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...mentary Documentation for an ...vironmental Impact Statement ...garding the Pantex Plant

...view of Occupational Exposures to Radiation

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Supplementary Documentation for an Environmental Impact Statement Regarding the Pantex Plant

Review of Occupational Exposures to Radiation

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SUPPLEMENTARY DOCUMENTATION FOR AN ENVIRONMENTAL IMPACT STATEMENT REGARDING THE PANTEX PLANT:

REVIEW OF OCCUPATIONAL EXPOSURES TO RADIATION

by

J. C. Elder

ABSTRACT

This report documents work performed in support of preparation of an Environmental Impact Statement (EIS) regarding the Department of Energy's (DOE) Pantex Plant near Amarillo, Texas. Radiation dosimetry records over the recent past were reviewed to provide an assessment of the occupational exposure control program. The results of that review are discussed in terms of dose measurement practices, sources of dose, and experience regarding dose accumulated by members of the work force over the period 1966 to 1981. Whole body doses to a group of workers receiving a defined above-average cumulative dose are discussed in terms of job assignments and sources of exposures. Results of a review of radiation incident reports are discussed. Ongoing efforts to reduce occupational doses (already well below existing DOE dose limits) are described.

I. INTRODUCTION

This report documents work performed in support of preparation of an Environmental Impact Statement (EIS) regarding the Department of Energy's (DOE) Pantex Plant near Amarillo, Texas. That EIS addresses continuing nuclear weapons operations at Pantex and the 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 concise 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.

Routine exposure of personnel to radiation at Pantex was examined to address possible public concern about (a) safe handling of radioactive materials, (b) control of exposure of workers, and (c) whether or not the incidence of cancer is higher than normal among workers.

This report describes the radiation dose history at Pantex and actual exposure-limiting practices currently in force. The statistical relationship between actual doses (exposure to radiation results in a dose) and expected incidence of cancer in the worker population is discussed, although an epidemiological study of Pantex workers now in progress is expected to provide specific data in the future Acquavella 1982

Final 1981 dosimetry records of Pantex workers showed 924 Mason and Hanger, Silas Mason (MHSM) employees of the approximately 2200 employees at Pantex were issued radiation dosimeters on a monthly basis. Company policy requires a dosimeter be issued to any person for whom a potential exists to receive a calendar quarter dose in excess of 10% of the quarterly limits (limits are discussed later). These are typically employees assigned regularly to weapons operations areas, locations where uranium or plutonium or other radioactive material are stored, or locations containing machines capable of delivering a radiation dose. In addition, all health protection workers and others routinely visiting these locations and any other employee who might request a dosimeter for personal reasons are issued dosimeters.

II. DOSE MEASUREMENT

The dosimeter program at Pantex is conducted by MHSM and provides measurements of whole body dose and skin dose by thermoluminescent dosimeters (TLD). The TLD badge contains four elements of thermoluminescent material, two of $CaSO_4$ and two of $LiBO_4$. The TLD badge measures gamma, neutron, beta, and x-ray radiation. It responds to exposures of gamma or x-ray (photon) radiation at a threshold of approximately 1 mrem; neutron radiation, approximately 10 mrem. One $CaSO_4$ element is covered by sufficient thickness of lead to exclude beta radiation, weak gamma, or weak x ray, yielding a measurement of photon dose capable of penetrating at least 1 cm into the body. This penetrating radiation contributes the whole body dose. The other $CaSO_4$ element is covered only by a protective layer of plastic, which permits response to less energetic gamma and x rays, but excludes beta. The ratio of the two $CaSO_4$ element readings is used to estimate energy of the radiation, which is necessary for the determination of the shallow photon dose.

Neutron radiation, the other contributor to whole body dose, is measured using two $LiBO_4$ elements. The first $LiBO_4$ element is covered with a thin plastic layer, the other with a thicker plastic layer that excludes weak photon and beta radiation. The difference between the readings from the $LiBO_4$ elements provides the beta skin dose. The absolute value of the lead-covered $CaSO_4$ element reading subtracted from the second $LiBO_4$ element reading provides the neutron dose. Specific neutron calibration factors have been determined from dosimeter response to neutrons from appropriate assembly stages and nuclear explosives packages.

The Pantex Plant recently participated in two standardized dosimeter test programs, both of which indicated satisfactory performance in measuring doses in all categories of radiation type and energy (University of Michigan 1982; PNL 1982). The tests were performed according to American National Standards Institute Standard N.13.11 (ANSI 1982).

Monthly readings of these dosimeters and partially automated data management by computer permit retention of permanent records (current year and prior years) of whole body dose (neutron and gamma or x rays) and skin dose. Records are also kept of dose due to internally deposited radioactive material and dose to the extremities as detected by finger-ring or wrist dosimeters. The dosimetry program and record keeping methods in use at Pantex are modern and apparently permit maintaining an accurate and complete record of each worker's dose.

III. SOURCES OF DOSE

Pantex operations require a variety of radiation sources to be in the plant. Some of these are fully shielded and interlocked to prevent excessive exposure of workers. Other sources cannot be shielded effectively without prohibitively impeding the operation. This occurs in the primary mission of the plant, assembly or disassembly of nuclear explosives packages. The plutonium and uranium contained in these packages can produce significant radiation dose rates (30 to 40 mrem/h maximum) at a typical working distance. Positive action such as adding shielding and/or reducing time near the source has been required to allow work in this radiation field. Occupational exposure of nuclear explosive workers was planned and conducted in accordance with the limits stated in Appendix A. These limits were compatible with occupational exposure limits stated in DOE Order 5480.1, Chapter XI (USDOE 1980A). Mason and Hanger, Silas Mason established lower exposure levels as goals in August 1981 (MHSM 1981B); these are listed in Appendix B and discussed further under ALARA Activities, Section VII.

