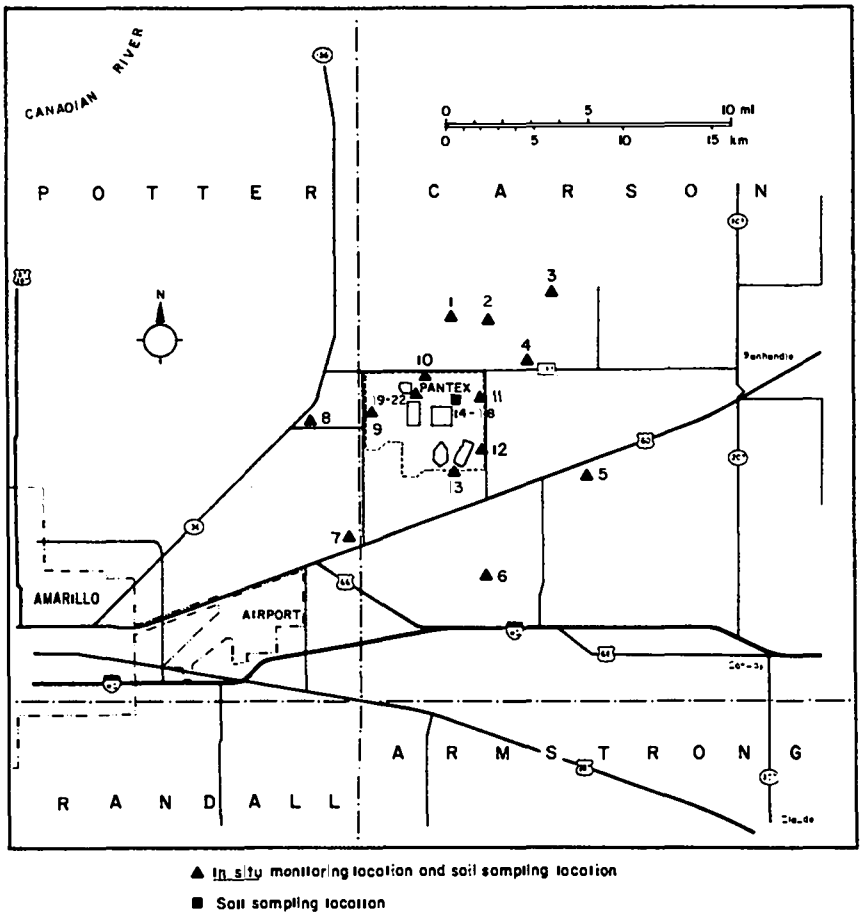

Fig. 6. In situ gamma measurement and soil sampling locations at Pantex.

(Ahlquist 1978), survey instruments, and soil and water sampling equipment that were used during this field work.

Twelve of the 14 sites at Pantex and 8 of the 10 sites at IAAP were used to determine background levels for external terrestrial radiation. One of the other two sites at each location was located at the firing site and the other at the burning pad. These two onsite locations were areas of known or possible radionuclide release during routine operations.

External radiation levels due to soil concentrations of uranium series radionuclides, thorium series radionuclides, ^{40}K, and ^{137}Cs are presented in Table XII. For uranium and thorium series radionuclides, radiation levels were obtained from measurement of selected ^{214}Bi, ^{228}Ac, and ^{208}Tl gamma-ray fluxes at 609, 911, and 583 keV, respectively. Concentrations in soil of uranium series and thorium series radionuclides were obtained from the ^{214}Bi, ^{228}Ac, and ^{208}Tl concentrations, based on the assumption of approximate secular equilibrium in the soil. Departures from secular equilibrium due to

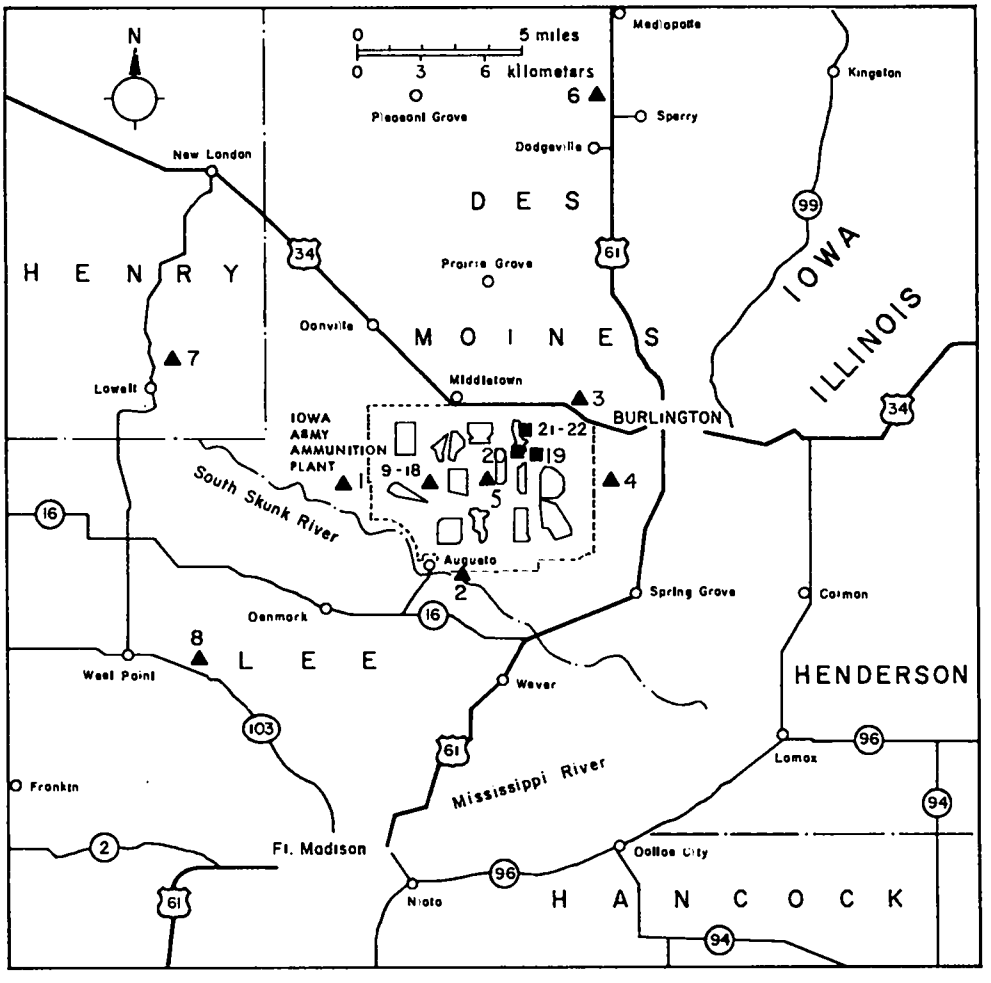

Fig. 7. In situ gamma measurement and soil sampling locations at the IAAP.

radon losses could result in an underestimate of uranium series activity. However, as noted by Beck, the determination of exposure rate would be relatively unaffected. Both gamma flux and exposure rate, which were calculated for an infinite half-space of uranium in equilibrium with its decay products, contain components from emanated radon. The ratio of flux to exposure rate, which is used to determine the exposure rate, would not be expected to be greatly affected by emanated radon (Beck 1972).

The procedure described by Beck (1972) was used in calculating the radiation levels. The naturally occurring radionuclides were assumed to be uniformly distributed with depth. The ^{137}Cs variation with depth was determined by sampling the soil at four depths and measuring the ^{137}Cs concentration at each depth.

TABLE XII

AVERAGE RADIONUCLIDE SOIL CONCENTRATIONS AND TERRESTRIAL RADIATION DOSE RATES (x ± s)

	Uranium Series	Thorium Series	^{40}K	^{137}Cs	Total External Dose	Corrected Total External Dose+
Pantex**						
Radionuclide soil concentration (pCi/g)	0.87 ± 0.07	1.15 ± 0.08	13.8 ± 0.8	148 ± 32*		
Exposure rate (mrem/yr)	12	25	19	3	59	38
IAAP**						
Radionuclide soil concentration (pCi/g)	0.66 ± 0.09	0.77 ± 0.07	9.3 ± 1.2	105 ± 34*		
Exposure rate (mrem/yr)	9	17	13	2	41	26
Hanford***						
Radionuclide soil concentration (pCi/g)	0.2	1	10	-		
Exposure rate (mrem/yr)	2.8	21.6	14	-	38	24

*Units for soil concentrations of ^{137}Cs are mCi/km^2.
**Measured with in situ gamma-ray spectroscopy with Los Alamos Environmental Surveillance Van.
***Taken from Miller (1978).
+Corrected by 20% for shielding by body and by an additional 20% for shielding by structures (NCRP 1975).

Soil samples were analyzed for depleted uranium, and in several cases, plutonium, as well as ^{137}Cs. Results of soil samples are discussed in Section III.E.

No above-background radionuclide concentrations were found in any offsite locations that were monitored at Pantex and IAAP. As expected, elevated levels of gamma rays associated with the ^{238}U decay products, ^{234}Th, ^{234m}Pa, and ^{234}Pa were detected at the firing sites at Pantex and IAAP and at the burn pad at Pantex. (No increase was detected at the burn pad at IAAP). These increased levels indicate the presence of depleted uranium.

In addition to in situ gamma spectra taken with a germanium detector, surveys were also performed at all sites with a phoswich detector, an instrument designed to detect x rays and low-energy gamma rays that would be less than the detection energy cutoff of the germanium detector (Ahlquist 1978). Results were similar to those obtained with the germanium detector. No above-background readings were found at any surveyed location offsite. Above-background readings were found at the firing sites at Pantex and the IAAP and around the burn pad at Pantex. One slightly elevated reading was obtained out of 52 readings taken in the Line One area at IAAP. A soil sample taken in this area had a uranium concentration of 13 ± 1.3 ppm, above the background levels of 2.6 to 4.4 ppm. Nearby soil had background phoswich readings. A nearby soil sample had a background uranium concentration of 3.0 ± 0.3 ppm, so that location was a small isolated area of slightly higher uranium concentration. The area is expected to have insignificant radiological impact.

C. Meteorology

1. Data. Meteorological data used to evaluate doses from routine releases of tritium, from depleted uranium released by test shots, and from future radiological releases by the proposed coal-fired power plant were annual average stability wind-rose (STAR) data. To evaluate the doses from the five test shots at Pantex in 1980, the actual meteorological conditions for those 5 hours were obtained and used in the dispersion analysis.

The STAR data were available for all three sites. Five years of data were available for Amarillo (1972 to 1976) and Burlington (1967 to 1971), and three years for Hanford (1973 to 1975). The Amarillo and Burlington data are classified by the six Pasquill-Gifford (PG) stability classes, A-F (Turner 1970). The Hanford data, classified by a somewhat different system, are divided into four stability classes (USERDA 1976A): 3, D, moderate stable (ms), and very stable (vs). The B and D categories correspond to the B and the C and D PG classes. The ms and vs categories correspond to the PG E and F classes.

Wind roses for each of the sites are in Figs. 8, 9, and 10. The STAR data from which they were constructed are in Appendix C. Meteorological data and dispersion parameters for the 1980 test shots are in Table XIII.

2. Dispersion Factors. Methods for calculating atmospheric dispersion factors, required in the dose calculations for different sources, are in this section. Equations used to calculate the dispersion factors are Gaussian dispersion equations for either plume- or puff-type releases.

a. Depleted Uranium Test Shots: Pre-1980. Because a large number of test shots containing depleted uranium were performed each year before 1980

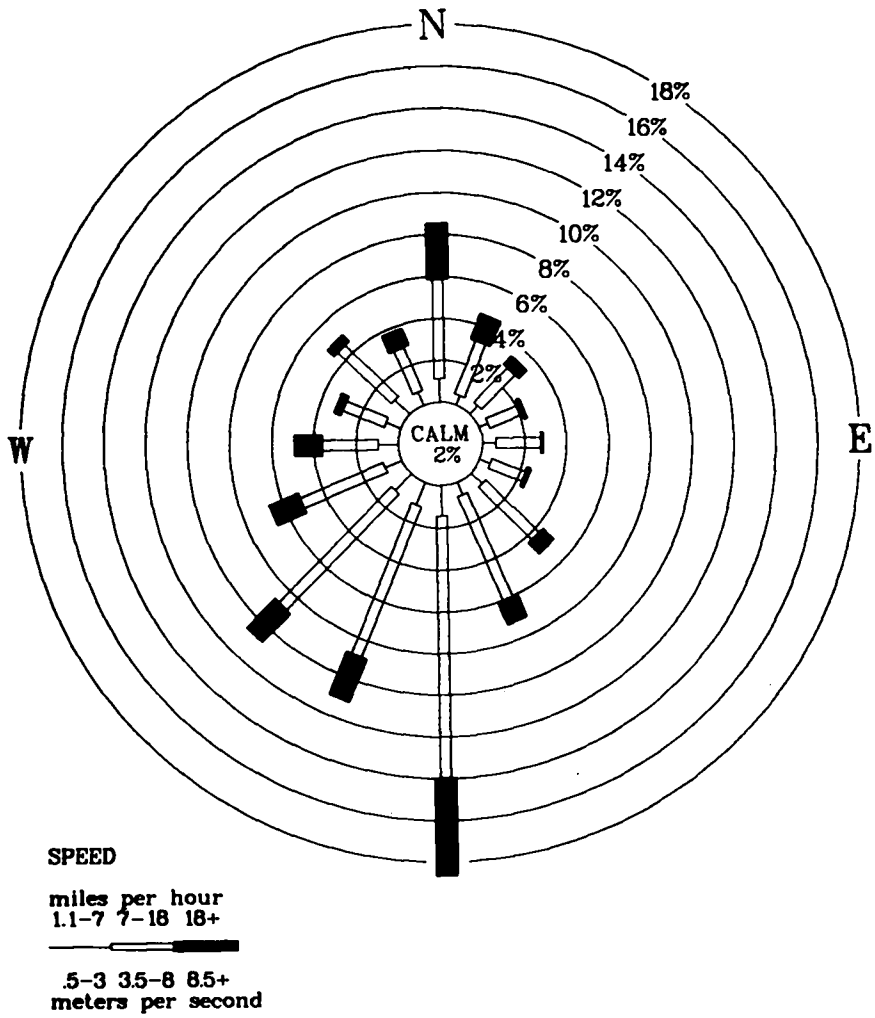

Fig. 8. Wind rose for Amarillo, 1972 to 1976.

(USERDA 1976B), the total amount of depleted uranium released per year was converted to an equivalent annual average release rate in grams per second. The doses from depleted uranium were calculated with this annual emission rate and an annual average dispersion factor. The annual average STAR data for each site (Appendix C) were used to calculate the dispersion factors with a sector-average Gaussian dispersion equation (USNRC 1977B):

$$\left(\frac{\chi}{Q}\right)_D = 2.032 \sum_{ij} \left[n_{ij} \frac{1}{xu\sigma_z} \exp\left(-\frac{h^2}{2\sigma_z{}^2}\right)\right],$$

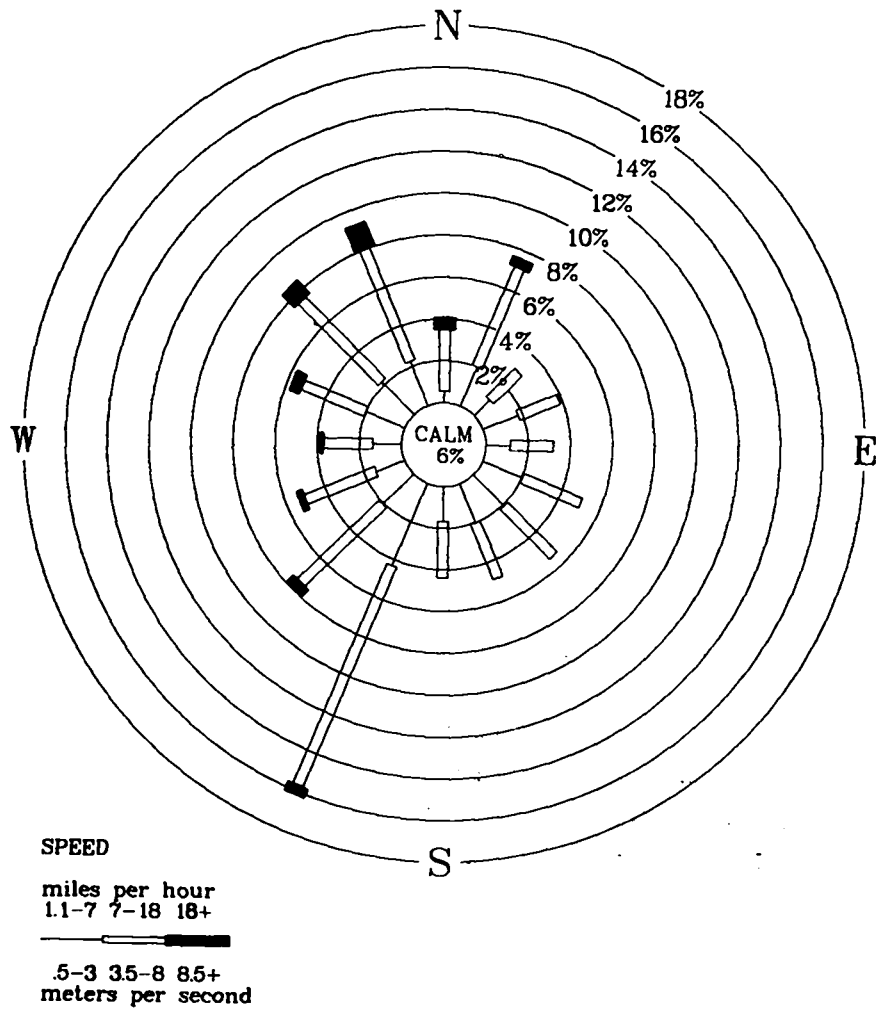

Fig. 9. Wind rose for Burlington, 1967 to 1971.

where

$(x/Q)_D$	is the atmospheric dispersion factor [x is the concentration at ground level (g/m^3), normalized by the source strength Q (g/s) in a given downwind direction D],
n_{ij}	is the frequency of occurrence of wind speed (i) and stability (j) in a given wind direction,
x	is the downwind distance (m),
u	is the wind speed (m/s),
σ_z	is the vertical dispersion coefficient (m),
h	is the release height (m), and
2.032	is $(2/\pi)^{1/2}$ divided by the width in radians of a 22.5° sector.

The depleted uranium was assumed to be released as a spherical puff with an initial diameter of 100 m and a cloud center height of 50 m. This approximates the size of a detonation cloud produced from 1.4 kg of high

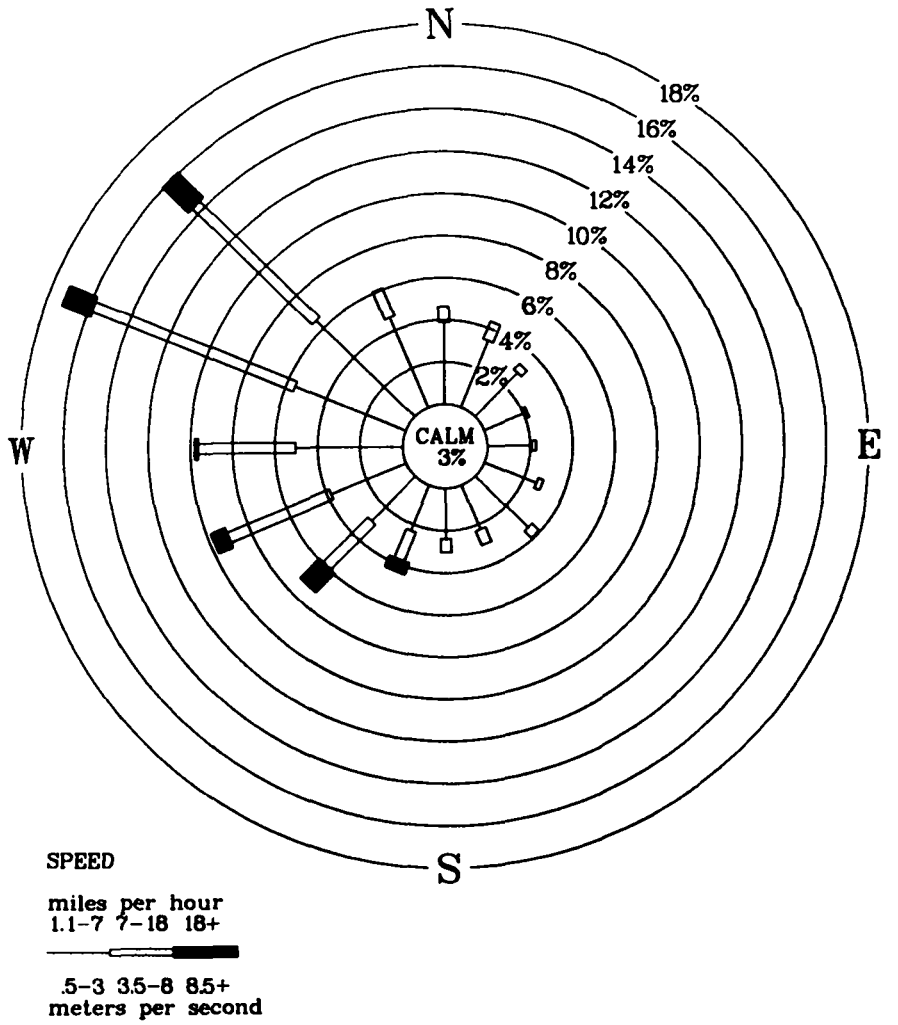

Fig. 10. Wind rose for Hanford, 1973 to 1975.

explosives, based on the equation for estimating cloud top height (Church 1969):

$$H = 76\ (HE)^{0.25}\ ,$$

where

H is the height of the cloud top (m) and
HE is the amount of high explosives (lb).

The amount of high explosives involved in a test shot has ranged from 2.7 to 16.8 kg, so all of the test shots would produce a taller cloud than what was assumed for this analysis, resulting in lower downwind doses. Thus, this analysis provides a conservative estimate of the downwind doses from depleted uranium released by test shots.

TABLE XIII

1980 DEPLETED URANIUM TEST SHOTS
METEOROLOGICAL AND DISPERSION PARAMETERS

1. January 5, 1980 1511 CST
   Overcast skies - 90% low-level altocumulus
   10% cirrus
   Winds - 8 knots, 190°
   Dispersion parameters - D stability
   4.1 m/s

2. April 8, 1980 1450 CST
   Clear skies
   Winds - 14 knots, 340°
   Dispersion parameters - C stability
   7.2 m/s

3. April 14, 1980 1520 CST
   Clear skies
   Winds - 14 knots, 340°
   Dispersion parameters - C stability
   7.2 m/s

4. September 12, 1980 1430 CST
   Partly cloudy skies - 10% cirrus
   Winds - 15 knots, 250°
   Dispersion parameters - C stability
   7.7 m/s

5. November 11, 1980 1750 CST
   Clear skies
   Winds - 13 knots, 170°
   Dispersion parameters - D stability
   6.7 m/s

The vertical dispersion coefficients (σ_z) were calculated using the equations for a puff release (Slade 1968). The wind speed used in the dispersion equation was adjusted using a stability-dependent power law formula (USEPA 1977) to reflect the height of the release.

b. Depleted Uranium Test Shots: 1980. Dispersion factors for the five test shots occurring in 1980 that used depleted uranium were calculated for each individual test shot. The observed weather conditions for the five test

shots are in Table XIII. The stability classes were determined using Pasquill's method (Turner 1970).

For an elevated puff release, the dispersion factor is calculated with (Slade 1968)

$$\frac{X}{Q} = \frac{1}{\pi \sigma_y \sigma_z u} \exp\left[\frac{-H^2}{2\sigma_z{}^2}\right],$$

where

x/Q is the dispersion factor (s/m^3),

x is the integrated air concentration ($g \cdot s/m^3$) at ground level,

Q is the total source term (g),

σ_y is the horizontal dispersion coefficient (m), and

σ_z is the vertical dispersion coefficient (m).

The cloud release height, dispersion coefficients, and wind speed were calculated as discussed in Section III.C.2.a.

These dispersion factors were used to calculate the dose to the maximum exposed individual. To calculate the doses to the population, a sector-average dispersion factor was also calculated. The sector-average dispersion equation for a single puff release is (USNRC 1977B)

$$\frac{X}{Q} = \frac{2.032}{xu\sigma_z} \exp\left[\frac{-H^2}{2\sigma_z{}^2}\right],$$

where all the terms are as defined in Section III.C.2.a, except that the x/Q represents only one test shot instead of test shots for an entire year.

c. Depleted Uranium Test Shots: 1982 to 1990. Dispersion factors for future shots (1/year) at Pantex, IAAP, or Hanford were calculated assuming D stability and a 3 m/s wind speed in the centerline and sector-average puff dispersion equations. The cloud center height and diameter were 50 and 100 m, the same values as assumed for the past test shots. These are conservative meteorological (for daytime hours) and release assumptions, so the doses from depleted uranium released by future dynamic test shots were overestimated.

d. Tritium Releases. Dispersion factors to calculate doses from release of tritium were calculated using the same equation as the pre-1980 dynamic test shots. The releases were assumed to be puff-type releases at ground level. The puff size was estimated as being 10 m in diameter.

e. Coal-Fired Cogeneration Plant. Dispersion factors for radiological releases from the proposed coal-fired cogeneration plant were calculated using the EPA computer code AIRDOS-EPA (Moore 1979). The code uses annual average STAR data to calculate sector-average dispersion factors. Dispersion coefficients appropriate for a continuous plume-type release (Briggs 1973) were used in the dispersion equation.

D. Foodstuff Sampling

On 2 September 1981, 16 vegetable gardens were sampled, 7 on or near the Pantex Plant and 9 approximately 30 to 32 km from the Pantex Plant in and around the town of Claude, Texas. Samples taken at Claude served as controls for comparison with Pantex samples. Figure 11 depicts the gardens sampled on

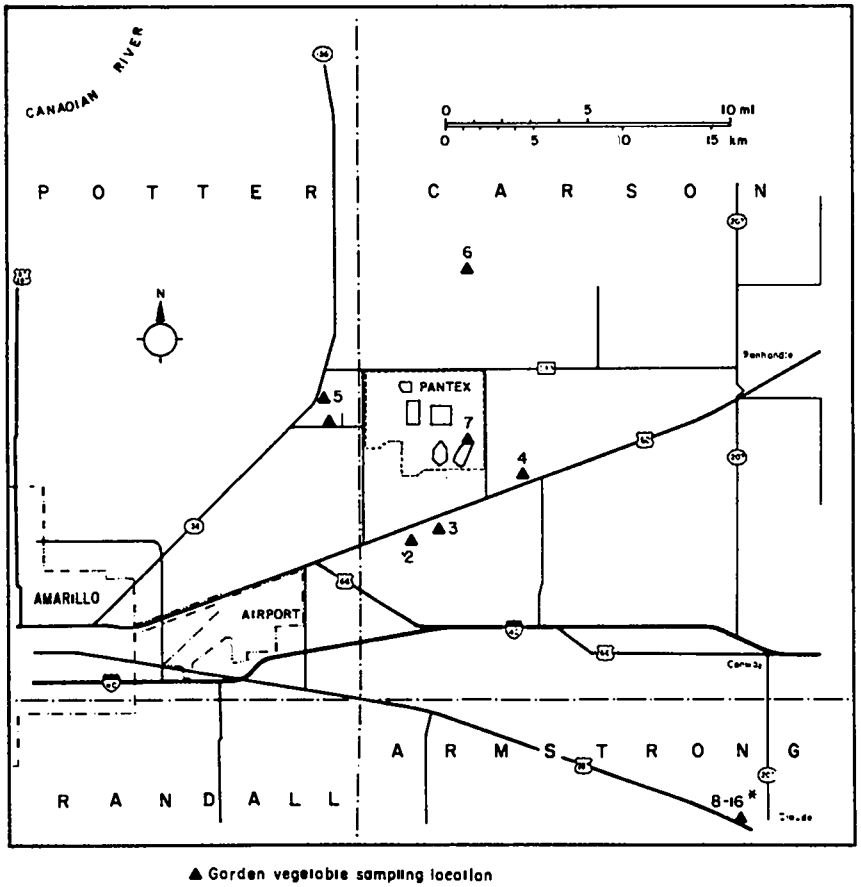

Fig. 11. Garden vegetable sampling locations at Pantex.

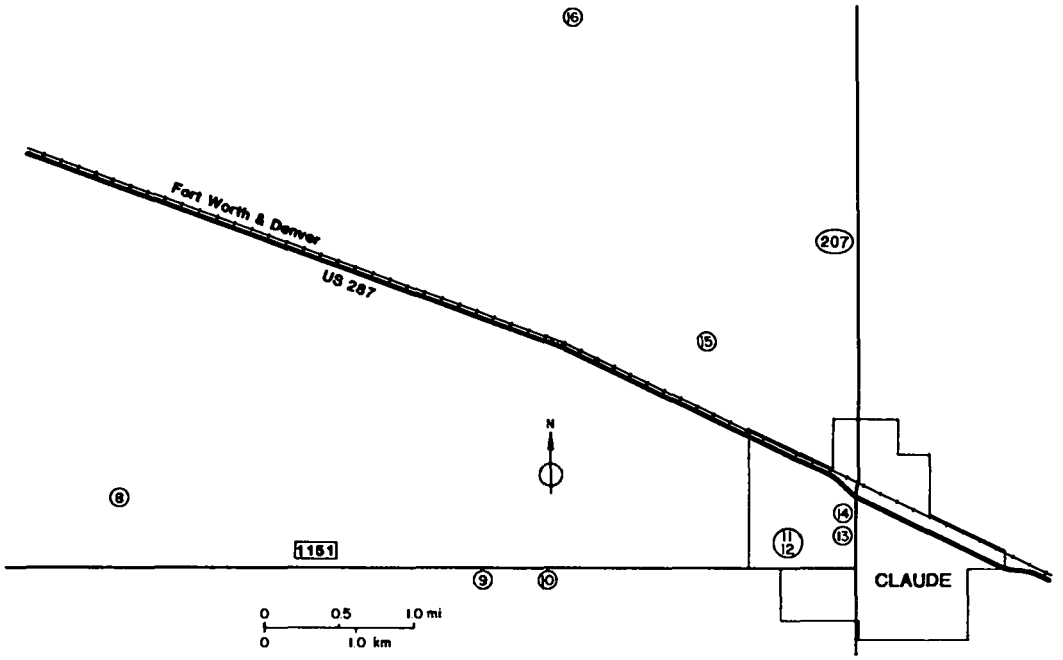

Fig. 12. Garden vegetable sampling locations at Claude, Texas.

and near Pantex and Fig. 12 depicts those sampled at Claude, Texas. The samples were purchased from each gardener with location and sample number documented, packaged in double plastic bags, sealed, and then quickly frozen in dry ice. Tables C-XI and C-XII give the sample vegetable type collected from each garden. Samples were returned frozen to Los Alamos National Laboratory for analysis preparation.

Vegetables from each garden were washed as if for consumption and ashed for total uranium and plutonium analyses. Plutonium was at or below detection levels for all gardens. There was no significant difference between the Pantex perimeter and site gardens to those at Claude, Texas, for tritium and uranium at the 95% confidence level. Table B-I gives the statistical data. Therefore, no tritium, uranium, or plutonium was found above background levels in any samples.

Tritium, uranium, and plutonium analyses data are given in Table C-XIII of Appendix C. Sampling procedures and statistical treatment of data are discussed in Appendix B.

In addition to garden vegetable samples, 10 beef cattle grazing on the Pantex site were purchased from a local rancher. Twenty additional cattle were purchased at auction. These cattle were separated into five treatments consisting of different feeding regimens. Two treatments involved feeding the cattle locally grown milo at the Texas Tech feedlot on the southwest corner of Pantex. The results of the study are reported by Wenzel (1982B). No levels

of tritium, uranium, or plutonium were found above background in beef tissues, meat, ground beef, feed, or forage for cattle grazed on Pantex property or fed milo grown near Pantex.

E. Soil Sampling

Soil samples were taken at Pantex at eight locations offsite, five perimeter locations, and two locations onsite. At the IAAP soil samples were taken at three offsite locations, four perimeter locations, and three onsite locations. Soil and sediment sampling in support of this environmental impact statement was also performed by Purtymun (1982) and Wenzel (1982B). Pantex personnel also have an extensive soil sampling program; results are published annually in their environmental surveillance report (MHSM 1980, MHSM 1982). Soil and sediment sampling results obtained by these other authors are in agreement with the results obtained in this study.

Soil sampling locations at Pantex are shown in Fig. 6 and at IAAP in Fig. 8. Most soil sampling sites correspond to locations where *in situ* gamma-ray spectra were taken (Section III.B.2).

At Pantex a profile soil sample was taken at depths of 0 to 10 cm, 10 to 20 cm, 20 to 30 cm, and 30 to 40 cm at the locations indicated in Fig. 6. Soil samples of 0 to 10 cm were also taken at the firing site and burn pad. Surface soil samples of 0 to 1 cm were taken at all offsite and perimeter locations.

Soil profile samples at 0 to 5 cm, 5 to 10 cm, 10 to 15 cm, and 15 to 20 cm were collected at IAAP at the sites indicated in Fig. 7. Surface soil samples of 0- to 5-cm depth were also collected at the firing site and in selected areas along Line One (Fig. 7).

Selected samples were analyzed for ^{235}U and ^{238}U. The ratio of the measured ^{235}U mass to the ^{238}U mass indicates whether the uranium in the sample is naturally occurring (if the ratio is 0.0072), depleted (if the ratio is statistically significantly <0.0072), or enriched (if the ratio is statistically significantly >0.0072). Because depleted uranium has been released at both Pantex and IAAP, this ratio can be used as an indicator of whether the sampled soil has been affected by Pantex or IAAP depleted uranium emissions.

Results of soil sampling at Pantex are shown in Tables C-XIV, C-XV, and C-XVI, and at IAAP in Table C-XVII of Appendix C. No offsite or perimeter samples were found at either site to have a ^{235}U to ^{238}U ratio statistically significantly different at the 95% confidence level from 0.0072, the ratio for natural uranium. Uranium concentrations in offsite and perimeter soil samples ranged from 2.8 to 3.5 ppm at Pantex and from 2.6 to 4.0 ppm at IAAP. These soil concentrations are typical background levels for uranium in soil.

As expected, soil samples collected at the firing sites used for tests involving depleted uranium at both Pantex and IAAP, and at the one burn pad at Pantex where high explosive attached to depleted uranium was burned, had elevated concentrations of uranium depleted in the ^{235}U isotope. As mentioned in Section III.B.2, a slightly elevated soil sample having 13 ppm uranium was also found in the only area along Line One at IAAP having a high phoswich reading. Monitoring near the sampled area with the phoswich and a soil sample taken from this nearby area detected only background, indicating that this slightly elevated area is an isolated area of contamination.

Selected soil samples were analyzed for ^{238}Pu and $^{239-240}Pu$. Results of these analyses are in Tables C-XIV through C-XVII in Appendix C.

Plutonium levels in soil at Pantex for both perimeter and offsite samples were found to be statistically indistinguishable at the 95% confidence level. Plutonium levels were low. The $^{239-240}Pu$ concentrations ranged from 0.002 to 0.040 pCi/g. The mean concentration for perimeter locations was 0.013 ± 0.011 pCi/g and for offsite locations 0.015 ± 0.014 pCi/g. For comparison, Robertson et al. collected surface soil samples at 19 background locations across the United States to obtain a typical background concentration of transuranic radionuclides in soil. The mean $^{239-240}Pu$ concentration in soil was 0.028 ± 0.020 pCi/g, about twice the mean concentrations found at Pantex (Robertson 1981).

Mean ^{238}Pu concentrations at Pantex were 0.0032 ± 0.0039 pCi/g for the perimeter samples, indistinguishable from the 0.0010 ± 0.0027 pCi/g for the offsite samples. The mean ^{238}Pu soil concentration in the 19 background soil samples taken across the United States by Robertson et al. was 0.0014 ± 0.0009 (Robertson 1981).

The ^{238}Pu and $^{239-240}Pu$ levels in soil samples collected near the IAAP also were not statistically different than were those levels from samples taken at regional locations. The mean $^{239-240}Pu$ concentration at perimeter stations was 0.018 ± 0.013 pCi/g, which was statistically indistinguishable from the mean at regional locations of 0.010 ± 0.007 pCi/g. The sample taken onsite was slightly higher than regional samples (0.031 versus 0.010 ± 0.007 pCi/g) but within the range of background values found by the Los Alamos Environmental Surveillance Group (ESG 1982) and Harley (1980). The ^{238}Pu soil levels in areas near the IAAP were similarly indistinguishable from those from regional areas.

F. Sediment and Water Sampling at IAAP

Water and sediment samples were collected at IAAP in 1981 and analyzed for ^{238}Pu, $^{239-240}Pu$, and uranium. Water samples were also analyzed for tritium. Water and sediment samples were collected at Pantex and Hanford by

Purtymun et al. and Sula et al. Results of sampling at those sites are discussed in reports by those authors (Purtymun 1982, Sula 1982).

Sampling locations are shown in Fig. 13. Surface water and sediment samples were taken at nine locations. Ground water samples were collected at nine wells. Results of the analyses are in Table C-XVIII (sediment samples) and Table C-XIX (water samples).

Uranium concentrations for all sediment samples taken both onsite and offsite were at background concentrations. The highest uranium concentration in sediment, 3.3 ± 0.4 pCi/g, was found in the background sample collected from the Skunk River upstream from IAAP. This concentration is equal to the average uranium concentration of 3.33 ± 0.70 pCi/g found in the background soil in the area (see Table C-XVII).

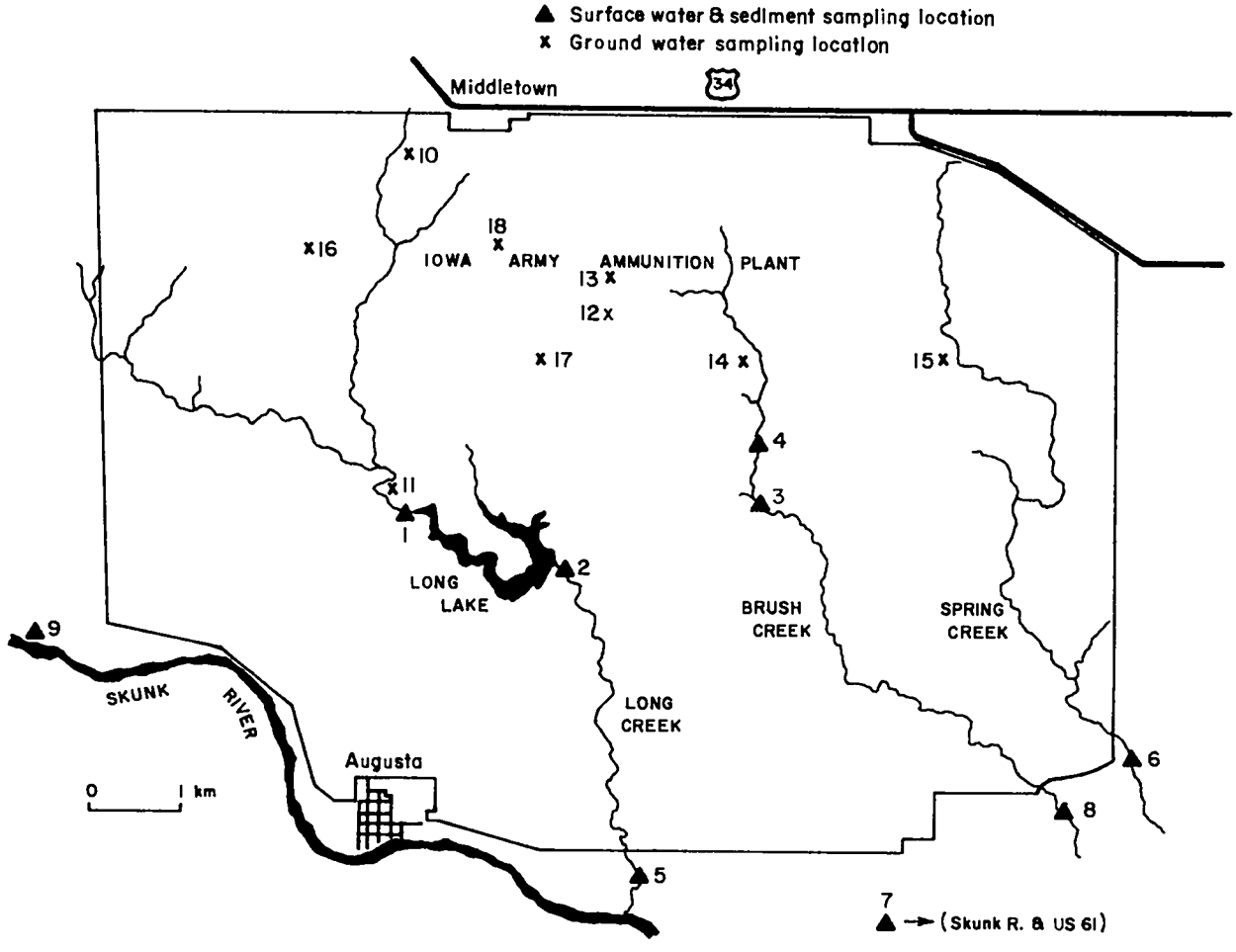

Fig. 13. Sediment and water sampling locations at the IAAP.

The $^{235}U/^{238}U$ ratio was indistinguishable from the value of 0.72% for naturally occurring uranium for all sediment samples except the sample collected onsite below the Long Creek Dam. This sample had a $^{235}U/^{238}U$ ratio of 0.57% ± 0.03%, indicating that the uranium was depleted in ^{235}U. This depleted uranium may have come from run-off from a portion of the IAAP firing site, which is in the drainage area of Long Creek and which has elevated concentrations of depleted uranium in the soil (see Section III.E). However, the total uranium concentration in this sample is low (2.4 ± 0.4 pCi/g versus the 3.3 ± 0.4 pCi/g found in the sample from the background location), which indicates that any depleted uranium present in the sample is not enough to raise the uranium content to any significant extent. Sediment samples taken offsite, including one taken at Long Creek downstream from the Long Creek sample having depleted uranium, had only natural abundances of ^{235}U relative to ^{238}U.

The ^{238}Pu and $^{239-240}Pu$ concentrations in sediment were at background levels. The highest concentrations of both radionuclides were found at the background location.

Surface water samples were indistinguishable from background for uranium, ^{238}Pu, and $^{239-240}Pu$. Concentrations of these radionuclides in ground water were low and typical of background concentrations. No detectable concentration of tritium was found in any surface or ground water sample. The highest uranium concentration was 0.1% of the relevant Department of Energy Concentration Guide. All ^{238}Pu and $^{239-240}Pu$ samples were less than 0.01% of their Concentration Guides.

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The authors are grateful for the help and cooperation provided by innumerable individuals throughout the course of this study. We would particularly like to single out Ronald Alexander and William Laseter at Pantex and Floyd Laue at the IAAP for their assistance in coordinating sampling trips and cheerfully answering questions. We thank John Healy, Wayne R. Hansen, John Rodgers, and Alan Stoker of Los Alamos National Laboratory for reviewing the report and providing especially helpful comments. Special thanks also go to Kathy Derouin, Verna Halloran, Mary Lou Keigher, and Lois Schneider for typing the manuscript.

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APPENDIX A

STANDARDS FOR ENVIRONMENTAL CONTAMINANTS

The concentrations of radioactive and chemical contaminants in air and water samples collected throughout the environment are compared with pertinent standards contained in regulations of several federal and state agencies to verify compliance with these standards. Pantex Plant operations pertaining to the environment are conducted in accordance with directives and procedures contained in Department of Energy Order 5480.1 (Environmental Protection, Safety, and Health Protection Program for DOE Operations), Chapter I (Environmental Protection, Safety, and Health Protection Standards), and Chapter XI (Requirements for Radiation Protection) (USDOE 1980); and Department of Energy Order 5484.1 (Environmental Protection, Safety, and Health Protection Information Reporting Requirements), Chapter III (Effluent and Environmental Monitoring Program Requirements) (USDOE 1981).

In the case of radioactive materials in the environment, guides contained in Chapter XI are used as a basis for evaluation. The standards are listed in Table A-I as Radioactivity Concentration Guides (CGs). A CG is the concentration of radioactivity in air breathed continuously or water constituting all that ingested during 50 years that will result in whole body or organ doses equal to the Radiation Protection Standards in the 50th year (RPSs, listed in Table A-II). Obviously, there are uncertainties in relating CGs to RPSs. Uncontrolled area CGs correspond to RPSs for the general public, whereas controlled area CGs correspond to RPSs for workers. Thus, common practice and stated Department of Energy policy in Chapter XI are that operations shall be "conducted in a manner to assure that radiation exposure to individuals and population groups is limited to the lowest levels reasonably achievable" (USDOE 1980).

The CG for a depleted uranium concentration in air in unrestricted areas was calculated using the rule that, for mixtures of radionuclides, the sum of the ratios of each radionuclide with its CG must be ≤ 1. That is, for a concentration in air C_i of radionuclide i whose CG in air is CG_i, then

$$\frac{C_1}{CG_1} + \frac{C_2}{CG_2} + \frac{C_3}{CG_3} + \ldots + \frac{C_n}{CG_n} \leq 1.0 \quad .$$

The CG for depleted uranium concentrations in air was calculated using the most restrictive CGs for ^{238}U, ^{234}U, and ^{235}U. These CGs are 5×10^{-12}, 4×10^{-12}, and 4×10^{-12} $\mu Ci/m\ell$ (which equal Ci/m^3), respectively. With the

fractions by mass of 0.997, 0.00002, and 0.003, and with specific activities of 3.33×10^{-7}, 6.19×10^{-3}, and 2.14×10^{-6} Ci/g, for ^{238}U, ^{234}U, and ^{235}U in the depleted uranium, respectively, the concentration C of depleted uranium in air, in g/m^3, would be just equal to the CG if

$$\frac{(3.33 \times 10^{-7})(0.997)C}{5 \times 10^{-12}} + \frac{(6.19 \times 10^{-3})(0.00002)C}{4 \times 10^{-12}} + \frac{(2.14 \times 10^{-6})(0.003)C}{4 \times 10^{-12}} = 1.0.$$

Solving for C gives $C = 1.01 \times 10^{-5}$ g/m^3, or 10 $\mu g/m^3$.

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TABLE A-I

US DEPARTMENT OF ENERGY RADIOACTIVITY CONCENTRATION GUIDES (CGs)

Concentration Guides for Uncontrolled Areas */**			Concentration Guides for Controlled Areas */**		
Nuclide	CG for Air (μCi/mℓ)	CG for Water (μCi/mℓ)	Nuclide	CG for Air (μCi/mℓ)	CG for Water (μCi/mℓ)
^{3}H	2×10^{-7}	3×10^{-3}	^{3}H	5×10^{-6}	1×10^{-1}
^{238}Pu	7×10^{-14}	5×10^{-6}	^{238}Pu	2×10^{-12}	1×10^{-4}
^{239}Pu***	6×10^{-14}	5×10^{-6}	^{239}Pu***	2×10^{-12}	1×10^{-4}
	(pg/m^3)+	(μg/ℓ)		(pg/m^3)+	(μg/ℓ)
U, natural+	6×10^{6}	1.8×10^{3}	U, natural+	1.8×10^{8}	6×10^{4}
U, depleted	10×10^{6}				

*This table contains the most restrictive CGs for nuclides of major interest at Pantex (DOE Order 5480.1, Chapter XI).

**CGs apply to radionuclide concentrations in excess of that occurring naturally or due to fallout.

***The CGs of ^{239}Pu and ^{90}Sr are the most appropriate to use for gross alpha and gross beta CGs, respectively.

+One curie of natural uranium is equivalent to 3000 kg of natural uranium. Hence, uranium masses may be converted to the DOE "uranium special curie" by using the factor 3.3×10^{-13} μCi/pg.

TABLE A-II

US DEPARTMENT OF ENERGY RADIATION PROTECTION STANDARDS FOR EXTERNAL AND INTERNAL EXPOSURES

Individuals and Population Groups in Uncontrolled Areas		
	Annual Dose Equivalent or Dose Commitment* (rem)	
Type of Exposure	Based on Dose to Individuals at Points of Maximum Probable Exposure	Based on an Average Dose to a Suitable Sample of the Exposed Population
Whole body, gonads, or bone marrow	0.5	0.17
Other organs	1.5	0.5

Individuals in Controlled Areas		
Type of Exposure	Exposure Period	Dose Equivalent [Dose or Dose Commitment* (rem)]
Whole body, head and trunk, gonads, lens of the eyes,** red bone marrow, active blood-forming organs	Year	5***
	Calendar Quarter	3
Unlimited areas of the skin (except hands and forearms) Other organs, tissues, and organ systems (except bone)	Year	15
	Calendar Quarter	5
Bone	Year	30
	Calendar Quarter	10
Forearms+	Year	30
	Calendar Quarter	10
Hands+ and feet	Year	75
	Calendar Quarter	25

*To meet the above dose commitment standards, operations must be conducted in such a manner that it would be unlikely that an individual would assimilate in a critical organ, by inhalation, ingestion, or absorption, a quantity of a radionuclide or mixture of radionuclides that would commit the individual to an organ dose that exceeds the limits specified in the above table.

**A beta exposure below a maximum energy of 700 keV will not penetrate the lens of the eye; therefore, the applicable limit for these energies would be that for the skin (15 rem/yr).

***In special cases with the approval of the Deputy Assistant Secretary for Environmental Safety and Health, a worker may exceed 5 rem/yr provided his or her average exposure per year since age 18 will not exceed 5 rem/yr. This does not apply to emergency situations.

+All reasonable effort shall be made to keep exposure of forearms and hands to the general limit for the skin.

APPENDIX B
SAMPLING PROCEDURES AND STATISTICAL TREATMENT OF DATA

I. AIR SAMPLING

A. Sampling Procedures

Samples were collected weekly at 14 continuously operating stations. High-volume air samplers with constant flow rates of approximately 1.1 m^3/min were used to collect atmospheric aerosols on 25- by 20-cm polystyrene filters.

The weekly air filters were collected by Pantex Plant personnel, sealed in plastic bags, and mailed to the Los Alamos National Laboratory's Environmental Surveillance Group for analysis. Immediately upon being received from Pantex, an 80-mm-diameter disk was cut from each filter, mounted on a metal counting planchet, and covered with a plastic film. This procedure insured adequate sample preservation.

Gross alpha and gross beta activities on the weekly filters were measured with a gas-flow proportional counter approximately 10 days after collection. This count (made after absorbed, naturally occurring, radon-thoron daughters had reached equilibrium with their long-lived parents) provided a record of long-lived atmospheric radioactivity.

Two clean control filters were used to detect any possible contamination of the 15 sampling filters while they were in transit. The control filters accompanied the 15 sampling filters when they were placed in the air samplers and when they were retrieved. The control filters were analyzed for radioactivity just like the 15 sampling filters. Analytical results for the control filters were subtracted from the appropriate gross analytical results to obtain net analytical results.

After being counted for gross alpha and gross beta activities, the weekly 80-mm-diameter filter disks were cut in half. The first group of filter halves was combined to produce 4-week composite samples for each station for plutonium analyses. The second group of filter halves was similarly composited for uranium analyses.

The air filters were ignited in platinum dishes, treated with HF-HNO_3 to dissolve silica, wet ashed with HNO_3-H_2O_2 to decompose organic residue, and treated with HNO_3HCl to ensure isotopic equilibrium. Plutonium was separated from the resulting solution by anion exchange. The purified plutonium samples were separately electrodeposited and measured for alpha-particle emission with a solid-state alpha detection system. Alpha-particle energy groups associated with the decay of ^{238}Pu and ^{239}Pu were integrated, and the

concentration of each radionuclide in its respective air sample was calculated. This technique does not differentiate between ^{239}Pu and ^{240}Pu. Uranium analyses by neutron activation analysis were done on the second group of filter halves. Specific details about the gross alpha, gross beta, plutonium, and uranium analyses have been summarized (ESG 1981).

Analytical quality control and quality assurance for analyses done in this air sampling program have been described (Gladney 1981). In brief, both blanks and standards are analyzed in conjunction with normal analytical procedures. About 10% of the analyses are devoted to the quality control and assurance program.

B. Statistical Analysis

Measurements of the air particulate samples require that chemical or instrumental backgrounds be subtracted to obtain net values. Thus, net values lower than the minimum detection limit of an analytical technique are sometimes obtained. Consequently, individual measurements result in values of zero or negative numbers because of statistical fluctuations in the measurements. Although a negative value does not represent a physical reality, a valid long-term average of many measurements can be obtained only if the very small and negative values (Gilbert 1975) are included in the population.

Uncertainties reported for maximum and minimum concentrations reflect uncertainties introduced in both the field (flow rate and time determinations) and laboratory (counting, pipetting, etc.). These values indicate the precision of the maxima and minima and represent twice the propagated measurement uncertainties.

Standard deviations for station means were calculated using the following equation:

$$S_{\bar{c}} = \left[\frac{\sum_{i=1}^{N} (\bar{c} - c_i)^2}{N(N-1)} \right]^{1/2},$$

where

$S_{\bar{c}}$ = standard deviation of $\bar{c}$,

$\bar{c}$ = annual mean of a station,

c_i = concentration for station i, and

N = number of concentrations (sampling periods).

II. FOODSTUFF SAMPLES

Wet weights, dry weights (105°C), and ash weights (500°C for 2-3 days) were measured on all garden samples. Tritium was distilled from a portion of each garden sample and analyzed in a PCS II (Amersham Corp, Arlington Heights, Illinois) cocktail using standard computing techniques (Gladney 1982A).

Total uranium was determined from ashed samples by thermal neutron activation (Gladney 1982A). Plutonium isotopic composition was determined by radiochemical separation and alpha spectroscopy (Gladney 1982B).

Table B-I gives the statistical data treatment for ^{3}H and total uranium. No difference exists between means for the Pantex perimeter and onsite gardens versus the Claude, Texas, gardens, located 30 km from Pantex. Plutonium levels in all cases were at the detection limit with no indication of any measurable plutonium.

III. SOIL SAMPLES

Surface soil samples were collected at Pantex by taking a 1-cm-depth and 20-cm-diameter plug. Profile samples were taken at depths of 0-10 cm, 10-20 cm, 20-30 cm, and 30-40 cm. These samples were 10-cm-depth and 10-cm-diameter plugs.

At IAAP, 0- to 5-cm surface soil samples, 5-cm-depth and 10-cm-diameter plugs, were taken. Profile samples were plugs of the same dimensions taken at depths of 0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm.

Selected samples were analyzed for ^{235}U, ^{238}U, ^{238}Pu, and $^{239-240}Pu$. Gamma scans were performed on the profile samples to determine variation with depth of gamma emitting radionuclides, principally those resulting from worldwide fallout.

The ^{235}U and ^{238}U concentrations in soil were measured using delayed neutron activation and epithermal neutron activation, respectively. Concentrations of ^{238}Pu and $^{239-240}Pu$ were determined by alpha spectrometry. Details of the methods that were used have been published by the Los Alamos Environmental Surveillance Group (ESG 1981) and Gladney (1982C).

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TABLE B-I

STATISTICS BETWEEN MEANS FOR TRITIUM AND URANIUM

Number		^3H, X_i pCi/ℓ	X_i^2	U, X_i fCi/g dry	X_i^2
Pantex Parameters					
1		-100	10 000	0.0	0
2		-200	20 000	0.53	0.2809
3		1400	1 960 000	1.2	1.44
4		1400	1 960 000	0.12	0.014
5		400	160 000	0.15	0.0225
6		400	160 000	0.0	0
7a		1200	1 440 000	0.45	0.2025
7b		400	160 000	0.18	0.0324
	Σ	4900	5 870 000	2.63	1.9923
Claude, Texas					
8		600	360 000	0.098	0.009604
9		100	10 000	0.053	0.002809
10		700	490 000	0.0	0
11		500	250 000	0.0	0
12		900	810 000	0.10	0.01
13		-200	20 000	0.097	0.009409
14		0	0	0.15	0.0225
15		400	160 000	0.0	0
16		300	90 000	0.076	0.005776
	Σ	3300	2 190 000	0.574	0.060098
	ΣΣ	8200	8 060 000	3.204	2.052398

Equations and Reference

(Dixon 1957)

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_p \sqrt{1/8+1/9}}$$

$$S_p^2 = \left[\Sigma X_1^2 - \frac{(\Sigma X_1)^2}{8} + \Sigma X_2^2 - \frac{(\Sigma X_2)^2}{9}\right] /15$$

H: means are not equal

Reject at $\alpha = 0.05$ when
$t < -2.131$ or > 2.131

df = 15, α = 0.05

t = 0.9988 ∴ means are the same for ^3H

df = 15, α = 0.05

t = 1.3747 ∴ means are the same for U

APPENDIX C

ENVIRONMENTAL DATA TABLES

TABLE C-I

COMPARISON OF AVERAGE BACKGROUND
ATMOSPHERIC RADIOACTIVITY CONCENTRATIONS DURING 1981

Constituent	Units	Oklahoma City, Oklahoma*	Los Alamos, New Mexico (Los Alamos National Laboratory)**	Amarillo, Texas (Pantex Plant)***	Uncontrolled Area Concentration Guide
Gross alpha	10^{-15} µCi/mℓ	Not reported	1.1 ± 0.3[+]	3.3 ± 4.5	60
Gross beta	10^{-15} µCi/mℓ	100 ± 190	121 ± 33	48 ± 66	3 000
^{238}Pu	10^{-18} µCi/mℓ	1.5 ± 1.7	-1.5 ± 0.6	3.8 ± 5.4	70
$^{239-240}Pu$	10^{-18} µCi/mℓ	18 ± 29	8.2 ± 5.9	11 ± 22	60
Uranium	10^{-18} µCi/mℓ	45 ± 24	8.9 ± 4.3	16 ± 28	2 000 000
Uranium	pg/m^3	137 ± 73	27 ± 13	49 ± 85	6 000 000
Total suspended radionuclides	µg/m^3	---	GM = 38, 2 GSD = 3[++]	GM = 57, 2 GSD = 3[++,+++]	---

*Data from the Environmental Radiation Ambient Monitoring System of the US Environmental Protection Agency for 1981. Oklahoma City is about 416 km (260 mi) east of Amarillo.

**Data from the Los Alamos National Laboratory's three regional background stations that are outside any possible influence of its operations. Data for 1981.

***Data from the Pantex Plant's one regional (background) station that is outside any possible influence of its operations. Data for 1981.

[+]$\bar{X}$ ± 2S.

[++]Quoted measurement is the geometric mean (GM) and twice the geometric standard deviation (GSD).

[+++]Data has been provided by the Texas Air Surveillance report published by the State of Texas Air Control Board.

TABLE C-II

GROSS ALPHA CONCENTRATIONS IN AMBIENT AIR AT THE PANTEX PLANT

Station Number	Number of Weekly Samples*	Concentrations in fCi/m^3 (10^{-15} $\mu Ci/m\ell$)**			Mean as % Concentration Guide+
		Maximum***	Minimum***	Mean***	
Regional Station - Uncontrolled Area					
OA-AR-13	24	8.2 ± 1.8	0.7 ± 0.6	3.3 ± 4.5	5.5
Perimeter Stations - Uncontrolled Areas					
OA-AR-02	51	7.4 ± 3.2	0.2 ± 0.4	2.6 ± 4.0	4.3
OA-AR-03	51	6.9 ± 2.8	0.2 ± 0.4	2.3 ± 3.4	3.8
OA-AR-04	51	7.8 ± 3.7	0.1 ± 0.6	2.6 ± 3.9	4.3
OA-AR-05	52	6.9 ± 2.8	0.2 ± 0.4	2.6 ± 3.8	4.3
OA-AR-06	52	6.4 ± 2.8	0.0 ± 0.4	2.3 ± 3.8	3.8
OA-AR-08	52	9.2 ± 3.7	-0.1 ± 0.5	3.1 ± 6.1	5.2
OA-AR-09	52	6.9 ± 2.8	0.1 ± 0.5	2.2 ± 3.3	3.7
OA-AR-10	52	7.4 ± 3.7	0.2 ± 0.5	2.8 ± 4.4	4.7
Onsite Stations - Controlled Areas					
PA-AR-01	51	6.9 ± 2.8	-0.3 ± 0.4	2.2 ± 3.5	0.1
PA-AR-03	23	7.4 ± 3.7	1.0 ± 0.6	3.6 ± 2.7	0.2
PA-AR-04	52	7.4 ± 3.7	0.1 ± 0.5	2.1 ± 3.1	0.1
PA-AR-06	30	6.0 ± 2.8	0.5 ± 0.6	4.0 ± 3.4	0.2
PA-AR-07	28	6.9 ± 2.8	1.1 ± 0.6	3.7 ± 3.1	0.2

*Samples collected from 4 February 1981 through 4 February 1982.
**Minimum detectable concentration = 0.3×10^{-15} $\mu Ci/m\ell$.
***Uncertainties are ±2 standard deviations (see Appendix B).
+The Concentration Guide of ^{239}Pu is the most appropriate to use for gross alpha.
Controlled Area Concentration Guide = 2×10^{-12} $\mu Ci/m\ell$.
Uncontrolled Area Concentration Guide = 6×10^{-14} $\mu Ci/m\ell$.

TABLE C-III

GROSS BETA CONCENTRATIONS IN AMBIENT AIR AT THE PANTEX PLANT

Station Number	Number of Weekly Samples*	Concentrations in fCi/m^3 (10^{-15} µCi/mℓ)**			Mean as % Concentration Guide+
		Maximum***	Minimum***	Mean***	
Regional Station - Uncontrolled Area					
OA-AR-13	24	110 ± 28	12 ± 3	48 ± 66	1.6
Perimeter Stations - Uncontrolled Areas					
OA-AR-02	51	202 ± 28	12 ± 3	75 ± 96	2.5
OA-AR-03	51	285 ± 37	17 ± 5	72 ± 112	2.4
OA-AR-04	51	276 ± 37	18 ± 2	73 ± 106	2.4
OA-AR-05	52	207 ± 28	16 ± 4	66 ± 102	2.2
OA-AR-06	52	166 ± 23	12 ± 2	58 ± 84	1.9
OA-AR-08	52	179 ± 46	13 ± 4	69 ± 87	2.3
OA-AR-09	52	189 ± 23	13 ± 4	64 ± 90	2.1
OA-AR-10	52	235 ± 32	21 ± 6	70 ± 92	2.3
Onsite Stations - Controlled Areas					
PA-AR-01	51	175 ± 46	14 ± 6	63 ∓ 83	0.07
PA-AR-03	23	179 ± 46	17 ± 5	38 ± 74	0.04
PA-AR-04	52	216 ± 28	17 ± 2	62 ± 96	0.07
PA-AR-06	30	156 ± 37	23 ± 4	54 ± 86	0.06
PA-AR-07	28	133 ± 37	17 ± 5	57 ± 79	0.06

*Samples collected from 4 February 1981 through 4 February 1982.
**Minimum detectable concentration = 0.3 x 10^{-15} µCi/mℓ.
***Uncertainties are ±2 standard deviations (see Appendix B).
+The Concentration Guide of ^{241}Pu is the most appropriate to use for gross beta.
Controlled Area Concentration Guide = 9 x 10^{-11} µCi/mℓ.
Uncontrolled Area Concentration Guide = 3 x 10^{-12} µCi/mℓ.

TABLE C-IV

AMBIENT AIR CONCENTRATIONS OF ^{238}Pu AT THE PANTEX PLANT

Station Number	Number of Monthly Samples*	Concentrations in aCi/m^3 (10^{-18} µCi/mℓ)** Maximum***	Minimum***	Mean***	Mean as % Concentration Guide+
Regional Station - Uncontrolled Area					
OA-AR-13	12	7.8 ± 3.9	0.8 ± 1.9	3.8 ± 5.4	0.005
Perimeter Stations - Uncontrolled Areas					
OA-AR-02	12	4.3 ± 1.6	0.8 ± 2.3	2.1 ± 2.6	0.003
OA-AR-03	12	5.8 ± 2.7	1.0 ± 0.8	2.9 ± 3.5	0.004
OA-AR-04	12	6.6 ± 3.5	0.8 ± 1.2	2.5 ± 4.1	0.004
OA-AR-05	12	19 ± 2	0.8 ± 1.2	4.7 ± 13	0.007
OA-AR-06	12	3.1 ± 1.9	0.8 ± 1.6	1.6 ± 1.8	0.002
OA-AR-08	12	11 ± 3	0.4 ± 1.2	3.0 ± 5.7	0.004
OA-AR-09	12	19 ± 23	0.8 ± 1.2	4.5 ± 10	0.006
OA-AR-10	12	4.3 ± 2.3	0.8 ± 1.9	2.3 ± 3.2	0.003
Onsite Stations - Controlled Areas					
PA-AR-01	9	4.7 ± 2.7	0.8 ± 1.6	2.0 ± 2.4	0.0001
PA-AR-03	6	3.1 ± 2.3	0.4 ± 0.8	2.4 ± 3.9	0.0001
PA-AR-04	9	24 ± 528	1.9 ± 0.8	5.0 ± 14	0.0003
PA-AR-06	7	6.6 ± 2.7	1.2 ± 1.6	2.8 ± 3.5	0.0001
PA-AR-07	7	4.7 ± 1.6	0.54 ± 1.6	2.4 ± 3.5	0.0001

*Samples collected from 4 February 1981 through 4 February 1982.
**Minimum detectable concentration = 2 x 10^{-18} µCi/mℓ.
***Uncertainties are ±2 standard deviations (see Appendix B).
+Controlled Area Concentration Guide = 2 x 10^{-12} µCi/mℓ.
Uncontrolled Area Concentration Guide = 7 x 10^{-14} µCi/mℓ.

TABLE C-V

AMBIENT AIR CONCENTRATIONS OF $^{239-240}Pu$ AT THE PANTEX PLANT

Station Number	Number of Monthly Samples*	Concentrations in aCi/m³ (10^{-18} µCi/mℓ)** Maximum***	Minimum***	Mean***	Mean as % Concentration Guide+
Regional Station - Uncontrolled Area					
OA-AR-13	12	34 ± 5	0.8 ± 1.2	11 ± 22	0.02
Perimeter Stations - Uncontrolled Areas					
OA-AR-02	12	19 ± 7	0.8 ± 2.3	7.9 ± 11	0.01
OA-AR-03	12	28 ± 6	1.2 ± 1.2	10 ± 14	0.02
OA-AR-04	12	26 ± 5	0.8 ± 1.6	10 ± 17	0.02
OA-AR-05	12	22 ± 5	3.9 ± 2.3	12 ± 13	0.02
OA-AR-06	12	39 ± 16	7.0 ± 2.3	12 ± 19	0.02
OA-AR-08	12	28 ± 6	1.9 ± 2.3	10 ± 16	0.02
OA-AR-09	12	26 ± 5	1.9 ± 1.9	13 ± 14	0.02
OA-AR-10	12	39 ± 16	8.9 ± 2.7	14 ± 16	0.02
Onsite Stations - Controlled Areas					
PA-AR-01	9	12 ± 3	2.7 ± 1.6	6.9 ± 6.6	0.0003
PA-AR-03	6	23 ± 9	3.9 ± 1.9	9 ± 14	0.0005
PA-AR-04	9	19 ± 73	3.9 ± 1.9	13 ± 12	0.0007
PA-AR-06	7	39 ± 12	7.0 ± 2.3	14 ± 24	0.0007
PA-AR-07	7	19 ± 6	3.9 ± 3.1	9.6 ± 10	0.0005

*Samples collected from 4 February 1981 through 4 February 1982.
**Minimum detectable concentration = 3×10^{-18} µCi/mℓ.
***Uncertainties are ±2 standard deviations (see Appendix B).
+Controlled Area Concentration Guide = 2×10^{-12} µCi/mℓ.
Uncontrolled Area Concentration Guide = 6×10^{-14} µCi/mℓ.

TABLE C-VI

URANIUM CONCENTRATIONS IN AMBIENT AIR AT THE PANTEX PLANT

Station Number	Number of Monthly Samples*	Concentrations in pg/m³**			Mean as % Concentration Guide+
		Maximum***	Minimum***	Mean***	
Regional Station - Uncontrolled Area					
OA-AR-13	12	156 ± 16	17 ± 4	49 ± 85	0.0008
Perimeter Stations - Uncontrolled Areas					
OA-AR-02	12	42 ± 5	15 ± 4	13 ± 17	0.0006
OA-AR-03	12	69 ± 7	11 ± 4	40 ± 32	0.0007
OA-AR-04	12	46 ± 5	21 ± 4	34 ± 19	0.0006
OA-AR-05	12	75 ± 7	16 ± 4	39 ± 28	0.0007
OA-AR-06	12	80 ± 8	25 ± 4	34 ± 33	0.0006
OA-AR-08	12	41 ± 5	11 ± 4	29 ± 20	0.0005
OA-AR-09	12	52 ± 6	11 ± 4	23 ± 25	0.0004
OA-AR-10	12	58 ± 6	18 ± 4	31 ± 28	0.0005
Onsite Stations - Controlled Areas					
PA-AR-01	9	71 ± 7	17 ± 4	33 ± 32	0.00002
PA-AR-03	6	41 ± 4	16 ± 4	29 ± 17	0.00002
PA-AR-04	9	127 ± 13	14 ± 4	40 ± 68	0.00002
PA-AR-06	7	26 ± 4	12 ± 4	22 ± 10	0.00001
PA-AR-07	7	29 ± 4	14 ± 4	24 ± 11	0.00001

*Samples collected from 4 February 1981 through 4 February 1982.
**Minimum detectable concentration = 1 pg/m^3.
***Uncertainties are ±2 standard deviations (see Appendix B).
+Controlled Area Concentration Guide = 1.8×10^8 pg/m^3.
Uncontrolled Area Concentration Guide = 6×10^6 pg/m^3.

Useful Conversion Factors: 3.3×10^{-13} µCi/pg
$10^6 m\ell/m^3$
$(pg/m^3)\ (3.3 \times 10^{-18}) = (\mu Ci/m\ell)$

TABLE C-VII

ANNUAL THERMOLUMINESCENT DOSIMETER MEASUREMENTS

Group	Number	Dose (mrem)
Offsite	1	68 ± 5
	2	76 ± 5
	3	76 ± 5
	4	72 ± 5
	5	80 ± 5
	6	72 ± 5
	8	68 ± 5
	9	68 ± 5
	10	68 ± 5
Perimeter	101	80 ± 5
	102	76 ± 5
	103	84 ± 5
	104	80 ± 5
	105	84 ± 5
Onsite	1001	64 ± 5
	1002	76 ± 5
	1003	80 ± 5
	1004	76 ± 5
	1005	84 ± 5
	1006	132 ± 5
	1007	68 ± 5
	1008	84 ± 5
	1009	72 ± 5
	1010	68 ± 5

TABLE C-VIII

STABILITY WIND-ROSE DATA FOR AMARILLO
1972-1976

Stability A - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.02	0.02	0.00	0.00	0.00	0.00	0.04
NNE	0.01	0.01	0.00	0.00	0.00	0.00	0.02
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENE	0.01	0.01	0.00	0.00	0.00	0.00	0.02
E	0.00	0.01	0.00	0.00	0.00	0.00	0.01
ESE	0.01	0.02	0.00	0.00	0.00	0.00	0.03
SE	0.02	0.01	0.00	0.00	0.00	0.00	0.03
SSE	0.00	0.01	0.00	0.00	0.00	0.00	0.01
S	0.02	0.03	0.00	0.00	0.00	0.00	0.04
SSW	0.03	0.01	0.00	0.00	0.00	0.00	0.03
SW	0.00	0.01	0.00	0.00	0.00	0.00	0.01
WSW	0.02	0.01	0.00	0.00	0.00	0.00	0.03
W	0.02	0.01	0.00	0.00	0.00	0.00	0.03
WNW	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NW	0.03	0.01	0.00	0.00	0.00	0.00	0.03
NNW	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.18	0.17	0.00	0.00	0.00	0.00	0.35

Stability B - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.01	0.09	0.01	0.00	0.00	0.00	0.11
NNE	0.00	0.03	0.03	0.00	0.00	0.00	0.06
NE	0.01	0.04	0.04	0.00	0.00	0.00	0.09
ENE	0.01	0.06	0.01	0.00	0.00	0.00	0.08
E	0.05	0.12	0.06	0.00	0.00	0.00	0.22
ESE	0.02	0.04	0.01	0.00	0.00	0.00	0.07
SE	0.01	0.06	0.08	0.00	0.00	0.00	0.14
SSE	0.01	0.06	0.05	0.00	0.00	0.00	0.12
S	0.03	0.09	0.10	0.00	0.00	0.00	0.23
SSW	0.00	0.04	0.07	0.00	0.00	0.00	0.11
SW	0.01	0.03	0.07	0.00	0.00	0.00	0.11
WSW	0.00	0.04	0.08	0.00	0.00	0.00	0.13
W	0.01	0.06	0.07	0.00	0.00	0.00	0.14
WNW	0.01	0.06	0.08	0.00	0.00	0.00	0.14
NW	0.03	0.10	0.09	0.00	0.00	0.00	0.22
NNW	0.02	0.08	0.07	0.00	0.00	0.00	0.16
Total	0.26	0.98	0.91	0.00	0.00	0.00	2.15

TABLE C-VIII (cont)

Stability C - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.01	0.08	0.45	0.09	0.03	0.01	0.66
NNE	0.01	0.05	0.18	0.04	0.03	0.01	0.31
NE	0.00	0.06	0.13	0.12	0.03	0.01	0.35
ENE	0.00	0.03	0.23	0.03	0.01	0.00	0.30
E	0.00	0.06	0.20	0.04	0.01	0.00	0.31
ESE	0.00	0.04	0.13	0.03	0.01	0.00	0.22
SE	0.00	0.06	0.18	0.08	0.00	0.00	0.32
SSE	0.02	0.04	0.24	0.13	0.02	0.02	0.47
S	0.00	0.06	0.58	0.34	0.18	0.06	1.21
SSW	0.01	0.10	0.47	0.41	0.20	0.03	1.21
SW	0.02	0.11	0.42	0.34	0.15	0.04	1.08
WSW	0.02	0.11	0.27	0.15	0.05	0.03	0.63
W	0.02	0.09	0.35	0.11	0.02	0.06	0.64
WNW	0.02	0.10	0.26	0.03	0.00	0.01	0.43
NW	0.01	0.12	0.47	0.09	0.00	0.01	0.69
NNW	0.02	0.13	0.23	0.06	0.01	0.01	0.46
Total	0.16	1.23	4.76	2.11	0.73	0.29	9.28

Stability D - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.03	0.22	0.88	2.62	1.60	1.01	6.36
NNE	0.01	0.07	0.62	1.49	0.85	0.40	3.44
NE	0.02	0.09	0.56	1.10	0.39	0.11	2.27
ENE	0.02	0.10	0.40	0.64	0.14	0.01	1.33
E	0.02	0.18	0.61	0.75	0.09	0.01	1.66
ESE	0.03	0.12	0.52	0.66	0.13	0.04	1.50
SE	0.02	0.16	0.84	1.60	0.52	0.19	3.33
SSE	0.01	0.16	1.08	2.84	0.75	0.27	5.12
S	0.04	0.23	1.87	7.14	3.50	0.93	13.70
SSW	0.01	0.11	1.21	3.97	1.61	0.40	7.31
SW	0.02	0.16	1.08	3.69	1.39	0.34	6.68
WSW	0.03	0.13	0.61	2.19	0.84	0.57	4.36
W	0.01	0.11	0.40	1.12	0.71	0.53	2.88
WNW	0.01	0.09	0.37	0.77	0.21	0.10	1.54
NW	0.02	0.15	0.68	1.27	0.23	0.18	2.53
NNW	0.03	0.08	0.38	1.06	0.48	0.36	2.40
Total	0.33	2.16	12.11	32.91	13.44	5.45	66.39

TABLE C-VIII (cont)

Stability E - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.00	0.19	0.72	0.00	0.00	0.00	0.91
NNE	0.00	0.07	0.37	0.00	0.00	0.00	0.44
NE	0.00	0.06	0.36	0.00	0.00	0.00	0.41
ENE	0.00	0.05	0.33	0.00	0.00	0.00	0.38
E	0.00	0.06	0.48	0.00	0.00	0.00	0.53
ESE	0.00	0.09	0.36	0.00	0.00	0.00	0.45
SE	0.00	0.14	0.76	0.00	0.00	0.00	0.90
SSE	0.00	0.11	1.11	0.00	0.00	0.00	1.22
S	0.00	0.28	2.53	0.00	0.00	0.00	2.81
SSW	0.00	0.15	1.60	0.00	0.00	0.00	1.75
SW	0.00	0.21	2.08	0.00	0.00	0.00	2.29
WSW	0.00	0.10	1.00	0.00	0.00	0.00	1.10
W	0.00	0.10	0.60	0.00	0.00	0.00	0.70
WNW	0.00	0.07	0.64	0.00	0.00	0.00	0.71
NW	0.00	0.12	0.90	0.00	0.00	0.00	1.02
NNW	0.00	0.06	0.47	0.00	0.00	0.00	0.52
Total	0.00	1.85	14.29	0.00	0.00	0.00	16.14

Stability F - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.09	0.35	0.00	0.00	0.00	0.00	0.44
NNE	0.04	0.18	0.00	0.00	0.00	0.00	0.22
NE	0.04	0.21	0.00	0.00	0.00	0.00	0.24
ENE	0.03	0.14	0.00	0.00	0.00	0.00	0.16
E	0.02	0.12	0.00	0.00	0.00	0.00	0.14
ESE	0.03	0.13	0.00	0.00	0.00	0.00	0.16
SE	0.05	0.21	0.00	0.00	0.00	0.00	0.26
SSE	0.03	0.18	0.00	0.00	0.00	0.00	0.21
S	0.14	0.52	0.00	0.00	0.00	0.00	0.66
SSW	0.11	0.56	0.00	0.00	0.00	0.00	0.67
SW	0.08	0.44	0.00	0.00	0.00	0.00	0.52
WSW	0.05	0.33	0.00	0.00	0.00	0.00	0.38
W	0.10	0.43	0.00	0.00	0.00	0.00	0.53
WNW	0.06	0.34	0.00	0.00	0.00	0.00	0.40
NW	0.08	0.36	0.00	0.00	0.00	0.00	0.44
NNW	0.03	0.23	0.00	0.00	0.00	0.00	0.27
Total	0.98	4.71	0.00	0.00	0.00	0.00	5.69

TABLE C-IX

STABILITY WIND-ROSE DATA FOR BURLINGTON
1967-1971

Stability A - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.01	0.01	0.00	0.00	0.00	0.00	0.02
NNE	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.01	0.00	0.00	0.00	0.00	0.01
ENE	0.01	0.01	0.00	0.00	0.00	0.00	0.02
E	0.02	0.05	0.00	0.00	0.00	0.00	0.07
ESE	0.01	0.01	0.00	0.00	0.00	0.00	0.02
SE	0.01	0.02	0.00	0.00	0.00	0.00	0.03
SSE	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S	0.01	0.02	0.00	0.00	0.00	0.00	0.03
SSW	0.01	0.01	0.00	0.00	0.00	0.00	0.02
SW	0.01	0.01	0.00	0.00	0.00	0.00	0.02
WSW	0.02	0.03	0.00	0.00	0.00	0.00	0.05
W	0.01	0.02	0.00	0.00	0.00	0.00	0.03
WNW	0.02	0.01	0.00	0.00	0.00	0.00	0.03
NW	0.01	0.02	0.00	0.00	0.00	0.00	0.03
NNW	0.01	0.01	0.00	0.00	0.00	0.00	0.02
Total	0.14	0.26	0.00	0.00	0.00	0.00	0.40

Stability B - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.04	0.14	0.08	0.00	0.00	0.00	0.25
NNE	0.02	0.09	0.06	0.00	0.00	0.00	0.17
NE	0.04	0.19	0.09	0.00	0.00	0.00	0.31
ENE	0.00	0.04	0.06	0.00	0.00	0.00	0.10
E	0.01	0.07	0.08	0.00	0.00	0.00	0.16
ESE	0.04	0.14	0.07	0.00	0.00	0.00	0.25
SE	0.02	0.18	0.06	0.00	0.00	0.00	0.26
SSE	0.03	0.08	0.10	0.00	0.00	0.00	0.21
S	0.05	0.29	0.18	0.00	0.00	0.00	0.52
SSW	0.02	0.12	0.05	0.00	0.00	0.00	0.18
SW	0.06	0.11	0.09	0.00	0.00	0.00	0.26
WSW	0.02	0.10	0.08	0.00	0.00	0.00	0.20
W	0.03	0.15	0.06	0.00	0.00	0.00	0.24
WNW	0.01	0.14	0.03	0.00	0.00	0.00	0.18
NW	0.01	0.09	0.08	0.00	0.00	0.00	0.18
NNW	0.01	0.06	0.01	0.00	0.00	0.00	0.08
Total	0.41	1.98	1.16	0.00	0.00	0.00	3.54

TABLE C-IX (cont)

Burlington - 1967-1971

Stability C - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.05	0.08	0.32	0.08	0.01	0.00	0.53
NNE	0.01	0.05	0.21	0.02	0.00	0.00	0.29
NE	0.03	0.09	0.31	0.01	0.00	0.00	0.44
ENE	0.01	0.07	0.23	0.02	0.00	0.00	0.34
E	0.03	0.09	0.25	0.01	0.00	0.00	0.38
ESE	0.07	0.13	0.24	0.03	0.00	0.00	0.48
SE	0.04	0.12	0.32	0.01	0.01	0.00	0.48
SSE	0.01	0.05	0.23	0.03	0.00	0.00	0.32
S	0.05	0.24	1.03	0.32	0.01	0.00	1.66
SSW	0.06	0.12	0.62	0.20	0.01	0.00	1.02
SW	0.04	0.07	0.46	0.23	0.01	0.00	0.81
WSW	0.01	0.04	0.34	0.10	0.00	0.00	0.49
W	0.04	0.10	0.43	0.10	0.01	0.00	0.68
WNW	0.04	0.12	0.47	0.06	0.00	0.00	0.68
NW	0.03	0.10	0.36	0.03	0.03	0.00	0.56
NNW	0.04	0.10	0.16	0.06	0.01	0.00	0.37
Total	0.55	1.56	5.98	1.31	0.10	0.00	9.50

Stability D - Wind Speed Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.07	0.45	1.67	2.16	0.40	0.02	4.77
NNE	0.05	0.36	0.76	0.64	0.05	0.01	1.86
NE	0.07	0.47	0.98	0.51	0.02	0.01	2.05
ENE	0.04	0.34	1.07	0.47	0.03	0.01	1.95
E	0.06	0.62	1.57	0.73	0.02	0.00	3.00
ESE	0.05	0.42	1.72	0.84	0.08	0.01	3.11
SE	0.06	0.50	1.43	0.78	0.08	0.00	2.85
SSE	0.05	0.36	1.23	0.86	0.08	0.00	2.59
S	0.12	0.92	3.68	4.33	0.43	0.02	9.49
SSW	0.04	0.55	1.56	2.04	0.36	0.04	4.59
SW	0.04	0.35	1.01	1.35	0.25	0.03	3.02
WSW	0.04	0.32	0.76	0.69	0.14	0.01	1.97
W	0.06	0.34	1.01	1.16	0.40	0.08	3.05
WNW	0.07	0.49	1.40	2.48	0.71	0.12	5.27
NW	0.04	0.36	1.51	2.93	1.02	0.12	5.98
NNW	0.04	0.28	0.92	1.77	0.50	0.07	3.59
Total	0.90	7.12	22.26	23.73	4.57	0.55	59.13

TABLE C-IX (cont)

Burlington - 1967-1971

Stability E - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.29	0.88	0.83	0.00	0.00	0.00	2.00
NNE	0.13	0.35	0.20	0.00	0.00	0.00	0.68
NE	0.24	0.66	0.19	0.00	0.00	0.00	1.09
ENE	0.15	0.47	0.19	0.00	0.00	0.00	0.81
E	0.28	0.82	0.36	0.00	0.00	0.00	1.46
ESE	0.28	0.92	0.43	0.00	0.00	0.00	1.63
SE	0.22	0.84	0.28	0.00	0.00	0.00	1.34
SSE	0.24	0.86	0.27	0.00	0.00	0.00	1.37
S	0.59	2.02	1.88	0.00	0.00	0.00	4.50
SSW	0.27	0.86	0.98	0.00	0.00	0.00	2.11
SW	0.17	0.60	0.48	0.00	0.00	0.00	1.25
WSW	0.16	0.63	0.37	0.00	0.00	0.00	1.16
W	0.28	0.98	0.50	0.00	0.00	0.00	1.76
WNW	0.38	0.93	0.97	0.00	0.00	0.00	2.27
NW	0.36	1.25	0.88	0.00	0.00	0.00	2.50
NNW	0.22	0.85	0.46	0.00	0.00	0.00	1.53
Total	4.25	13.93	9.26	0.00	0.00	0.00	27.44

TABLE C-X

STABILITY WIND-ROSE DATA FOR HANFORD
1973-1975

Stability B - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.55	1.16	0.34	0.06	0.03	0.00	2.14
NNE	0.79	1.12	0.46	0.16	0.01	0.00	2.54
NE	0.74	0.78	0.18	0.06	0.00	0.00	1.76
ENE	0.33	0.53	0.08	0.00	0.00	0.00	0.94
E	0.28	0.54	0.09	0.00	0.00	0.00	0.91
ESE	0.44	0.60	0.06	0.00	0.00	0.00	1.10
SE	0.39	0.66	0.08	0.00	0.00	0.00	1.13
SSE	0.17	0.34	0.08	0.03	0.00	0.00	0.62
S	0.20	0.35	0.08	0.02	0.00	0.00	0.65
SSW	0.15	0.50	0.27	0.15	0.06	0.02	1.15
SW	0.15	0.52	0.50	0.48	0.32	0.17	2.14
WSW	0.21	0.48	0.76	0.67	0.29	0.08	2.49
W	0.18	0.43	0.30	0.25	0.05	0.01	1.22
WNW	0.15	0.65	0.75	0.64	0.32	0.11	2.62
NW	0.30	1.25	1.33	0.80	0.57	0.21	4.46
NNW	0.39	1.33	0.42	0.07	0.01	0.01	2.23
Total	5.42	11.24	5.78	3.39	1.66	0.61	28.10

Stability D - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.54	0.39	0.14	0.06	0.01	0.00	1.14
NNE	0.55	0.28	0.16	0.04	0.01	0.00	1.04
NE	0.54	0.21	0.05	0.05	0.02	0.00	0.87
ENE	0.41	0.16	0.03	0.01	0.00	0.00	0.61
E	0.42	0.20	0.04	0.00	0.00	0.00	0.66
ESE	0.36	0.34	0.08	0.01	0.00	0.00	0.79
SE	0.48	0.28	0.10	0.01	0.00	0.00	0.87
SSE	0.27	0.17	0.11	0.04	0.00	0.00	0.59
S	0.25	0.20	0.09	0.08	0.05	0.01	0.68
SSW	0.20	0.21	0.27	0.30	0.17	0.11	1.26
SW	0.27	0.25	0.32	0.60	0.35	0.13	1.92
WSW	0.24	0.30	0.53	0.52	0.17	0.06	1.82
W	0.25	0.45	0.65	0.38	0.05	0.01	1.79
WNW	0.33	0.81	1.23	1.33	0.62	0.08	4.40
NW	0.41	0.96	1.02	0.86	0.65	0.11	4.01
NNW	0.50	0.63	0.32	0.09	0.02	0.00	1.56
Total	6.02	5.84	5.14	4.38	2.12	0.51	24.01

TABLE C-X (cont)

Stability MS - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.79	0.36	0.11	0.01	0.01	0.00	1.28
NNE	0.33	0.24	0.07	0.01	0.00	0.00	0.65
NE	0.27	0.26	0.02	0.01	0.02	0.00	0.58
ENE	0.32	0.20	0.03	0.00	0.00	0.00	0.55
E	0.30	0.26	0.06	0.00	0.00	0.00	0.62
ESE	0.36	0.44	0.11	0.00	0.00	0.00	0.91
SE	0.72	0.68	0.21	0.03	0.01	0.00	1.65
SSE	0.45	0.62	0.39	0.04	0.03	0.01	1.54
S	0.54	0.63	0.25	0.11	0.04	0.00	1.57
SSW	0.44	0.56	0.28	0.17	0.11	0.06	1.62
SW	0.59	0.90	0.62	0.43	0.19	0.09	2.82
WSW	0.54	1.70	1.74	0.65	0.09	0.02	4.74
W	0.67	2.48	2.48	0.34	0.02	0.00	5.99
WNW	0.68	2.45	4.06	1.42	0.25	0.02	8.88
NW	0.77	2.29	2.50	0.93	0.14	0.00	6.63
NNW	0.63	0.93	0.46	0.04	0.00	0.00	2.06
Total	8.40	15.00	13.39	4.19	0.91	0.20	42.09

Stability VS - Wind Speed, Knots

DIR	0-3	4-6	7-10	11-16	17-22	22+	Total
N	0.08	0.04	0.00	0.00	0.00	0.00	0.12
NNE	0.07	0.04	0.00	0.00	0.00	0.00	0.11
NE	0.05	0.03	0.00	0.00	0.00	0.00	0.08
ENE	0.06	0.01	0.00	0.00	0.00	0.00	0.07
E	0.06	0.02	0.00	0.00	0.00	0.00	0.08
ESE	0.07	0.02	0.00	0.00	0.00	0.00	0.09
SE	0.11	0.14	0.02	0.00	0.00	0.00	0.27
SSE	0.07	0.15	0.03	0.00	0.00	0.00	0.25
S	0.11	0.10	0.01	0.00	0.00	0.00	0.22
SSW	0.08	0.17	0.02	0.00	0.00	0.00	0.27
SW	0.08	0.18	0.05	0.00	0.00	0.00	0.31
WSW	0.07	0.26	0.39	0.01	0.00	0.00	0.73
W	0.10	0.47	0.21	0.00	0.00	0.00	0.78
WNW	0.09	0.44	0.78	0.01	0.00	0.00	1.32
NW	0.14	0.39	0.43	0.00	0.00	0.00	0.96
NNW	0.10	0.15	0.01	0.00	0.00	0.00	0.26
Total	1.34	2.61	1.95	0.02	0.00	0.00	5.92

TABLE C-XI

GARDEN SAMPLES FROM OFFSITE AND ONSITE AT PANTEX

Garden Number	Vegetables Collected 2 September 1981
1	onions, peaches, apples, cucumbers, squash (acorn, summer, zucchini), radishes, black-eyed peas, string beans, leaf lettuce
2	tomatoes, grapes, onions, lettuce, string beans
3	tomatoes, beets, cucumbers, okra, string beans
4	string beans, tomatoes, cucumbers, okra, peppers, broccoli
5	broccoli, cucumbers, tomatoes, onions, lettuce, cantaloupe, beans
6	corn, okra, string beans, black-eyed peas, squash
7	cucumbers, squash, string beans, tomatoes, onions, okra, black-eyed peas, peaches

TABLE C-XII

GARDEN SAMPLES FROM CLAUDE, TEXAS

Garden Number	Vegetables Collected 2 September 1981
8	squash, tomatoes, peaches, string beans, cucumbers, pumpkins, peppers, onions
9	okra, corn, black-eyed peas, string beans
10	peppers, tomatoes, cucumbers, broccoli, squash
11	okra, peppers, tomatoes, black-eyed peas
12	onions, squash, cucumbers, okra, tomatoes, black-eyed peas
13	squash, black-eyed peas
14	tomatoes, pears, peppers, grapes, string beans, cucumbers
15	corn, squash, okra, black-eyed peas, tomatoes
16	corn, okra, peas, string beans

TABLE C-XIII

GARDEN VEGETABLE TRITIUM, TOTAL URANIUM, AND PLUTONIUM CONCENTRATIONS

Garden Number	Wet Wt.(g)	Dry Wt.(g)	^{3}H (pCi/ℓ)	Wet Wt.(g)	Dry Wt.(g)	Ash Wt.(g)	U Dry Wt. (fCi/g)	^{238}Pu Dry Wt. (fCi/g)	$^{239-240}Pu$ Dry Wt. (fCi/g)
Pantex Perimeter									
1	383	68.9	-100 ± 400	2108	123.64	8.50	0.0 ± 0.047	-2 ± 0.5	2 ± 2
2	171	34.2	-200 ± 300	238.2	19.86	1.84	0.53 ± 0.062	-5 ± 2	1 ± 2
3	436	204.9	1400 ± 400	801.8	57.27	5.18	1.2 ± 0.061	1 ± 1	-1 ± 0.3
4	341	27.3	1400 ± 400	1063.8	68.50	6.09	0.12 ± 0.060	-2 ± 0.2	-0.5 ± 0.6
5	453	45.3	400 ± 400	1388.8	101.05	8.92	0.15 ± 0.060	0.3 ± 0.6	0.3 ± 0.4
6	277	94.2	400 ± 400	1734	398.50	11.30	0.0 ± 0.019	-0.1 ± 0.6	-0.4 ± 0.04
7a	447	35.8	1200 ± 400	1720	78.24	12.89	0.45 ± 0.11	-4 ± 2	-0.9 ± 2
7b	276	38.6	400 ± 400	1048	58.37	5.23	0.18 ± 0.061	0.7 ± 2	-2 ± 0.7
Claude, Texas									
8	345	131.1	600 ± 400	1893	226.74	16.39	0.098 ± 0.049	0.2 ± 0.3	0.4 ± 0.8
9	216	62.6	100 ± 400	525.9	155.40	4.90	0.053 ± 0.021	-0.07 ± 0.07	-0.1 ± 0.2
10	395	31.6	700 ± 400	1235.	75.07	7.93	0.0 ± 0.072	-2 ± 0.2	-2 ± 0.5
11	227	45.4	500 ± 400	912.4	96.01	6.88	0.0 ± 0.049	0.4 ± 0.5	-1 ± 0.1
12	289	66.5	900 ± 400	2319	135.11	13.24	0.10 ± 0.066	-0.3 ± 0.5	0.9 ± 0.9
13	186	29.8	-200 ± 300	448.0	28.90	2.75	0.097 ± 0.064	2 ± 2	-9 ± 2
14	266	93.1	0.0 ± 400	1295	147.57	16.81	0.15 ± 0.077	-0.9 ± 0.4	-2 ± 0.7
15	400	40.0	400 ± 400	1406	134.37	8.14	0.0 ± 0.041	0.2 ± 0.2	0.2 ± 0.3
16	145	27.6	300 ± 400	689.1	95.03	5.30	0.076 ± 0.038	-0.2 ± 0.2	0.2 ± 0.3

TABLE C-XIV

RESULTS OF SURFACE SOIL SAMPLES TAKEN AT PANTEX (x ± s)

Location (see Fig. 6)	Total Uranium (ppm)	$^{235}U/^{238}U$ x 100	^{238}Pu (pCi/g	$^{239-240}Pu$ (pCi/g)
Offsite				
1	2.8 ± 0.3	0.71 ± 0.04	-0.002 ± 0.001	0.005 ± 0.002
2	3.1 ± 0.3	NA	0.002 ± 0.002	0.006 ± 0.003
3	2.8 ± 0.3	0.66 ± 0.03	0.006 ± 0.002	0.007 ± 0.002
4	2.8 ± 0.3	0.73 ± 0.04	0.001 ± 0.002	0.002 ± 0.003
5	3.0 ± 0.3	0.73 ± 0.04	-0.0008 ± 0.0003	0.027 ± 0.005
6	2.4 ± 0.2	0.70 ± 0.03	-0.002 ± 0.001	0.010 ± 0.003
7	2.2 ± 0.2	0.79 ± 0.04	0.002 ± 0.002	0.040 ± 0.006
8	2.8 ± 0.3	0.68 ± 0.03	0.002 ± 0.002	0.024 ± 0.005
Maximum	3.1 ± 0.3	0.66 ± 0.03	0.006 ± 0.002	0.040 ± 0.006
Minimum	2.2 ± 0.2	0.79 ± 0.04	-0.002 ± 0.002	0.002 ± 0.003
Average ($\bar{x}$ ± s)	2.74 ± 0.30	0.71 ± 0.04	0.0010 ± 0.0027	0.015 ± 0.014
Perimeter				
9	2.9 ± 0.3	0.75 ± 0.04	0.001 ± 0.001	0.002 ± 0.002
10	3.3 ± 0.3	0.68 ± 0.03	0.001 ± 0.001	0.012 ± 0.003
11	2.9 ± 0.3	0.68 ± 0.03	0.001 ± 0.002	0.021 ± 0.005
12	3.5 ± 0.4	0.74 ± 0.04	0.010 ± 0.005	0.028 ± 0.009
13	3.0 ± 0.3	0.75 ± 0.04	0.003 ± 0.002	0.004 ± 0.003
Maximum	3.5 ± 0.4	0.68 ± 0.03	0.010 ± 0.005	0.028 ± 0.009
Minimum	2.9 ± 0.3	0.75 ± 0.04	0.001 ± 0.001	0.002 ± 0.002
Average ($\bar{x}$ ± s)	3.12 ± 0.27	0.72 ± 0.04	0.0032 ± 0.0039	0.013 ± 0.011
Regional Samples* (n=8)				
Maximum	3.4 ± 0.3	0.68 ± 0.03	0.005 ± 0.001	0.026 ± 0.005
Minimum	1.2 ± 0.3	0.80 ± 0.04	0.001 ± 0.001	0.000 ± 0.000
Average ($\bar{x}$ ± s)	2.3 ± 0.7	0.73 ± 0.05	0.002 ± 0.001	0.008 ± 0.009

*W. D. Purtymun, N. M. Becker, and M. Maes, "Supplementary Documentation for an Environmental Impact Statement Regarding the Pantex Plant: Geohydrologic Investigations," Los Alamos National Laboratory report LA-9445-PNTX-H (1982).

TABLE C-XV

SOIL SAMPLE RESULTS FOR SOIL SAMPLES TAKEN
AT THE FIRING SITE (FS-5) AND BURN PAD 18 AT PANTEX

Location (See Fig. 6)	Total Uranium (ppm)	$^{235}U/^{238}U$ x 100	^{238}Pu (pCi/g)	$^{239-240}Pu$ (pCi/g)	Comments
Firing Site FS-5					
14	120 ± 10	0.168 ± 0.008	0.002 ± 0.001	0.018 ± 0.003	0-10 cm composite of surface samples at FS-5
15	1500 ± 150	0.19 ± 0.01	0.002 ± 0.001	0.002 ± 0.001	
16	140 ± 10	0.13 ± 0.01	0.0040 ± 0.0005	0.016 ± 0.003	0-10 cm *
17	27 ± 3	0.23 ± 0.01	0.003 ± 0.002	0.029 ± 0.004	10-20 cm*
18	30 ± 3	0.22 ± 0.01	0.002 ± 0.001	0.037 ± 0.004	20-30 cm*
Burn Pad					
19	170 ± 20	0.26 ± 0.01	0.0016 ± 0.0009	0.023 ± 0.003	0-1 cm
20	350 ± 40	0.26 ± 0.01	0.001 ± 0.001	0.020 ± 0.003	0-10 cm*
21	23 ± 2	0.34 ± 0.02	0.0012 ± 0.0008	0.005 ± 0.002	10-20 cm*
22	35 ± 4	0.26 ± 0.01	0.0098 ± 0.0000	0.008 ± 0.002	20-30 cm*

*Profile sample.

TABLE C-XVI

PROFILE SAMPLES TAKEN ON PANTEX PERIMETER

Location (see Fig. 6)	^{238}Pu (pCi/g) 0-10 cm	10-20 cm	20-30 cm	30-40 cm
8	0.0009 ± 0.0009	0.001 ± 0.002	0.0007 ± 0.0009	0.002 ± 0.001
9	0.001 ± 0.001	0.002 ± 0.002	0.003 ± 0.002	0.002 ± 0.001
10	0.002 ± 0.002	0.001 ± 0.001	0.0004 ± 0.0007	0.001 ± 0.001
11	0.0012 ± 0.0008	-0.017 ± 0.001	0.0005 ± 0.0009	0.0004 ± 0.0009
13	0.0014 ± 0.0013	0.003 ± 0.001	0.003 ± 0.001	0.001 ± 0.001

Location (see Fig. 6)	$^{239-240}Pu$ (pCi/g) 0-10 cm	10-20 cm	20-30 cm	30-40 cm
8	0.010 ± 0.002	0.001 ± 0.002	0.001 ± 0.002	0.002 ± 0.001
9	0.008 ± 0.002	0.006 ± 0.002	0.004 ± 0.002	0.0005 ± 0.0008
10	0.016 ± 0.003	0.013 ± 0.003	0.002 ± 0.001	0.004 ± 0.002
11	0.030 ± 0.003	0.010 ± 0.003	0.006 ± 0.002	0.005 ± 0.002
13	0.011 ± 0.002	0.006 ± 0.002	0.012 ± 0.003	0.002 ± 0.001

TABLE C-XVII

RESULTS OF SOIL SAMPLING AT THE IAAP (x ± s)

Location (see Fig. 7)	Uranium (ppm)	$^{235}U/^{238}U$ x 100 Surface Samples	^{238}Pu (pCi/g)	$^{239-240}Pu$ (pCi/g)	Comments
Perimeter					
1	3.5 ± 0.4	0.68 ± 0.03			west of IAAP
2	3.0 ± 0.4	0.74 ± 0.04	-0.001 ± 0.001	0.019 ± 0.003	south of IAAP
3	3.5 ± 0.4	0.72 ± 0.04	-0.0004 ± 0.0007	0.004 ± 0.001	NNE of IAAP
4	3.4 ± 0.4	0.75 ± 0.04	-0.003 ± 0.002	0.030 ± 0.004	E of IAAP
Maximum	3.5 ± 0.4	0.75 ± 0.04	-0.001 ± 0.001	0.030 ± 0.004	
Minimum	3.0 ± 0.4	0.68 ± 0.03	-0.0004 ± 0.0007	0.004 ± 0.001	
Average ($\bar{x}$ ± s)	3.35 ± 0.24	0.72 ± 0.03	-0.0015 ± 0.0014	0.018 ± 0.013	
Onsite					
5	4.4 ± 0.4	0.68 ± 0.03	-0.0024 ± 0.0012	0.031 ± 0.004	
Regional					
6	3.4 ± 0.4	0.76 ± 0.04	-0.001 ± 0.001	0.012 ± 0.004	
7	4.0 ± 0.4	0.68 ± 0.03	-0.004 ± 0.001	0.016 ± 0.004	
8	2.6 ± 0.4	0.81 ± 0.04	0.0008 ± 0.0007	0.002 ± 0.001	
Maximum	4.0 ± 0.4	0.81 ± 0.04	0.0008 ± 0.0007	0.016 ± 0.004	
Minimum	2.6 ± 0.4	0.68 ± 0.03	-0.004 ± 0.001	0.002 ± 0.001	
Average ($\bar{x}$ ± s)	0.33 ± 0.70	0.75 ± 0.07	-0.0016 ± 0.0021	0.010 ± 0.007	
Samples Taken at the Firing Site					
9	200 ± 20	0.16 ± 0.03			
10	23 ± 2	0.20 ± 0.04			
11	1930 ± 200	0.19 ± 0.04			
12	180 ± 20	0.20 ± 0.04			
13	94 ± 10	0.20 ± 0.04			
14	820 ± 90	0.17 ± 0.03			
15	830 ± 90	0.21 ± 0.04	-0.0003 ± 0.0002	0.003 ± 0.001	
16	260 ± 30	0.17 ± 0.03			
17	240 ± 30	0.21 ± 0.04			
18	420 ± 40	0.17 ± 0.03			
Samples Taken Along Line 1					
19	3.0 ± 0.3				
20	4.0 ± 0.4				
21	13.0 ± 1.3	0.47 ± 0.02			Isolated Area
22	3.0 ± 0.3				Taken 10 m away from sample 21

TABLE C-XVIII

RESULTS OF SEDIMENT SAMPLES COLLECTED AT IAAP ($\bar{x} \pm s$)

Sampling Location (See Fig. 13)	Total Uranium (ppm)	$^{235}U/^{238}U \times 100$	^{238}Pu (pCi/g)	$^{239-240}Pu$ (pCi/g)
Onsite				
1	2.3 ± 0.4	0.71 ± 0.03	0.001 ± 0.001	0.004 ± 0.002
2	2.4 ± 0.4	0.57 ± 0.03	0.000 ± 0.001	0.001 ± 0.001
3	1.3 ± 0.4	0.72 ± 0.04	0.001 ± 0.000	0.001 ± 0.001
4	1.4 ± 0.4	0.76 ± 0.03	0.002 ± 0.001	0.001 ± 0.001
Maximum	2.4 ± 0.4	0.76 ± 0.03	0.002 ± 0.001	0.004 ± 0.002
Minimum	1.3 ± 0.4	0.57 ± 0.03	0.000 ± 0.001	0.001 ± 0.001
Average ($\bar{x} \pm s$)	1.85 ± 0.58	0.69 ± 0.08	0.001 ± 0.001	0.0018 ± 0.0015
Offsite				
Downstream				
5	2.9 ± 0.4	0.74 ± 0.04	0.002 ± 0.001	0.002 ± 0.002
6	1.2 ± 0.4	0.76 ± 0.04	0.001 ± 0.001	0.002 ± 0.001
7	2.8 ± 0.4	0.76 ± 0.04	0.001 ± 0.001	0.013 ± 0.003
8	2.7 ± 0.4	0.72 ± 0.04	0.001 ± 0.001	0.005 ± 0.004
Maximum	2.9 ± 0.4	0.76 ± 0.04	0.002 ± 0.001	0.013 ± 0.003
Minimum	1.2 ± 0.4	0.72 ± 0.04	0.001 ± 0.001	0.002 ± 0.001
Average ($\bar{x} \pm s$)	2.40 ± 0.80	0.74 ± 0.02	0.0013 ± 0.0005	0.0055 ± 0.0052
Upstream				
9	3.3 ± 0.4	0.68 ± 0.03	0.002 ± 0.003	0.014 ± 0.006

TABLE C-XIX

RESULTS OF WATER SAMPLES COLLECTED AT IAAP ($x \pm s$)

Sampling Location (see Fig. 13)	Total Uranium (ppb)	^{238}Pu (10^{-9} µCi/mℓ)	$^{239-240}Pu$ (10^{-9} µCi/mℓ)	^{3}H (10^{-3} pCi/mℓ)
I. SURFACE WATER				
Onsite				
1	0.9 ± 0.4	0.009 ± 0.008	0.018 ± 0.012	-1.5 ± 0.3
2	0.0 ± 0.4	0.019 ± 0.013	0.006 ± 0.013	-2.0 ± 0.3
3	0.9 ± 0.4	0.034 ± 0.005	0.005 ± 0.010	-1.6 ± 0.3
4	0.9 ± 0.4	0.011 ± 0.013	0.023 ± 0.008	-1.4 ± 0.3
Maximum	0.9 ± 0.4	0.034 ± 0.005	0.023 ± 0.008	-1.4 ± 0.3
Minimum	0.0 ± 0.4	0.009 ± 0.008	0.005 ± 0.010	-2.0 ± 0.3
Average ($\bar{x} \pm s$)	0.67 ± 0.45	0.018 ± 0.011	0.013 ± 0.009	-1.63 ± 0.26
Offsite				
Downstream				
5	0.7 ± 0.4	0.006 ± 0.008	0.006 ± 0.010	-1.5 ± 0.3
6	1.4 ± 0.4	0.019 ± 0.013	0.050 ± 0.020	-1.6 ± 0.3
7	1.8 ± 0.4	0.010 ± 0.009	0.015 ± 0.011	-1.6 ± 0.3
8	1.2 ± 0.4	0.020 ± 0.012	0.010 ± 0.009	-1.1 ± 0.3
Maximum	1.8 ± 0.4	0.020 ± 0.012	0.050 ± 0.020	-1.1 ± 0.3
Minimum	0.7 ± 0.4	0.006 ± 0.008	0.006 ± 0.010	-1.6 ± 0.3
Average ($\bar{x} \pm s$)	1.28 ± 0.46	0.014 ± 0.007	0.020 ± 0.020	-1.4 ± 0.2
Upstream				
9	2.1 ± 0.4	0.011 ± 0.013	0.017 ± 0.014	-1.3 ± 0.3
II. GROUND WATER				
10	0.0 ± 0.4	0.006 ± 0.011	0.013 ± 0.006	-2.1 ± 0.3
11	0.0 ± 0.4	0.017 ± 0.006	0.006 ∓ 0.010	-1.0 ± 0.4
12	0.0 ± 0.4	0.016 ± 0.011	0.004 ± 0.004	-1.5 ± 0.3
13	1.0 ± 0.4	0.004 ± 0.008	0.009 ± 0.004	-1.5 ± 0.3
14	0.0 ± 0.4	0.007 ± 0.001	0.036 ± 0.001	-1.5 ± 0.3
15	1.1 ± 0.4	0.007 ± 0.007	0.007 ± 0.013	-1.5 ± 0.3
16	0.0 ± 0.4	0.004 ± 0.009	0.060 ± 0.020	-2.0 ± 0.3
17	0.0 ± 0.4	0.005 ± 0.007	0.005 ± 0.007	-2.5 ± 0.3
18	0.8 ± 0.4	0.040 ± 0.030	0.070 ± 0.050	-1.1 ± 0.4
Maximum	1.1 ± 0.4	0.040 ± 0.030	0.070 ± 0.050	-1.0 ± 0.4
Minimum	0.0 ± 0.4	0.004 ± 0.009	0.004 ± 0.004	-2.5 ± 0.3
Average	0.32 ± 0.49	0.012 ± 0.012	0.023 ± 0.026	-1.63 ± 0.48

APPENDIX D

CALCULATION OF RADIATION DOSES

I. RADIATION DOSES ESTIMATED WITH DOSE MODELS

A. Introduction

Doses were calculated using the computer program AIRDOS-EPA, modified to include evaluation of doses resulting from resuspension and instantaneous releases. This appendix briefly describes the computer code, modifications that were made, and input parameters.

The topics discussed are (1) the AIRDOS-EPA Computer Code, (2) Modifications Made to AIRDOS-EPA, (3) Radionuclide Release Rates, (4) Meteorological Parameters, (5) Description of the Assessment Areas, (6) Dose Conversion Factors.

Many radionuclides considered in this study have long residence times in certain organs, especially bone, so that they continue to irradiate these organs long after the intake occurs. This long-term irradiation was taken into account by use of the 50-year dose commitment for all doses reported here. The 50-year dose commitment is the accumulated dose that an organ receives from an intake of radioactive material in the 50 years following that intake.

Doses to 11 organs were calculated: total body, red marrow, lung, endosteal bone, stomach wall, large intestine, bone, liver, kidney, testes, and ovaries. The organ doses reported in Section II are lung and bone (the two organs receiving the highest dose), whole body, and gonadal doses (used to estimate genetic effects). All other organ doses were less than the lung or bone doses and are not reported.

B. The AIRDOS-EPA Computer Code

Moore et al. have extensively documented the AIRDOS-EPA program (Moore 1979). The reader is referred to that report for a detailed description of the computation procedures used in the program.

The AIRDOS-EPA code uses a Gaussian plume dispersion model and the food pathway model from USNRC Regulatory Guide 1.109 (USNRC 1977) to calculate doses in offsite areas for airborne releases of radionuclides. The code calculates both maximum individual dose and population dose.

The three assessment areas in this study (Pantex, IAAP, and Hanford) were divided into 10 annular areas at the following radii: 1, 2, 4, 8, 16, 25, 32, 50, 64, and 80 km. Each area was then divided into 16 directional

segments (north, north-northeast, northeast, etc.) so that there were 160 annular segments for each assessment area.

Air and ground concentrations of radionuclides released by Pantex operations were calculated for each annular segment from radionuclide release rates (see Appendix D, Section I-C) and meteorological data (see Appendix D, Section I-D). A Gaussian plume dispersion model supplied by AIRDOS-EPA was used to calculate the airborne radionuclide concentrations for all releases except those resulting from the dynamic test shots in 1980 and the dynamic test shots expected to take place in 1983-1990. For those test shots a Gaussian instantaneous release dispersion model was used (see Section III-C). Ground deposition rates were obtained by multiplying the airborne radionuclide concentration by the deposition velocity, here taken to be 0.0018 m/s (Moore 1979).

As described in Appendix D, Section I-C, a resuspension term was added to the code. The ground deposition was used to calculate a second air concentration in each of the 160 annular segments that resulted from previously deposited material becoming resuspended due to wind shear forces. This second air concentration was added to the airborne radionuclide concentration calculated by the dispersion model to give the total airborne radionuclide concentration for each segment.

Inhalation doses were calculated by multiplying the total airborne radionuclide concentration by the breathing rate and exposure time to give the total activity inhaled and then by the organ dose conversion factors to give the 50-year dose commitments to the different organs.

Ingestion doses were calculated by following radionuclide movement through the food chain. Radionuclides could be deposited on plant surfaces either from the aerosol directly released by the facility or from resuspended material that had been previously released. Radionuclides could also enter the plant through the root zone. Both processes were considered in these dose estimates.

The plants could be either produce used for human consumption or pasture and stored feed for animal consumption. In the first case, a radionuclide intake by man was calculated using the radionuclide content in and on the produce estimated by AIRDOS-EPA and the annual consumption rate of produce by humans. In the second case, animal intakes were estimated from plant radionuclide content and animal feed consumption rates. Knowing the animal radionuclide intake allowed calculation of radionuclide concentrations in meat and milk. From the concentrations in meat and milk and the annual consumption by humans of meat and milk products, the annual radionuclide intake was found.

The total annual intake of radionuclides from consumption of produce, meat, and milk by humans was found by summing the separate intakes calculated above. Multiplication of the total ingestion intake by ingestion dose conversion factors gave the 50-year dose commitments for the various organs being considered. Summing these doses with the inhalation doses calculated previously gave the total dose to each organ.

Doses in 1981 from test shots and tritium releases occurring before 1981 were obtained using this same pathway calculation but with the air concentration due to current releases set equal to zero. Calculated doses were then due to inhalation of resuspended material and ingestion of food-stuffs affected by material previously deposited offsite by past releases. Doses for the termination option were also calculated using this procedure.

The AIRDOS-EPA code was also used to calculate external radiation doses due to cloud submersion and exposure to radionuclides deposited on the ground surfaces. These doses were found to be negligible for the radionuclides considered here compared to doses from inhalation and ingestion.

The maximum exposed individual is the hypothetical person who receives an organ dose that is the highest fraction of the RPS of all the organ doses calculated for all individuals in the 80-km assessment area.

The population dose is obtained by estimating the dose for individuals living in each of the 160 annular segments in the assessment area. Each dose was multiplied by the population in its segment, and all resulting doses are summed for each organ.

Table D-I lists selected input parameters used in estimating these doses. Other parameters, such as dose conversion factors and population distributions, are presented in the following sections.

C. Modifications Made to AIRDOS-EPA

The AIRDOS-EPA code was modified to include increases in airborne radionuclide concentrations due to resuspension of previously deposited material. The total air concentration of radionuclide j at time t, $\chi_j^T(t)$, is given by

$$\chi_j^T(t) = \chi_j^D(t) + \chi_j^R(t) \ ,$$

where

$x_j^D(t)$ is the air concentration of radionuclide j at time t due to emissions coming directly from the source (pCi/m^3) and

$x_j^R(t)$ is the air concentration of radionuclide j at time t due to resuspended material (pCi/m^3).

The term $x_j^R(t)$ was calculated from

$$x_j^R(t) = R(t)D_j ,$$

where

D_j = surface ground concentration of radionuclide j (pCi/m^2) and

$R(t)$ = resuspension coefficient (m^{-1}).

The value of the resuspension coefficient was taken to be

$$R(t) = 10^{-5} e^{-\left(\frac{\ell n 2}{50}\right) t} \; m^{-1} \qquad (t \text{ in days}) \qquad t \leq 1.82 \text{ yr} = 664 \text{ days}$$

$$= 10^{-9} \; m^{-1} \qquad t > 1.82 \text{ yr} = 664 \text{ days.}$$

This assigns a value to R of 10^{-5} m^{-1} to freshly deposited material. The value R decreases exponentially with a 50-day half-life to a minimum value of 10^{-9} m^{-1}. This equation for the resuspension coefficient was derived in (USNRC 1974) after review of experimental measurements of resuspension of freshly deposited and aged material, mostly ^{239}Pu.

Doses for the individual test shots in 1980, which were instantaneous releases, were not calculated using AIRDOS-EPA directly, which was written for continuous releases. Instead, AIRDOS-EPA was modified for treatment of instantaneous releases according to the procedures of Healy (Slade 1968) and USNRC Regulatory Guide 1.109 (USNRC 1977).

The time integral ψ_j of the air concentration was used to calculate the inhalation 50-year dose commitment H_{ij} to organ i from radionuclide j according to

$$H_{ij} = \psi_j^T (BR) \quad DCF_{ij},$$

where

$\psi_j^T = \int_o^\infty \chi_j^T(t)\, dt$, $\chi_j^T(t)$ is the total air concentration of radionuclide j at time t ($pCi \cdot s/m^3$),

BR = breathing rate, 0.020 m^3/min = 0.00033 m^3/s, typical of an adult doing light work (ICRP 1974), and

DCF_{ij} = dose conversion factor giving the 50-year dose commitment to organ i per unit inhaled activity of radionuclide j $\left(\frac{mrem}{pCi}\right)$.

The concentration of radionuclide j in vegetation due to foliar deposition, $C^v_{j,FD}$, is given by

$$C^v_{j,FD}(t) = \frac{Rv_d \psi_j^D}{Y_v}\left\{e^{-\left(\lambda_w+\lambda_D\right)\left(t-t_o\right)} + 10^{-5} v_d \left[\frac{e^{-\left(\lambda_w+\lambda_D\right)\left(t-t_o\right)} - e^{-\left(\lambda_R+\lambda_L+\lambda_D\right)\left(t-t_o\right)}}{\lambda_R + \lambda_L - \lambda_w}\right]\right\}$$

and for $0 < t - t_o \leq 1.82$ yr

$$C^v_{j,FD}(t) = \frac{Rv_d \psi_j^D}{Y_v}\left\{e^{-\left(\lambda_w+\lambda_D\right)\left(t-t_o\right)} + 10^{-9} v_d \left[\frac{e^{-\left(\lambda_w+\lambda_D\right)\left(t-t_o\right)} - e^{-\left(\lambda_L+\lambda_D\right)\left(t-t_o\right)}}{\lambda_L - \lambda_w}\right]\right\},$$

for $t - t_o > 1.82$ yr

where

R = interception fraction,

v_d = deposition velocity (m/s),

$$\psi_j^D = \int_{t_o}^{\infty} x_j^D(t)\, dt \quad (pCi \cdot s/m^3),$$

Y_v = aerial yield of the vegetation (kg/m^2), and

$\lambda_w = \ell n2/T^W_{1/2}$, where $T^W_{1/2}$ = 14 days = 1.21 x 10^6 s, the removal half-time for loss of radioactivity on leaf surfaces due to weathering.

$\lambda_D = \ell n2/T^D_{1/2}$, where $T^D_{1/2}$ = radioactive half-life (s).

$\lambda_R = \ell n2/T^R_{1/2}$, where $T^R_{1/2}$ = 50 days = 4.32 x 10^6 s the half-time for decrease of the resuspension coefficient.

$\lambda_L = \ell n2/T^L_{1/2}$, where $T^L_{1/2}$ = 50 yr = 1.58x10^9 s, the half time for the removal of radionuclides from soil due to leaching.

t = time at which the radionuclide concentration in vegetation is estimated (s).

t_o = time at which the deposition occurred (s).

The concentration in vegetation of radionuclide j due to root uptake, $C^v_{j,RU}$, is

$$C^{v}_{j,RU} = \frac{B_{jv}}{P} \; v_d \; \psi^{D}_{j} \; e^{-\left(\lambda_L + \lambda_D\right)\left(t - t_o\right)} ,$$

where

B_{jv} = $\frac{\text{activity per unit mass of the plant}}{\text{activity per unit dry weight of the soil}}$ and

P = effective surface density of the soil

= 240 $\frac{kg}{m^2}$ (assuming a 15-cm plow layer).

The total concentration in vegetation of radionuclide j, C^{v}_{j}, is given by

$$C^{v}_{j}(t) = C^{v}_{j,FD}(t) + C^{v}_{j,RU}(t).$$

Following the procedure used in AIRDOS-EPA, B_{jv} and Y_v values for produce were based on the wet weight of plants, and the values for pasture and animal feed were based on dry weight of the plants. We adjusted by giving plant consumption rates by humans in wet weight per year and by animals in dry weight per year.

After determining radionuclide concentrations in vegetation, ingestion doses to humans were calculated in the same manner as in AIRDOS-EPA (Moore 1979). Radionuclide intake through ingestion of plants was calculated for both humans and animals. Concentrations of these radionuclides in animal meat and milk were determined, and radionuclide intake by humans through ingestion of these animal products was calculated. Finally, given the intake by humans of each radionuclide in produce, meat, and milk, ingestion 50-year dose commitments were calculated.

Radionuclide intake through ingestion depended on how long after the test shot a particular plant was harvested. It was conservatively assumed that the September 1980 test shot and the 1983-1990 test shots occurred during the harvest of both produce and feed, so that no reduction of radionuclide content occurred from removal by wind or rain.

Estimates of population doses from test shots occurring during 1983-1990 depend on the prevailing wind direction at the time of the shot. To conservatively estimate the maximum population dose, the population doses were calculated for all 16 wind directions considered here. The largest population dose was reported in the text (see Section II-B).

D. Radionuclide Release Rates

1. Introduction. In this section the procedures used to calculate radionuclide release rates are described. These release rates are summarized in Table D-II.

2. Test Shots Containing Depleted Uranium. Releases of depleted uranium were estimated as 5% of the total amount of depleted uranium in each test shot. The depleted uranium was assumed to be 99.7% ^{238}U, 0.3% ^{235}U, and 0.002% ^{234}U by mass.

The 5% release fraction was based on studies made by Pantex personnel (USERDA 1976) and by Dahl and Johnson (Dahl 1977). Measurements made by Pantex indicated that approximately 95% ± 5% (at the 95% confidence level) of the depleted uranium in a test shot could be accounted for at the firing site.

Dahl and Johnson measured depleted uranium concentrations in test shot clouds using aircraft equipped with samplers that were flown through the cloud. Assuming that the uranium concentration was uniform throughout the cloud, they estimated that the depleted uranium in the cloud was approximately 10% of that in the device that was tested. However, if it is assumed that the uranium is distributed normally (according to a Gaussian distribution) rather than uniformly in the cloud, this estimate is lowered to under 5%. The 5% value was used in this report because it is favored by the Gaussian dispersion model, which is generally accepted to represent dispersive atmospheric processes (Slade 1978). As the test cloud contained depleted uranium from both the tested device and from the test site soil resuspended by the explosion, the 5% value is an estimate of both the amount of uranium released directly by the explosion as well as that mechanically resuspended. The estimate is in agreement with the estimate made at Pantex (which included only the percentage released from the device) when statistical uncertainties and the small amount of mechanically resuspended soil are taken into account. However, determination of these source terms is a difficult procedure, and measurement errors could be factors of 2 or 3. (See Section I.D.4 of this Appendix for a discussion of mechanical resuspension.)

From 1983 to 1990, it was assumed that one shot occurred each year involving not more than 10 kg of depleted uranium (Laseter 1982A). The source term is 167 μCi of ^{238}U, 61.9 μCi of ^{234}U, and 3.2 μCi of ^{235}U for each year.

Doses in 1981 due to inhalation or ingestion of material contaminated by test shots occurring from 1963-1979 were estimated using an annual average source term. An average of 971 kg/yr of depleted uranium was involved in test shots during this time period. From a release rate of 5% and the above mass fractions of ^{238}U, ^{234}U, and ^{235}U, release rates are calculated to be 16.1, 6.0, and 0.31 mCi/yr of ^{238}U, ^{234}U, and ^{235}U, respectively.

Five test shots occurred during 1980: one in January, two in April, one in September, and one in November. These dynamic tests were modeled individually, using the meteorological conditions prevailing when each shot occurred. The total amount of depleted uranium released from these five tests was 604 g or 201 μCi of ^{238}U, 75 μCi of ^{234}U, and 3.9 μCi of ^{235}U.

Doses in 1981 in the IAAP assessment area due to dynamic tests performed at IAAP during 1965-1974 were calculated using annual average source terms of 24.5 mCi of ^{238}U, 9.1 mCi of ^{234}U, and 0.5 mCi of ^{235}U for 1965-1974 and zero mCi for 1974-1981. These source terms were determined using the same procedure as was used for the Pantex releases.

3. Burning of Materials Attached to Depleted Uranium. A study was performed by Pantex personnel to determine the depleted uranium release rate from burning high explosives off materials attached to depleted uranium. A burning operation was conducted inside a 1- by 3.7-m culvert oriented with its axis along the wind direction (Laseter 1982B). Two air samplers, one along the culvert axis and one at ground level, were placed 3.0 m downwind from the culvert. Wind speed and direction were monitored continuously throughout the test. After the burning, the air filters were analyzed for uranium, and a source term was calculated using the measured air concentrations, burn time, and wind speed. To give the total source term for 1981, this term was multiplied by 18, the number of burns taking place in 1981. This total release rate was estimated to be 0.10 μCi of ^{238}U, 0.04 μCi of ^{234}U, and 0.002 μCi of ^{235}U.

A special configuration involving suspending the material to be burned about 1 m off the ground was used for all burning operations. It was observed that the heat generated during the burn melted the glue binding the high explosive to the depleted uranium. As a result, the depleted uranium would slide out of the burning material and fall to the ground relatively unaffected by the fire. In many cases, lettering was still plainly visible on the depleted uranium indicating that little material was lost during burning.

4. Resuspension of Depleted Uranium from Soil. The procedure proposed by Travis (1975) as modified by the USNRC (1980) was used to calculate the wind resuspension source term at both Pantex and IAAP. This method involves

calculating a threshold shear velocity, below which no particle saltation and therefore no resuspension occurs. From the wind shear velocity, which involves calculating ground level wind velocities from measured wind speeds and the threshold velocity, the horizontal mass flux is calculated. The vertical mass flux, which gives the source term, is related to the horizontal mass flux and terms involving particle size. The reader is referred to Appendix G of USNRC (1980) for a detailed explanation of the calculational procedure.

The contaminated areas were treated as area sources by AIRDOS-EPA. The radius of each area source was assumed to be 150 m. The highest depleted uranium concentration obtained by soil sampling was used to estimate the source term. These concentrations were 1500, 350, and 1930 ppm for the firing site and burning ground at Pantex and the firing site at IAAP, respectively.

Parameters needed to calculate the mass flux are the surface roughness height, the fraction of soil particles less than 20 μm in diameter, and the soil moisture. Soils at both Pantex and the IAAP were classified as silty clay loam (Wenzel 1982, Purtymun 1982). A 14.4% fraction of the particles was taken to be less than 20 μm (Travis 1975). A 0.01-m surface roughness height was used for both Pantex and the IAAP. Soil moisture was taken to be 9.8% at Pantex (Unger 1981) and 10% at the IAAP. Wind speed frequencies that were used are shown in Table C-IX of Appendix C.

In addition to soil resuspension by wind erosion, testing of high explosives at Pantex results in some resuspension of underlying soil. For soil containing above-background concentrations of depleted uranium from previous tests, this mechanical resuspension could lead to a release of depleted uranium to offsite areas.

Axetell has estimated that the release of fugitive dust from blasting at coal surface mines was approximately 74.3 lb (34 kg) per blast for overburden and 28.7 lb (13 kg) per blast for coal (Axetell 1981). Blasting at these mines usually involves the detonation of a large amount of explosive, at least several TNT-equivalent metric tons, at several locations on a regular grid.

The amount of high explosive in dynamic tests with depleted uranium at Pantex ranges from 2.7 to 16.8 kg (TNT equivalent). The average amount of high explosive used for other dynamic tests at Pantex in 1981 not involving depleted uranium is 0.37 kg. Because these amounts of high explosive are three orders of magnitude less than those used for blasting at coal mines, resuspension should be considerably less. Somewhat compensating for this expected reduction is the fact that the detonation of a large part of the high explosive at a coal surface mine occurs at depths of several feet below

the ground surface, which would reduce the effectiveness of the dust generation. In this report, it was assumed that the detonation of 1 TNT-equivalent kg of high explosive at Pantex would generate 0.5 kg of resuspended dust in the stabilized cloud. The resulting release of dust per detonation is less than that estimated for blasting at coal surface mines (because of the much smaller amount of high explosive) but considerably larger than that obtained from a simple scaling of the amount of fugitive dust to the amount of high explosive used.

Releases were calculated for the dynamic tests that contained depleted uranium, all of which took place at FS5. These releases were estimated to be less than 4% of the release of aerosolized depleted uranium from the test device itself (described in Section I.D.2 of this Appendix). This small percentage was well within the uncertainties in the estimation of the aerosolization fraction and was assumed to be included in that fraction. Soil at FS4, where 171 dynamic tests not involving depleted uranium were performed in 1981, was found to contain low levels of depleted uranium, approximately 25%-35% of those at FS5. Releases of depleted uranium from mechanical resuspension of the soil by explosive testing were calculated at FS4. These releases were 4% of the total release of depleted uranium from Pantex in 1981 and so were considered negligible.

Radionuclide release rates for Pantex and IAAP are presented in Table D-II.

5. Release of Tritium. Measurements of tritium are performed regularly by Pantex personnel. Approximately 95 mCi of tritium was estimated to have been released during 1981 (MHSM 1982). Future tritium releases are expected to be about the same. A tritium release rate of 100 mCi/yr was adopted in this report for future releases.

6. Coal-Fired Power Plant. Coal contains trace amounts of naturally occurring radionuclides usually at concentrations lower than those found in rocks and soil. During combustion of the coal, concentrations of these radionuclides are increased in both bottom ash and fly ash. Airborne release of fly ash could result in radiation exposures to the public.

Release rates from the coal-fired power plant were calculated using data from the report written by the engineering design company (United Engineers 1979) and from an environmental assessment prepared for the coal plant (USDOE 1982) and using the methodology of Beck (1978).

An average of 29 200 tons of coal per year will be burned in the plant with an ash content of 5% and fly ash to bottom ash partition function of 25:75. The plant will use a baghouse with a 99% filter efficiency (USDOE 1982). The source term is

$$(29\ 200\ \text{tons})\left(\frac{909\ \text{kg}}{\text{ton}}\right)\left(\begin{matrix}0.05\ \text{ash}\\ \text{content}\end{matrix}\right)\left(\begin{matrix}0.25\ \text{fly ash}\\ \text{content}\end{matrix}\right)\left(\begin{matrix}0.01\ \text{removal}\\ \text{efficiency}\end{matrix}\right)$$

$$= 3318\ \text{kg of fly ash released per year.}$$

Following Beck (1978) we assume that the coal has trace levels of naturally occurring radionuclides. The concentrations are assumed to be typical values found in coal: 0.6 pCi/g of ^{238}U, 0.5 pCi/g of ^{232}Th, and 1.4 pCi/g of ^{40}K (Beck 1978). All daughter radionuclides in the uranium and thorium decay series are assumed to be in equilibrium with their ^{238}U or ^{232}Th parents. All radioactive material is assumed to be contained in the ash after the coal is burned, which would increase the concentrations of these radionuclides by a factor of (1/0.05 =) 20, or 12, 10, and 28 pCi/g for uranium series radionuclides, thorium series radionuclides, and ^{40}K, respectively.

An additional enrichment mechanism occurs for fly ash released to the atmosphere. Radionuclide concentrations are higher for smaller particle sizes, which are not as efficiently removed by filtration as other particle sizes. Beck et al. have estimated an enrichment of 2 for uranium, 1 for thorium, 1.5 for radium, 5 for lead, 5 for polonium, and 1 for potassium (Beck 1978). These enrichment factors give a net enrichment over the radionuclide levels in coal to the values shown in Table D-III. Multiplying these activities by 3318 kg of fly ash released per year gives the annual release rates presented in Table D-II.

The ^{222}Rn source term was based on the assumption that 100% of the radon present in the coal is released to the atmosphere. This radon is released from the coal at the time of its combustion. No above-background radon release is attributed to either the coal storage pile or the ash pile. The coal has a lower ^{226}Ra content than does typical soil and a similar ^{222}Rn emanation rate per ^{222}Rn formation rate so that the ^{222}Rn release from the coal storage pile is expected to be lower than is the release from soil. In the ash pile, the ^{226}Ra concentration is expected to be several times that of normal soil (18 pCi/g versus 1 pCi/g). However, ash piles are usually wet, which effectively reduces the radon emanation. In addition, work by Beck et al. indicated that the ratio of radon emanated per radon produced for ash is much less than that for typical soil. They conclude that little ^{222}Rn would escape the ash pile even if the pile were allowed to completely dry (Beck 1978). Thus, the ash pile is expected to release less ^{222}Rn than the underlying soil would have released had no ash pile been placed on top of it.

Potassium is under homeostatic control by the body, and the amount of ^{40}K present in the body is biologically regulated (NCRP 1975). Because potassium is not being enriched in ^{40}K as a result of the power plant

operations, no above-background uptake of ^{40}K by the body and, therefore, no excess ^{40}K radiation dose attributable to the coal plant would occur. As a result, ^{40}K emissions have no radiological impact and are not considered further.

Doses resulting from increased radon emissions at coal mining sites due to the removal of coal and subsequent exposure of underlying rock, which has a slightly higher concentration of radon-emitting ^{226}Ra than the coal has, were not considered, as the principal impact would occur outside the assessment areas. For similar reasons, the dose reduction from the Seuss effect was not treated. The Seuss effect is the dilution of atmospheric carbon dioxide containing trace amounts of ^{14}C produced by cosmic rays and man's activities with ^{14}C-free carbon dioxide released during coal combustion. Dose estimates from these two mechanisms are discussed in Cohen (1982) and Beck (1978), respectively.

E. Meteorological Parameters

A Gaussian plume dispersion model was used to estimate offsite air concentrations due to releases from tritium handling, the coal-fired power plant, and resuspension of soil contaminated by depleted uranium from releases at the firing site and burning grounds.

Offsite ground deposition at Pantex, resulting from the 617 test shots in 1963-1979 containing depleted uranium, and deposition at IAAP, resulting from the 704 test shots in 1965-1974, were also calculated using the Gaussion plume model because the many test shots approximated a more continuous release. Because of the exponentially decreasing value with time of the resuspension coefficient from $10^{-5}m^{-1}$ to $10^{-9}m^{-1}$ (see Appendix D, Section I-B), the effect of individual shots on dose in 1981, mainly through resuspension of deposited material for inhalation doses and on plants for ingestion doses, is negligible compared to the total impact from all shots.

Doses from individual test shots were estimated using the puff dispersion procedures (Slade 1968). These procedures were used for future tests occurring at the rate of one per year from 1983 to 1990, as well as for the five tests at Pantex occurring in 1980. For future tests, we assumed that, to obtain an estimate of the maximum dose, all test shot releases would occur in the same direction. Doses from the 1980 test shots were estimated using the actual wind speed, wind direction, and stability class that prevailed when the test shot occurred. Centerline concentrations were used for the maximum individual doses, whereas sector-averaged concentrations were used for the population doses.

Deposition was determined in all cases by multiplying the air concentration by the deposition velocity. A value of 0.0018 m/s was chosen for the deposition velocity (Moore 1979).

Meteorological parameters used in making these estimates are discussed in Section III-C.

F. Description of the Assessment Areas

The computer code AIRDOS-EPA requires data describing the population distribution and food production in the area within 80 km of each facility. These same data were also used in the modified AIRDOS-EPA code that calculated doses from depleted uranium released during the dynamic tests.

Population distributions around each facility for the years 1980 and 1990 were provided by a special study performed by Los Alamos Technical Associates (LATA 1982). These distributions are shown in Tables D-IV, D-V, and D-VI.

The base year used in the environmental impact statement was 1981. Because the populations in the three assessment areas are increasing, using the unadjusted 1980 population distribution to calculate the 1981 population dose would slightly underestimate the population dose. Calculating the population dose using the 1980 population distribution and increasing the dose by 1.4%, 0.35%, and 2.0% for Pantex, IAAP, and Hanford, respectively, corrected the underestimate. [The 2% increase at Hanford was used only for the 1981 population dose from natural background, as other doses were taken from Sula (1982).] These percentages are the changes in population in each area between 1980 and 1990 divided by 10 years. The uncertainties in estimating the 1981 population dose in this manner are well within other uncertainties in estimating the population dose.

Land use, agricultural practices, and agricultural yields were obtained from annual reports published by state agriculture departments in conjunction with the US Department of Agriculture (Texas 1980, Iowa 1981, Illinois 1981, Washington 1981) and from a compilation of 1974 agricultural census data (Shor 1982). Computer analysis results of Landsat photographs were used to determine land use patterns in the Hanford area (Stephan 1979).

In calculating the maximum individual dose, it was assumed that maximally exposed individuals obtained all produce from their gardens. The agricultural yield was taken to be 2.0 kg/m^2 (USNRC 1977). For population doses, we used yields of typical crops grown for human consumption at each site: wheat at Pantex, corn at IAAP, and mixed produce at Hanford.

G. Dose Conversion Factors

The annual intake of each radionuclide through inhalation and ingestion was estimated from the predicted concentrations in air and foodstuffs and from food consumption rates and air inhalation rates. Doses to 11 organs

were then calculated using dose conversion factors that relate dose to intake. As discussed at the beginning of this appendix, for releases modeled here, either bone or lung was the organ receiving the highest dose, depending on the release that was being evaluated. Only bone, lung, whole body, and gonadal dose (for calculation of genetic effects) are reported in the text. All other organ doses are less than the bone or lung dose. As stated earlier, in this assessment the calculated dose is the 50-year dose commitment, that is, the total dose resulting from an intake of radioactive material during the 50 years following that intake.

The lung dose is the 50-year dose commitment to the lung, mass-averaged over nasal-pharynx, tracheobronchial, pulmonary, and pulmonary lymph nodes. The bone dose is the dose averaged over the entire 5 000 g bone.

The dose conversion factors used in this assessment were calculated by the computer code INREM II by Dunning (1981). These dose conversion factors used a quality factor of 20 for alpha radiation. The bone dose conversion factors were calculated using a relative damage factor of 5 for thorium and ^{224}Ra and a relative damage factor of 1 for chains whose parent isotope is one of the long-lived radioisotopes of uranium, radium, lead, and polonium. These values were based on published research showing that thorium and ^{224}Ra are distributed over bone surface and these other radionuclides are distributed over bone volume (ICRP 1979, ICRP 1980).

The dose conversion factors for inhalation were calculated using the ICRP Task Group Lung Model (ICRP 1966) with parameters from ICRP Publication 19 (ICRP 1972).

The factors for inhalation of uranium from dynamic tests were calculated assuming an activity median aerodynamic diameter (AMAD) of 1 μm. AMAD values from particle sizing measurements made by Dahl and Johnson during three dynamic tests at Los Alamos National Laboratory were 0.9 μm, 1 μm, and 0.1 μm (Dahl 1977). An AMAD of 1 μm was chosen here because this value was recommended for use by the ICRP Task Group on Lung Dynamics when the exact particle size is not known (ICRP 1966). In addition, 1 μm was favored by particle size measurements in two of the three dynamic tests studied by Dahl and Johnson. A mixed solubility classification of 57% Y and 43% D was used for the uranium aerosol as a result of the work of Glissmeyer and Mishima with uranium aerosols generated by test firing of ammunition (Glissmeyer 1979).

Dose conversion factors for radionuclides released by the coal-fired power plant were also chosen for an AMAD of 1 μm. Because particle size in fly ash is a strong function of boiler design (not yet determined), the fly ash particle size is not known. A value of 1 μm for the AMAD was used in accordance with the recommendations of the ICRP Task Group on Lung Dynamics.

Recent studies have found evidence of a bimodal particle size distribution in fly ash (McElroy 1982) with a peak in the 0.1-μm range, comprising some 0.2 to 2.2% of the total fly ash produced. For a baghouse filter, which will be used in the Pantex coal-fired power plant, the contributions of particles to released fly ash in this submicrometer range were 2% (McElroy 1982). Because of this relatively small amount of material in the submicrometer range, a bimodal particle size distribution was not used in calculating the dose conversion factors.

Fly ash is considered quite insoluble (Beck 1978), and the radionuclides in fly ash were given the most insoluble classification of those recommended by the ICRP for each radionuclide (ICRP 1979, ICRP 1980). These solubilities are uranium Y, thorium Y, radium W, polonium W, and lead D. All dose conversion factors except those for ^{210}Pb were taken from Dunning (1981). The ^{210}Pb dose conversion factors for solubility class D and for gastrointestinal (GI) tract absorption of 20%, not published by Dunning et al., were obtained using the computer program INREM II (Killough 1978).

The dose conversion factor for tritium conservatively assumes that all the tritium is released as tritium oxide. The inhalation factor includes a 50% increase in dose due to skin absorption.

Radon daughter exposure resulting from radon released by the coal-fired power plant was calculated for radon daughters in 64% equilibrium with indoor radon. This value was the average of the equilibrium ratios for measurements made on the first and second floors of residential buildings by George and Breslin (George 1978).

Dose conversion factors for uranium ingestion conservatively assumed a GI tract uptake fraction for uranium of 20%. This value has been observed for uptake of uranium in trace concentrations in food (Adams 1974, Durbin 1975). We use this relatively high value for absorption from the GI tract because trace amounts of uranium are expected to be ingested as a result of routine releases. In addition, any error in GI tract absorption caused by use of this factor would be conservative because the 20% value, if in error, would most likely be too high, causing the doses to be overestimated.

The GI tract uptake factors used for inhaled uranium that had been cleared from the lung and swallowed were 0.002 for Class Y and 0.5 for Class D material because this material had not yet entered the food matrix. GI tract uptake factors used for both ingestion and inhalation of thorium, radium, polonium, and lead were the ICRP 30 values of 2×10^{-4}, 0.2, 0.1, and 0.2, respectively (ICRP 1979, ICRP 1980).

A list of dose conversion factors for internal exposure, used in this assessment, is presented in Table D-VII.

Dose conversion factors for external penetrating radiation are in Table D-VIII. Factors are given for external whole body radiation from both submersion in a cloud of radioactive material and from exposure to radioactive material deposited on the ground. The dose conversion factors were taken from Kocher (1979). It was assumed that all organ doses were equal to the whole body dose.

II. CALCULATION OF BACKGROUND RADIATION DOSE FROM INTERNAL EXPOSURE

Background radiation doses were calculated for the organs of concern in this report: bone (average skeletal dose), lung, whole body, and gonads. These doses were estimated using a quality factor of 20 for alpha radiation and a distribution factor of 1 for members of decay series that originate with one of the long-lived isotopes of uranium, radium, lead, and polonium. (Appendix D, Section I-G; also see ICRP 1979 and ICRP 1980.)

Lung dose is based on the value of 100 mrem given in NCRP Report 45 (NCRP 1975). Because this dose is almost entirely due to the alpha emitting radon daughter products, calculating the dose with a quality factor of 20 instead of 10 as used in NCRP Report 45 would result in a background lung dose from internally deposited radionuclides of 200 mrem/yr.

Doses to sections of the lung from natural background radiation have been reported by different authors. The NCRP has estimated the dose to the segmental bronchioles from inhaled radioactivity to be 450 mrem/yr or 900 mrem/yr using a quality factor of 20 (NCRP 1975). Harley and Pasternack estimated the absorbed dose to the bronchial epithelium from inhalation of background levels of radon daughters to be 170, 300, 170, and 190 mrad/yr for the infant, 10-year-old child, adult female, and adult male, respectively (Harley 1981). However, because the lung doses for Pantex operations are calculated for the entire 1 000-g lung (with the exception of the doses from radon released by the proposed coal-fired power plant, treated separately below), as recommended by the ICRP (ICRP 1977), the 200 mrem/yr background dose to total lung was the appropriate dose for comparison of impacts of Pantex with natural background.

Background exposure levels due to inhalation of short-lived radon decay products expressed in working level months (WLM) were used in calculating risk of lung cancer from these radionuclides. This procedure was used because the epidemiological studies, on which estimates of lung cancer from radon exposure are based, have related lung cancer rates in uranium and other miners to exposure in WLM. Exposure to background levels of short-lived radon decay products was taken to be 0.2 WLM/yr. This background exposure taken from Evans (1981) is based on the work of George and Breslin (George 1978) and assumes that the results of their work in homes in the New Jersey-New York areas are representative of radon decay product levels in the three assessment areas.

NCRP Report 45 does not give a background average skeletal dose but does estimate doses to parts of the bone such as osteocytes and trabecular surfaces. However, average skeletal dose can be calculated directly from the average radionuclide content of bone in Table 43 and the effective energies given in Table 41 of NCRP Report 45 (NCRP 1975). Sections of these two tables are reproduced in Tables D-IX and D-X. Table D-IX has been modified from Table 41 of NCRP Report 45 to have a quality factor of 20 for alpha radiation and distribution factor of 1 for uranium, radium, lead, and polonium. The bone dose from each radionuclide is then equal to the radionuclide concentration in bone times the effective energy in bone. For ^{210}Pb-^{210}Po, for example, this is

$$\left(\frac{60\ pCi}{kg}\right)\left(\frac{0.037\ dps}{pCi}\right)\left(\frac{106\ MeV}{disintegration}\right)\left(\frac{1.6 \times 10^{-6}\ ergs}{MeV}\right)\left(\frac{1\ kg}{1000g}\right)\left(\frac{3.15 \times 10^{7} s}{yr}\right)\left(\frac{1}{100\ ergs/g/rad}\right)$$

$$= 0.119\ rem/yr = 119\ mrem/yr.$$

The total bone dose is the sum of the doses from ^{238}U - ^{234}U, ^{226}Ra - ^{228}Ra, and ^{210}Pb - ^{210}Po, giving 185 mrem/year.

Whole body internal dose, which is not given in NCRP Report 45, is reported by Klement (1972). In Table II-3 of their report, they list the contribution to whole body dose from each radionuclide. Doses from alpha emitting radionuclides were adjusted for a quality factor of 20 and summed with the doses from the remaining radionuclides to give the background dose from internal radiation.

Background gonadal dose from internally deposited radionuclides is given by NCRP Report 45 to be 27 rem/yr: 19 mrem/yr from ^{40}K, 0.7 mrem/yr from ^{14}C, 0.3 mrem/yr from ^{87}Rb, and 8 mrem/yr from alpha emitters (NCRP 1975). Doubling the alpha dose because the quality factor is 20 rather than 10 as used by the NCRP gives a total background gonadal dose from internal radiation of 36 mrem/yr.

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TABLE D-I

INPUT PARAMETERS FOR DOSE CALCULATIONS

Breathing rate	22.8 m^3/day (all releases except instantaneous release)				(ICRP 1974)
	20 ℓ/min (instantaneous release)				(ICRP 1974)
Ingestion rates	Max Individual	Population			(USNRC 1977, Moore 1979)
Produce (kg/yr)	520	176			
Leafy vegetables (kg/yr)	64	18			
Milk (ℓ/yr)	310	112			
Meat (kg/yr)	110	94			
Half time for physical loss of radioactivity on plants by weathering	14 days				(USNRC 1977)
Half time for physical removal of radioactivity from soil by leaching	50 years				(USNRC 1980)
Average agricultural productivity per unit area	Pantex*	IAAP**	Hanford***		
Feed crops (kg/m^2) (dry weight)	0.388	0.422	0.487		
Produce or leafy vegetables (kg/m^2) (wet weight)	0.143	0.448	1.106		
Produce or leafy vegetables for garden of maximum exposed individual (kg/m^2)(wet weight)	2.0	2.0	2.0		(USNRC 1977)
Consumption rate of feed by animal (dry weight)	11.9 kg/day+				
Effective surface density of soil	240 kg/yr				(USNRC 1977)
Fallout interception fraction					
Feed crops	0.2				(Moore 1979)
Vegetable crops	0.2				
Fraction of radioactivity removed from plant by washing	0.5				(USNRC 1982)
Fraction of foliar deposition reaching edible portions of vegetation					
Above-ground vegetables	1.0				(USNRC 1982)
Below-ground vegetables	0.1				(USNRC 1982)

*(Texas 1980).
**(Iowa 1981).
***(Shor 1982).
+Taken as 2.5% of body weight, where the average live weight of cattle at slaughter of 477 kg (Shor 1982) was conservatively used.

TABLE D-I (Cont)

Transfer Parameters	F_M+ (days/ℓ)	F_F+ (days/kg)	B_{iv1}+	B_{iv2}+
Uranium	1.2×10^{-4}	1.6×10^{-6}	8.5×10^{-3}	2.9×10^{-4}
Thorium	5.0×10^{-6}	1.6×10^{-6}	2.7×10^{-3}	3.5×10^{-4}
Radium	5.9×10^{-4}	3.0×10^{-3}	9.7×10^{-2}	6.2×10^{-2}
Lead	9.9×10^{-5}	9.1×10^{-4}	1.1×10^{-1}	3.9×10^{-3}
Polonium	1.2×10^{-4}	4.0×10^{-3}	4.2×10^{-3}	2.6×10^{-4}

(Moore 1979)

+F_M = Fraction of each day's radionuclide intake appearing in each ℓ of milk.

F_F = Fraction of each day's radionuclide intake appearing in each kg of flesh.

B_{iv1} = Concentration ratio for radionuclide uptake from soil to pasture or feed (pCi/kg dry weight per pCi/kg dry soil).

B_{iv2} = Concentration ratio for radionuclide uptake from soil to edible parts of vegetable crops (pCi/kg wet weight per pCi/kg dry soil).

TABLE D-II

RADIONUCLIDE RELEASE RATES (μCi/Yr)

Release Scenario	^{238}U	^{234}U	^{235}U	^{3}H	^{230}Th	^{226}Ra	^{222}Rn	^{210}Pb	^{210}Po	^{232}Th	^{228}Ra	^{228}Th	^{224}Ra
Pantex													
DU* test shots, 1963-1979	16 100	6000	311										
DU* test shots, 1980	201	75	3.9										
DU* test shots, 1981	0	0	0										
Resuspension from firing site, 1981	109	40.5	2.10										
Resuspension from burning grounds, 1981	25.8	9.59	0.50										
Burning material containing DU, 1981	0.10	0.04	0.002										
Releases from packaging, 1981				95 000									
IAAP													
DU* test shots 1965-1974	24 500	9120	473										
Resuspension from firing site, 1981	2.24	0.834	0.043										
Future emissions at Pantex, IAAP, and Hanford													
DU* test shots	167	61.9	3.21										
Coal-fired power plant	79.6	79.6	3.58		39.8	59.7	15 930	199	199	33.2	49.8	33.2	49.8
Releases from packaging				100 000									

*DU = depleted uranium.

TABLE D-III

ACTIVITIES OF NATURALLY OCCURRING RADIONUCLIDES IN FLY ASH

Radionuclide	Activity Per Gram of Fly Ash (pCi/g)
^{238}U	24
^{234}U	24
^{230}Th	12
^{226}Ra	18
^{210}Pb	60
^{210}Po	60
^{232}Th	10
^{228}Ra	15
^{228}Th	10
^{224}Ra	15
^{40}K	93

TABLE D-IV

SUMMARY OF 1980 RESIDENTIAL POPULATION - PANTEX*

1980 Residential Population for Study Area: 253 156

Distance from Site (km)

Sector	0-1	1-2	2-4	4-8	8-16	16-25	25-32	32-50	50-64	64-80	Totals
N	0	0	0	6	25	54	60	3 317	179	245	3 886
NNE	0	0	0	6	25	51	47	17 032	2 988	521	20 670
NE	0	0	0	6	25	51	47	1 372	1 287	2 107	4 895
ENE	0	0	0	6	25	51	37	1 460	22 013	279	23 871
E	0	0	0	6	25	2 277	47	411	507	1 209	4 482
ESE	0	0	0	6	25	51	47	957	278	222	1 586
SE	0	0	0	5	25	50	1 155	116	99	401	1 851
SSE	0	0	0	5	25	48	43	105	73	156	455
S	0	0	0	4	25	55	81	267	208	438	1 078
SSW	0	0	0	4	62	416	419	604	482	1 192	3 179
SW	0	0	0	14	86	9 592	23 762	21 339	5 972	1 104	61 869
WSW	0	0	0	21	86	23 435	56 090	15 190	1 294	1 411	97 527
W	0	0	0	22	86	9 482	166	644	270	217	10 887
WNW	0	0	0	21	86	180	166	644	446	516	2 059
NW	0	0	0	16	86	180	166	511	278	264	1 501
NNW	0	0	0	7	62	177	166	272	206	12 470	13 360
Totals	0	0	0	155	779	46 150	82 499	64 241	36 580	22 752	253 156

*Taken from (LATA 1982).

TABLE D-IV (cont)

SUMMARY OF 1990 TOTAL POPULATION - PANTEX*

Total 1990 Population for Study Area: 288 909

Distance from Site (km)

Sector	0-1	1-2	2-4	4-8	8-16	16-25	25-32	32-50	50-64	64-80	Totals
N	0	0	0	6	25	55	61	3 398	181	247	3 973
NNE	0	0	0	6	25	51	47	17 642	3 116	526	21 413
NE	0	0	0	6	25	51	47	1 385	1 299	2 127	4 940
ENE	0	0	0	6	25	51	37	1 624	22 970	282	24 995
E	0	0	0	6	50	2 548	47	415	512	1 270	4 848
ESE	0	0	0	6	50	51	47	966	281	224	1 625
SE	0	0	0	5	25	50	1 166	117	100	405	1 868
SSE	0	0	0	5	25	48	43	106	74	157	458
S	0	0	0	4	25	56	82	270	210	442	1 089
SSW	0	0	0	4	388	420	423	610	487	1 353	3 685
SW	0	0	0	14	5 712	9 732	24 485	32 540	6 628	1 114	80 225
WSW	0	0	0	21	412	23 855	59 217	21 333	1 306	1 424	107 568
W	0	0	0	22	87	11 121	1 668	650	273	469	14 290
WNW	0	0	0	21	87	182	168	650	450	521	2 079
NW	0	0	0	16	87	182	168	516	331	316	1 616
NNW	0	0	0	7	63	179	168	275	208	13 337	14 237
Totals	0	0	0	155	7 111	48 632	87 874	82 497	38 426	24 214	288 909

*Taken from (LATA 1982).

TABLE D-V

SUMMARY OF 1980 RESIDENTIAL POPULATION - IAAP*

1980 Residential Population for Study Area: 370 654

Distance from Site (km)

Sector	0-1	1-2	2-4	4-8	8-16	16-25	25-32	32-50	50-64	64-80	Totals
N	0	0	23	187	389	417	806	4 224	8 981	11 237	26 264
NNE	0	0	23	187	569	2 170	321	2 446	2 394	16 685	24 795
NE	0	0	0	985	661	553	314	2 237	5 387	6 598	16 735
ENE	0	0	0	1 759	3 750	1 080	1 960	1 667	14 102	39 992	64 310
E	0	0	0	1 115	27 388	516	325	3 760	1 616	7 956	42 676
ESE	0	0	0	130	785	329	1 274	1 082	3 121	7 124	13 765
SE	0	0	0	100	729	879	322	3 634	24 836	2 795	33 295
SSE	0	0	0	120	337	1 822	361	3 540	1 703	3 137	11 020
S	0	0	0	89	274	852	460	5 036	1 510	3 377	11 598
SSW	0	0	0	91	366	14 322	2 043	19 078	3 718	4 668	44 286
SW	0	0	0	127	832	660	982	1 701	3 836	1 741	9 879
WSW	0	0	0	119	295	1 572	511	3 461	973	1 629	8 560
W	0	0	0	47	320	554	542	1 719	2 814	2 550	8 546
WNW	0	0	0	47	328	431	599	2 347	1 581	12 410	17 743
NW	0	0	10	95	1 292	2 506	3 074	6 452	3 075	9 450	25 954
NNW	0	0	520	99	270	347	465	1 929	4 127	3 471	11 228
Totals	0	0	576	5 297	38 505	29 010	14 359	64 313	83 774	134 820	370 654

*Taken from (LATA 1982).

TABLE D-V (cont)

SUMMARY OF 1990 TOTAL POPULATION - IAAP*

Total 1990 Population for Study Area: 383 637

Distance from Site (km)

Sector	0-1	1-2	2-4	4-8	8-16	16-25	25-32	32-50	50-64	64-80	Totals
N	0	0	23	188	391	394	784	4 292	9 024	10 971	26 067
NNE	0	0	23	188	572	2 180	298	1 906	1 658	17 635	24 460
NE	0	0	0	1 040	664	531	291	1 725	3 419	6 488	14 158
ENE	0	0	0	3 917	7 948	1 036	1 722	1 627	14 537	49 362	80 149
E	0	0	0	1 530	28 720	494	302	3 758	1 626	10 271	46 701
ESE	0	0	0	181	894	331	1 182	1 038	3 180	6 841	13 647
SE	0	0	0	100	757	759	299	2 771	25 460	2 702	32 848
SSE	0	0	0	121	364	1 633	388	2 561	1 513	3 306	9 886
S	0	0	0	89	300	882	438	4 141	1 419	3 822	11 091
SSW	0	0	0	91	368	14 491	1 905	19 169	3 708	4 783	44 515
SW	0	0	0	128	836	638	962	1 619	4 029	1 861	10 073
WSW	0	0	0	120	296	1 555	488	3 278	942	1 681	8 360
W	0	0	0	47	322	557	495	1 627	2 508	2 362	7 918
WNW	0	0	0	47	330	433	602	2 358	1 439	12 270	17 479
NW	0	0	10	95	1 298	2 518	3 114	6 558	2 770	9 295	25 658
NNW	0	0	522	90	271	324	417	1 838	3 997	3 168	10 627
Totals	0	0	578	7 972	44 331	28 756	13 687	60 266	81 229	146 818	383 637

*Taken from (LATA 1982).

TABLE D-VI

SUMMARY OF 1980 RESIDENTIAL POPULATION - HANFORD*

1980 Residential Population for Study Area: 323 885

Distance from Site (km)

Sector	0-1	1-2	2-4	4-8	8-16	16-25	25-32	32-50	50-64	64-80	Totals
N	0	0	0	0	0	128	804	447	1 313	7 128	9 820
NNE	0	0	0	0	0	128	200	738	17 787	1 200	20 053
NE	0	0	0	0	24	403	492	5 808	1 646	234	8 607
ENE	0	0	0	0	0	188	303	1 124	914	509	3 038
E	0	0	0	0	0	171	147	1 077	2 790	587	4 772
ESE	0	0	0	0	0	24	317	1 133	217	283	1 974
SE	0	0	0	0	0	0	238	1 279	23 620	3 494	28 631
SSE	0	0	0	0	0	0	1 471	45 363	45 122	2 085	94 041
S	0	0	0	0	0	0	438	6 774	1 775	155	9 142
SSW	0	0	0	0	0	0	591	1 740	11 239	528	14 098
SW	0	0	0	0	0	0	316	5 117	5 353	341	11 127
WSW	0	0	0	0	0	210	529	3 203	7 569	15 198	26 709
W	0	0	0	0	0	104	219	1 260	1 260	76 616	79 459
WNW	0	0	0	0	0	77	128	927	501	1 664	3 297
NW	0	0	0	0	51	128	128	517	501	826	2 151
NNW	0	0	0	0	51	128	128	441	1 109	5 109	6 966
Totals	0	0	0	0	126	1 689	6 449	76 948	122 716	115 957	323 885

*Taken from (LATA 1982).

TABLE D-VI (cont)

SUMMARY OF 1990 TOTAL POPULATION - HANFORD*

Total 1990 Population for Study Area: 388 563

Distance from Site (km)

Sector	0-1	1-2	2-4	4-8	8-16	16-25	25-32	32-50	50-64	64-80	Totals
N	0	0	0	0	0	129	809	450	1 421	7 673	10 482
NNE	0	0	0	0	0	129	201	743	18 399	1 308	20 780
NE	0	0	0	0	24	406	495	5 895	1 756	260	8 836
ENE	0	0	0	0	0	189	305	1 141	935	562	3 132
E	0	0	0	0	0	172	198	1 184	3 608	641	5 803
ESE	0	0	0	0	0	24	319	1 240	218	285	2 086
SE	0	0	0	0	0	0	239	1 487	36 419	3 666	41 811
SSE	0	0	0	0	0	0	1 480	70 649	58 076	2 098	132 303
S	0	0	0	0	0	0	441	7 367	1 786	1 656	11 250
SSW	0	0	0	0	0	0	595	2 051	11 310	531	14 487
SW	0	0	0	0	0	0	318	5 674	5 737	343	12 072
WSW	0	0	0	0	0	211	532	3 223	8 192	16 044	28 202
W	0	0	0	0	0	105	220	1 268	1 468	81 099	84 160
WNW	0	0	0	0	0	77	129	933	504	1 687	3 330
NW	0	0	0	0	51	129	129	520	554	836	2 219
NNW	0	0	0	0	51	129	129	444	1 216	5 641	7 610
Totals	0	0	0	0	126	1 700	6 539	104 269	151 599	124 330	388 563

*Taken from (LATA 1982).

TABLE D-VII

FIFTY-YEAR DOSE COMMITMENT CONVERSION FACTORS*

A. Uranium in Test Shots

^{238}U	Organ	Inhalation (rems/μCi)	Ingestion (rems/μCi)
	total body	1.07×10^{1}	2.00×10^{0}
	red bone marrow	9.30×10^{-1}	7.60×10^{-1}
	lungs	5.56×10^{2}	6.13×10^{-2}
	endosteal bone	1.37×10^{1}	1.10×10^{1}
	stomach wall	1.05×10^{-2}	8.52×10^{-3}
	large intestine	1.76×10^{-1}	1.40×10^{-1}
	bone	3.32×10^{1}	2.80×10^{1}
	liver	6.59×10^{-2}	5.35×10^{-2}
	kidneys	7.31×10^{0}	6.00×10^{0}
	testes	6.41×10^{-2}	5.38×10^{-2}
	ovaries	6.43×10^{-2}	5.34×10^{-2}
^{234}U	total body	1.15×10^{1}	2.30×10^{0}
	red bone marrow	1.13×10^{0}	9.30×10^{-1}
	lungs	6.25×10^{2}	6.87×10^{-2}
	endosteal bone	1.66×10^{1}	1.40×10^{1}
	stomach wall	8.20×10^{-3}	9.59×10^{-3}
	large intestine	8.03×10^{-2}	1.50×10^{-1}
	bone	3.76×10^{1}	3.10×10^{1}
	liver	7.37×10^{-2}	6.32×10^{-2}
	kidneys	7.85×10^{0}	6.70×10^{0}
	testes	7.37×10^{-2}	6.32×10^{-2}
	ovaries	7.37×10^{-2}	6.32×10^{-2}
^{235}U	total body	1.07×10^{1}	2.10×10^{0}
	red marrow bone	8.82×10^{-1}	7.20×10^{-1}
	lungs	5.63×10^{2}	6.45×10^{-2}
	endosteal bone	1.37×10^{1}	1.20×10^{1}
	stomach wall	2.02×10^{-2}	9.52×10^{-3}
	large intestine	1.61×10^{-1}	1.60×10^{-1}
	bone	3.38×10^{1}	2.80×10^{1}
	liver	7.39×10^{-2}	5.49×10^{-2}
	kidneys	7.31×10^{0}	6.00×10^{0}
	testes	6.39×10^{-2}	5.49×10^{-2}
	ovaries	6.51×10^{-2}	5.56×10^{-2}

TABLE D-VII (cont)

B. Tritium

Organ	Inhalation (rems/μCi)	Ingestion (rems/μCi)
total body	1.25×10^{-4}	8.30×10^{-5}
red bone marrow	1.24×10^{-4}	8.26×10^{-5}
lungs	1.25×10^{-4}	8.36×10^{-5}
endosteal bone	9.85×10^{-5}	6.56×10^{-5}
stomach wall	1.25×10^{-4}	1.08×10^{-4}
large intestine	1.33×10^{-4}	1.43×10^{-4}
bone	1.24×10^{-4}	8.28×10^{-5}
liver	1.24×10^{-4}	8.28×10^{-5}
kidneys	1.29×10^{-4}	8.56×10^{-5}
testes	1.25×10^{-4}	8.30×10^{-5}
ovaries	1.24×10^{-4}	8.29×10^{-5}

C. Radionuclides Released from Coal-Fired Power Plant

^{238}U	total body	1.50×10^{1}	2.00×10^{0}
	red bone marrow	2.00×10^{-1}	7.60×10^{-1}
	lungs	9.75×10^{2}	6.13×10^{-2}
	endosteal bone	2.90×10^{0}	1.10×10^{1}
	stomach wall	8.96×10^{-3}	8.52×10^{-3}
	large intestine	2.80×10^{-1}	1.40×10^{-1}
	bone	7.10×10^{0}	2.80×10^{1}
	liver	1.76×10^{-2}	5.35×10^{-2}
	kidneys	1.50×10^{0}	6.00×10^{0}
	testes	1.44×10^{-2}	5.38×10^{-2}
	ovaries	1.47×10^{-2}	5.34×10^{-2}
^{234}U	total body	1.60×10^{1}	2.30×10^{0}
	red bone marrow	2.40×10^{-1}	9.30×10^{-1}
	lungs	1.10×10^{3}	6.87×10^{-2}
	endosteal bone	3.50×10^{0}	1.40×10^{1}
	stomach wall	3.83×10^{-3}	9.59×10^{-3}
	large intestine	1.10×10^{-1}	1.50×10^{-1}
	bone	7.90×10^{0}	3.10×10^{1}
	liver	1.62×10^{-2}	6.32×10^{-2}
	kidneys	1.70×10^{0}	6.70×10^{0}
	testes	1.61×10^{-2}	6.32×10^{-2}
	ovaries	1.61×10^{-2}	6.32×10^{-2}

TABLE D-VII (cont)

C. Radionuclides Released from Coal-Fired Power Plant (cont)

	Organ	Inhalation (rems/μCi)	Ingestion (rems/μCi)
^{226}Ra	total body	4.70×10^{0}	3.40×10^{0}
	red bone marrow	2.50×10^{0}	2.20×10^{0}
	lungs	5.96×10^{1}	5.90×10^{-1}
	endosteal bone	2.30×10^{1}	2.00×10^{1}
	stomach wall	3.81×10^{-3}	5.37×10^{-3}
	large intestine	1.80×10^{-1}	3.30×10^{-1}
	bone	4.90×10^{1}	4.30×10^{1}
	liver	6.60×10^{-1}	5.90×10^{-1}
	kidneys	6.60×10^{-1}	5.90×10^{-1}
	testes	6.60×10^{-1}	5.90×10^{-1}
	ovaries	6.70×10^{-1}	5.90×10^{-1}
^{210}Po	total body	1.30×10^{0}	4.10×10^{-1}
	red bone marrow	8.30×10^{-1}	5.40×10^{-1}
	lungs	4.80×10^{1}	5.20×10^{-1}
	endosteal bone	3.70×10^{-1}	2.40×10^{-1}
	stomach wall	2.22×10^{-3}	4.54×10^{-3}
	large intestine	8.79×10^{-2}	1.80×10^{-1}
	bone	8.10×10^{-1}	5.20×10^{-1}
	liver	2.50×10^{0}	1.60×10^{0}
	kidneys	1.40×10^{1}	9.30×10^{0}
	testes	8.00×10^{-1}	5.20×10^{-1}
	ovaries	8.00×10^{-1}	5.20×10^{-1}
^{210}Pb	total body	1.11×10^{1}	4.35×10^{0}
	red bone marrow	5.23×10^{0}	2.04×10^{0}
	lungs	1.57×10^{-1}	1.92×10^{-4}
	endosteal bone	6.17×10^{1}	2.41×10^{1}
	stomach wall	2.82×10^{-4}	2.55×10^{-4}
	large intestine	3.88×10^{-3}	1.79×10^{-2}
	bone	1.32×10^{2}	5.16×10^{1}
	liver	9.19×10^{0}	3.59×10^{0}
	kidneys	6.00×10^{0}	2.34×10^{0}
	testes	3.03×10^{0}	1.18×10^{0}
	ovaries	3.03×10^{0}	1.18×10^{0}

TABLE D-VII (cont)

C. Radionuclides Released from Coal-Fired Power Plant (cont)

	Organ	Inhalation (rems/μCi)	Ingestion (rems/μCi)
^{222}Rn	total body	3.39×10^{-5}	4.60×10^{-3}
	red bone marrow	1.68×10^{-6}	3.03×10^{-3}
	lungs	2.34×10^{-3}	1.15×10^{-4}
	endosteal bone	1.03×10^{-5}	1.31×10^{-2}
	stomach wall	1.55×10^{-7}	1.48×10^{-2}
	large intestine	6.86×10^{-9}	6.90×10^{-1}
	bone	2.39×10^{-6}	2.78×10^{-3}
	liver	1.35×10^{-6}	1.90×10^{-3}
	kidneys	1.37×10^{-5}	1.40×10^{-2}
	testes	2.66×10^{-7}	7.06×10^{-4}
	ovaries	2.72×10^{-7}	5.43×10^{-3}
^{232}Th	total body	3.80×10^{1}	9.63×10^{-2}
	red bone marrow	2.71×10^{2}	1.10×10^{0}
	lungs	9.65×10^{2}	3.97×10^{-3}
	endosteal bone	4.53×10^{3}	1.80×10^{1}
	stomach wall	7.64×10^{-3}	3.47×10^{-3}
	large intestine	1.10×10^{-1}	1.50×10^{-1}
	bone	1.64×10^{3}	6.50×10^{0}
	liver	4.90×10^{0}	1.88×10^{-2}
	kidneys	1.10×10^{0}	3.75×10^{-3}
	testes	1.10×10^{0}	3.74×10^{-3}
	ovaries	1.10×10^{0}	3.75×10^{-3}
^{228}Th	total body	1.90×10^{1}	3.80×10^{-2}
	red bone marrow	3.70×10^{1}	3.80×10^{-1}
	lungs	1.09×10^{3}	7.50×10^{-3}
	endosteal bone	4.01×10^{2}	4.10×10^{0}
	stomach wall	9.23×10^{-2}	4.91×10^{-3}
	large intestine	2.90×10^{0}	4.70×10^{-3}
	bone	2.20×10^{2}	2.25×10^{-1}
	liver	2.50×10^{0}	2.34×10^{-2}
	kidneys	1.30×10^{0}	7.88×10^{-3}
	testes	8.10×10^{-1}	7.13×10^{-3}
	ovaries	8.30×10^{-1}	7.82×10^{-3}

TABLE D-VII (cont)

C. Radionuclides Released from Coal-Fired Power Plant (cont)

	Organ	Inhalation (rems/μCi)	Ingestion (rems/μCi)
^{228}Ra	total body	2.50×10^{0}	1.70×10^{0}
	red bone marrow	1.70×10^{0}	1.30×10^{0}
	lungs	7.18×10^{0}	4.10×10^{-1}
	endosteal bone	1.40×10^{1}	9.80×10^{0}
	stomach wall	9.58×10^{-3}	2.34×10^{-3}
	large intestine	6.99×10^{-2}	7.14×10^{-2}
	bone	2.90×10^{1}	2.10×10^{1}
	liver	7.50×10^{-1}	4.00×10^{-1}
	kidneys	5.40×10^{-1}	4.00×10^{-1}
	testes	5.40×10^{-1}	4.00×10^{-1}
	ovaries	5.40×10^{-1}	4.00×10^{-1}
^{224}Ra	total body	1.80×10^{-1}	7.47×10^{-2}
	red bone marrow	3.10×10^{-1}	4.10×10^{-1}
	lungs	8.77×10^{0}	8.36×10^{-2}
	endosteal bone	2.50×10^{0}	3.30×10^{0}
	stomach wall	6.66×10^{-3}	1.64×10^{-2}
	large intestine	2.50×10^{-1}	6.60×10^{-1}
	bone	1.5×10^{0}	2.0×10^{0}
	liver	6.69×10^{-2}	8.90×10^{-2}
	kidneys	8.32×10^{-2}	1.00×10^{-1}
	testes	6.03×10^{-2}	8.05×10^{-2}
	ovaries	6.11×10^{-2}	8.27×10^{-2}
^{230}Th	total body	3.80×10^{1}	9.24×10^{-2}
	red bone marrow	2.54×10^{2}	1.00×10^{0}
	lungs	1.07×10^{3}	4.56×10^{-3}
	endosteal bone	3.98×10^{3}	1.60×10^{1}

TABLE D-VII (cont)

C. Radionuclides Released from Coal-Fired Power Plant (cont)

	Organ	Inhalation (rems/μCi)	Ingestion (rems/μCi)
^{230}Th (cont)	stomach wall	2.67×10^{-3}	4.03×10^{-3}
	large intestine	1.00×10^{-1}	1.80×10^{-1}
	bone	1.53×10^{3}	6.00×10^{0}
	liver	5.50×10^{0}	2.18×10^{-2}
	kidneys	1.10×10^{0}	4.31×10^{-3}
	testes	1.10×10^{0}	4.30×10^{-3}
	ovaries	1.10×10^{0}	4.30×10^{-3}

*Fifty-year dose commitment conversion factors for depleted uranium were calculated from those given by Dunning (1981), assuming a mixture of 43% D and 57% Y aerosol. The ^{210}Pb factors were calculated using INREM II (Killough 1978). All other dose conversion factors were taken directly from Dunning (1981).

TABLE D-VIII

WHOLE BODY DOSE* CONVERSION FACTORS FOR EXTERNAL PENETRATING RADIATION**

Radionuclide	Cloud Submersion (rem/h) / ($\mu Ci/cm^3$)	Ground Concentrations (rem/h) / ($\mu Ci/cm^2$)
^{238}U	0.0392	6.23×10^{-5}
^{235}U	98.0	0.0218
^{234}U	0.0906	8.48×10^{-5}
^{232}Th	0.112	6.96×10^{-5}
^{230}Th	0.249	1.02×10^{-4}
^{228}Th	1.27	3.37×10^{-4}
^{228}Ra	2.33×10^{-8}	4.78×10^{-11}
^{226}Ra	4.36	9.64×10^{-4}
^{224}Ra	6.40	1.39×10^{-3}
^{222}Rn	0.244	5.03×10^{-5}
^{214}Bi	996.0	0.172
^{210}Po	0.00525	1.02×10^{-6}
^{214}Pb	156.0	0.0338
^{210}Pb	0.862	3.48×10^{-4}

*Doses to internal organs are assumed to equal whole body dose.
**Adopted from Kocher (1979).

TABLE D-IX

"EFFECTIVE MeV" FOR ^{226}Ra, ^{228}Ra, and ^{210}Pb SERIES
PER DISINTEGRATION OF THE PARENT NUCLIDE*
QUALITY FACTOR = 20

Series	Nuclide	Type of Radiation	Average Energy (MeV)	Quality Factor	Fractional Retention of Nuclide		Quality Factor X Retention (Effective MeV)
^{226}Ra	^{226}Ra	α	4.8	20	1		96.0
	^{222}Rn	α	5.5	20	0.3		33.0
	^{218}Po	α	6.0	20	0.3		36.0
	^{214}Pb	β	0.2	1	0.3		0.1
	^{214}Bi	β	0.56	1	0.3		0.2
	^{214}Po	α	7.7	20	0.3		46.2
						Total	212
^{228}Ra	^{228}Ra	β	0.02	1	1		0.0
	^{228}Ac	β	0.4	1	1		0.4
	^{228}Th	α	5.4	20	1		108.0
	^{224}Ra	α	5.7	20	1		114.0
	^{220}Rn	α	6.3	20	0.9		113.4
	^{216}Po	α	6.8	20	0.9		122.4
	^{212}Pb	β	0.2	1	0.9		0.2
	^{212}Bi	β(66%)	0.7	1	0.6		0.4
	^{212}Bi	α(34%)	6.1	20	0.3		36.6
	^{212}Po	α(66%)	8.8	20	0.6		105.6
	^{212}Tl	β(34%)	0.6	1	0.3		0.2
						Total	601
^{210}Pb	^{210}Pb	β	0.008	1	1		0.0
	^{210}Bi	β	0.4	1	1		0.4
	^{210}Po	α	5.3	20	1		106
						Total	106

*Taken from NCRP Report 45 (NCRP 1975) with modifications for quality factor of 20.

TABLE D-X

BACKGROUND CONCENTRATION OF NATURALLY OCCURRING
RADIONUCLIDES IN BONE*

Radionuclide	Concentration in Bone (pCi/kg)
$^{238,234}U$	6.9
^{226}Ra	7.8
^{228}Ra	3.8
^{210}Po	60

*Taken from NRCP Report 45 (NRCP 1975).

APPENDIX E

RISK ESTIMATORS FOR HEALTH EFFECTS FROM RADIATION

Cancer and genetic disorder risks from receiving radiation doses estimated in Section II were estimated using risk coefficients recommended in the 1980 report by the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (the BEIR III Committee) (BEIR III 1980). This appendix briefly describes the method used to obtain these risk coefficients.

The most important cancer risk coefficients for this report are those for bone and lung cancer and all cancers resulting from whole body radiation. This is because bone and lung receive the largest doses from the radionuclides considered here and together account for over 90% of the risk from cancer. The whole body risk coefficient is needed to estimate cancer risk from whole body radiation and from tritium exposure. In all cases the risk coefficient gives the total lifetime risk of dying from a cancer as a result of radiation exposure per unit of dose. Because doses are calculated for the general public, the risk coefficient is sex- and age-averaged.

The bone risk coefficient was taken from Appendix A of the BEIR III report. The recommended risk coefficient for high linear-energy-transfer (LET) radiation is 27×10^{-6}/rad of endosteal dose. This number was derived in the BEIR III report from a risk coefficient of 200×10^{-6}/rad of average skeletal dose for surface-seeking radionuclides using a 7000-g bone. Because bone doses reported here are average skeletal doses calculated for a 5000-g bone, the 200×10^{-6}/rad risk coefficient is corrected for bone mass to ($200 \times 10^{-6} \times 5000/7000 =$) 143×10^{-6}/rad of average skeletal dose for bone-surface-seeking radionuclides.

The risk coefficient for bone-volume-seeking radionuclides was obtained directly from the 27×10^{-6}/rad of endosteal dose. Because the endosteal dose and the average skeletal dose are approximately the same for bone-volume seekers (BEIR III 1980), the risk coefficient is 27×10^{-6}/rad of average skeletal dose. Correction for bone mass lowers this risk coefficient to 19×10^{-6}/rad of average skeletal dose.

The BEIR III report lists an alternate risk coefficient for bone cancer for use with a dose-squared response function. The report does not state which response function it prefers, linear or dose squared. In this report bone cancer mortality is conservatively estimated using the linear function that, for the low doses considered here, gives larger numbers of estimated bone cancers than does the dose-squared function.

The lifetime lung cancer risk coefficient for high-LET radiation was not given in the BEIR III report. This coefficient was calculated from the risk rate coefficients and latent periods given in Appendix A of the BEIR III report

and from the US Life Table for 1969-1971 published by the US National Center for Health Statistics (USNCHS 1975). The latent periods and risk rate coefficients for lung cancer are reproduced from BEIR III in Table E-I. The coefficient giving the lifetime risk of incurring a fatal lung cancer from radiation exposure is in Table E-II.

Risk factors for lung cancer recommended by the BEIR III committee have been criticized by Cohen as overestimating the true risks of lung cancer from inhalation of environmental radon by a factor of at least 40 for nonsmokers and by a factor of at least 10 for smokers (Cohen 1982). The International Commission on Radiological Protection (ICRP), in a recent review of animal experiments involving inhalation of radionuclides, concluded that current data support the ICRP's use of a lung cancer risk factor of 20 x 10^{-6}/rem, or 400 x 10^{-6}/rad (ICRP 1980), which is less than half of the calculated BEIR III risk estimate. In view of the uncertainties in calculating these risk factors and to maintain consistency in adopting the BEIR III approach, the lung cancer risk factor calculated from the parameters in Table E-I was used in this report for all high-LET lung doses except those from radon and its decay products, with the caveat that the calculated risks probably represent an estimate of the upper limit of the lung cancer risk. Risks from radon and radon decay product exposures were treated separately.

Lifetime risk of fatal lung cancer as a result of exposure to environmental levels of radon and radon decay products has been specifically addressed by Evans et al. (1981). They concluded that a risk coefficient of 100 cases of lung cancer per 10^6 person-WLM was an upper estimate of the total risk. This value for the risk was conservatively used in this report for exposure to radon and its decay products.

Lifetime risk of dying from any type of cancer as a result of exposure to whole body low-LET radiation was calculated from Table V-22 of the BEIR III report. The number of fatal cancers resulting from continuous exposure to 1 rad/year was used in the calculation. This exposure scenario was chosen because it was explicitly stated in BEIR III that only the linear portion of the dose-response function was used in calculation of its number of cancer cases. The risk coefficient can be calculated by dividing the number of fatal cancer cases by the life expectancy, taken here to be 71 years, and assuming equilibrium conditions in which fatal cancers/year/rad/year are equal to fatal cancers/lifetime/rad. The absolute and relative risk coefficients calculated in this manner are 67 x 10^{-6}/rad and 169 x 10^{-6}/rad, respectively. The average of these numbers, 118 x 10^{-6}/rad (rounded off to 120 x 10^{-6}/rad), was used in this report.

This risk coefficient was derived for a dose of 1 rad/year. Because the quadratic term in the linear-quadratic model becomes negligible for doses of 1 rad/year or less (BEIR III 1980), the model is effectively linear in dose at low doses. The risk coefficient, calculated in risk per rad at a dose of 1 rad, was

used to calculate total cancer risks for all low-LET doses in this report as if the risks depended linearly on dose.

The BEIR III Committee did not calculate risks of mortality from all cancers for doses smaller than 10 rad of low-LET radiation. The Committee stated (page 193) that it was uncertain that a total dose of 1 rad would have any effect, implying that the calculated risk would overestimate the true risk. To provide a comparison with the risks resulting from exposure to high-LET radiation, the risks of cancer mortality from a single year's exposure to low-LET radiation (principally background radiation) are calculated even though the total dose may have been below the range of doses considered by the BEIR III Committee. This procedure may result in an overestimate of the risk of cancer fatality from these exposures.

Recent work in calculating the gamma and neutron radiation fields produced at Hiroshima and Nagasaki may cause the radiation risk factors for cancer mortality in the BEIR III report to be revised (Straume 1981). This revision would affect the risk factors for all cancers resulting from exposure to low-LET radiation. The risk factors for high-LET alpha radiation would not be expected to be affected since they were not derived from the Japanese data. Consequently, cancer risks from whole body natural background radiation, which is primarily low-LET radiation, are considered tentative pending the outcome of this research. Cancer risks resulting from exposures to depleted uranium or radionuclides present in coal-fired power emissions, which are principally high-LET alpha radiation, should not change as a result of this work.

Risk of genetic disorders to offspring in all subsequent generations was calculated from the equilibrium frequency risk coefficients in Table IV-2 of BEIR III. As noted in the BEIR III report: "At genetic equilibrium, exactly as many future genetic effects are induced as are eliminated in any one generation. It follows that the total of all genetic effects that will be expressed over all future generations as a consequence of exposure limited to a single generation is numerically equal to the total for each generation in the equilibrium situation." (BEIR III 1980). The equilibrium frequency is 60-1100 genetic disorders per million liveborn offspring per rem for low-LET radiation and 180-3300 genetic disorders per million liveborn offspring per rem for high-LET radiation.

The dose in the genetic effect risk estimator is the dose to gametes rather than gonadal dose to parents. To calculate the gamete dose, we assumed that the age distributions in the assessment areas at Pantex, IAAP, and Hanford were the same as the US average population. Following the BEIR III report, the mean age of parents at the birth of a child was taken to be 30 years (BEIR III 1980). The gonadal population dose was multiplied by 0.26, the percentage of males or females in the population <30 years old, and then by 3.1, the average number of children per mother or father. The doses calculated for males and females were then summed to give the gamete dose.

The risk factors for lung cancer, bone cancer, all cancers following whole body irradiation, and genetic disorders in offspring are listed in Table E-II.

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TABLE E-I

RISK RATE COEFFICIENTS AND LATENT PERIODS FOR LUNG CANCER
TAKEN FROM BEIR III (1980)

Age at Diagnosis of Cancer (yr)	Risk Rate (Cases/yr/rem)
<35	0
35 - 49	1.5×10^{-6}
50 - 65	3.0×10^{-6}
>65	7.0×10^{-6}

Latent Period

Age at Exposure to Radiation (yr)	Latent Period (yr)
<15	25
15 - 34	17.5
>35	10

TABLE E-II

RISK FACTORS USED IN THIS REPORT

Organ Exposed/ Type of Cancer	Lifetime Risk of Mortality Per 10^6 Person-rad	Lifetime Risk of Mortality Per 10^6 Person-rem	Type of Radiation
Whole body/all cancer	120	120	low-LET
Lung/lung cancer	860	43	high-LET*
Bone surface/bone cancer**	140	1.4	high-LET
Total bone/bone cancer**	19	1	high-LET
Lung/lung cancer	100***		radon decay product

	Genetic Disorders Per 10^6 Liveborn Offspring in All Subsequent Generations Per rem	Type of Radiation
Gonads	60 - 1100	low-LET
	180 - 3300	high-LET

*Except radon decay product.
**Reduced from BEIR III estimates to account for different values of bone mass used in calculation of the dose.
***Lifetime risk of mortality per 10^6 person-WLM.

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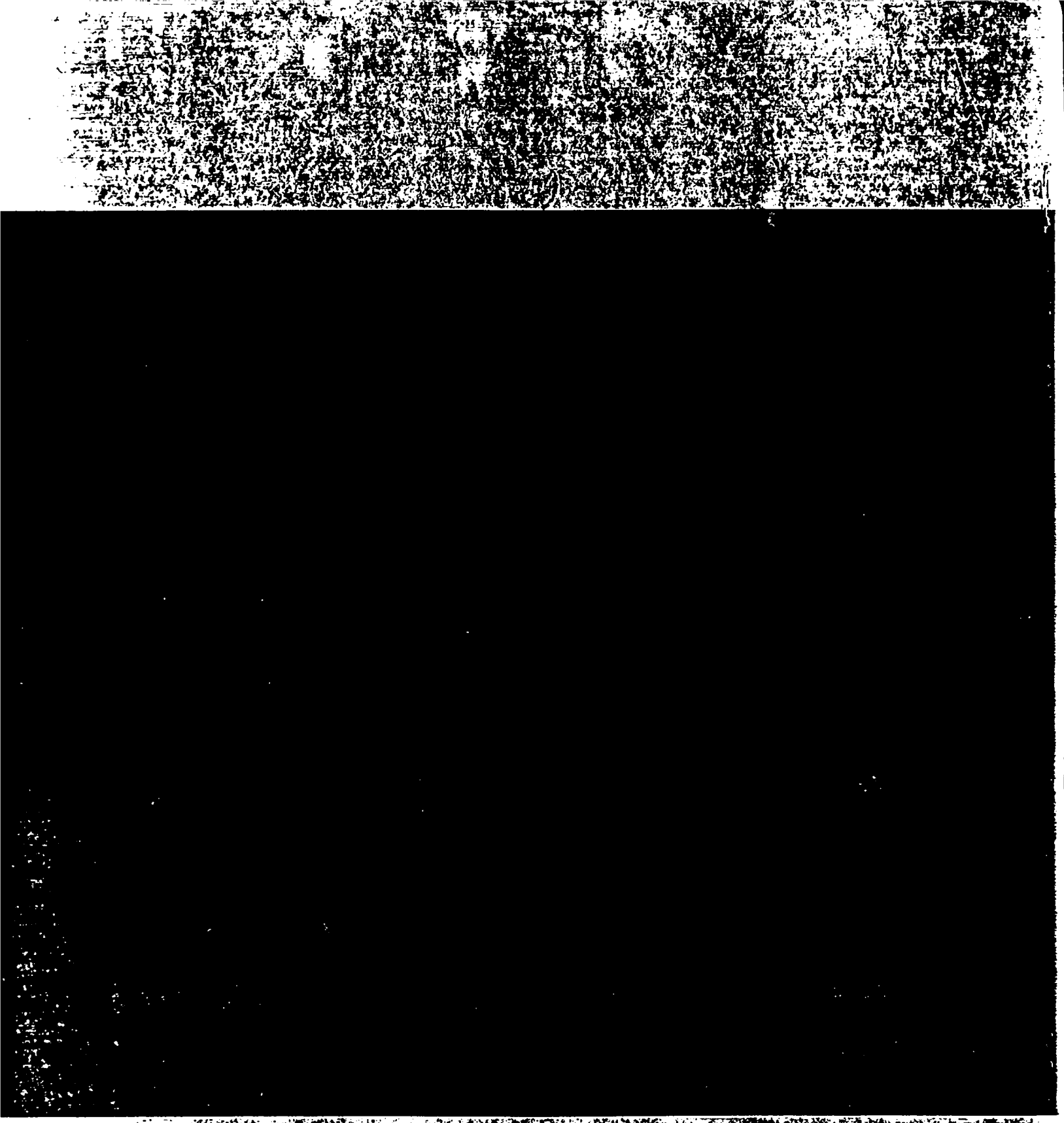

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