All major sources of potential occupational exposure at Pantex are listed in Appendix C. These include nuclear components containing plutonium or uranium (either stored separately or in the process of assembly into nuclear explosives packages), radiography sources (gamma and neutron), linear accelerators, and x-ray machines.

The radiography sources and machines receive periodic (at least semiannual) radiation protection surveys. Assembly cells and vaults containing nuclear components are equipped with gamma-reading nuclear criticality alarms; possible leaks in nuclear components are monitored by installed alpha radiation air monitors and, as appropriate, tritium air monitors. Radiation readings above the expected limit actuate alarms locally and, in most instances, at a central control station. Completion of the central alarm system is expected in 1983. Health physics technicians respond to alarm conditions and otherwise provide surveillance of nonroutine operations.

The primary source of occupational exposure is unshielded nuclear components as they are being incorporated into the nuclear explosives packages. Nuclear components produce gamma and x-ray radiation from radioactive decay of plutonium or uranium and their daughter products, x-ray radiation from bremsstrahlung interactions in uranium components, and neutron radiation by spontaneous emission from plutonium or from alpha-neutron reactions. These radiations are sufficiently penetrating to produce a whole body dose. Twenty-kiloelectron-volt x rays from plutonium and broad spectrum, low-energy x rays from bremsstrahlung in ^{238}U (from ^{234m}Pa beta radiation) are produced but are too weak to penetrate the container.

Tritium may also be contained in nuclear explosives packages. Tritium is a beta radiation emitter and is a source of whole body dose when taken into the body. Inhalation uptake and absorption across the skin can occur. However, no incident of major accidental release of tritium has occurred. A routine urinalysis program is conducted at Pantex to determine whether personnel exposures to tritium have occurred. Employees working in weapons assembly areas are monitored for tritium uptake at least annually. Employees working directly with tritium components are monitored monthly.

IV. WHOLE BODY DOSES

Whole body doses of MHSM employees in terms of number in dose ranges are listed in Table I for the years 1966-1981 (USDOE 1982). These doses are the sum of gamma and neutron doses derived directly from dosimeter readings and do not include skin, extremity, or other organ doses. These doses are expressed in units of dose equivalent (rem), which is absorbed dose times a modifying factor specific to the radiation type. The modifying factor is 1 for beta, gamma, and x-ray radiation; for neutrons it is variable from 2 to 11 depending on their energy. Absorbed dose is the energy imparted to the tissue of interest by the radiation and is expressed in terms of rad (100 ergs per gram of tissue).

Numbers of workers receiving dose decreased gradually over the period 1966 to 1973 in approximate proportion to the worker population. Integrated dose in terms of person-rem remained in a fairly narrow range over the period 1974 to 1978, averaging 59 person-rem. Over the period 1979 to 1981, a major workload increase caused integrated doses among workers to increase into the range 150 to 204 person-rem, substantially above the 50 to 72 person-rem range of previous years. Over this same period, efforts were accelerated to reduce worker doses to levels as low as reasonably achievable (ALARA). These efforts included improved shielding, procedures, and worker training. A recently established administrative limit of 2.5 rem/yr (50% of the DOE limit) has produced a favorable trend of lower doses distributed among a higher number of workers (MHSM 1981B).

Doses reported in Table I indicate the 5 rem/yr limit (Appendix A) was not exceeded except in the case of one man in 1979. Minor underestimation of expected dose resulted in his receiving 5.14 rem in 1 yr. This prompted an incident report followed by corrective measures. The occurrence was not repeated thereafter, nor were any workers subjected to doses near the 5 rem/yr limit.

As shown in Table II, workers at Pantex received whole body doses somewhat higher than the average doses of DOE workers in weapons fabrication and test (WFT) activities. However, as shown in Table III, average doses of WFT workers were lower than similarly determined average doses of personnel working in nuclear reactor operation, fuel fabrication, fuel processing, and accelerator operations. Only in 1979 did the Pantex average dose (0.28 rem) approach the average dose in these other facility types (0.16 to 0.42 rem).

Radiation histories of active Pantex workers receiving significant doses were examined on a worker-by-worker basis. Above-average dose was arbitrarily defined to be 3 rem or greater in the worker's career prior to 1980 and/or 1 rem or greater within the past year (1980). Of the 786 active employees monitored with dosimeters in 1980, 84 received above-average exposure by these criteria. These 84 workers, 5 of whom were women, were categorized as follows.

Dose Category	Number
A. Dose $\geq$3 rem prior to 1980 but $\leq$1 rem in 1980	45
B. Dose $\geq$3 rem prior to 1980 and $\geq$1 rem in 1980	9
C. Dose <3 rem prior to 1980 but $\geq$1 rem in 1980	30
	84

All of the 45 in group A were employed at Pantex at least 9 yr and acquired their doses at a maximum rate of approximately 1 rem/yr. Newer employees in group C have acquired their doses at a higher rate (2.1 rem/yr maximum), probably reflecting the increased exposure due to increased workload discussed earlier.

Doses of workers in the highly skilled departments were categorized in terms of above-average exposure of these same 84 people as related to the

TABLE I

PANTEX PLANT
ANNUAL WHOLE BODY DOSES FOR 1966-1981*

Year	Dose Ranges (rem)							Total Number of Workers Monitored	Integrated Dose*** (person-rem)
	<Meas**	<1	1-2	2-3	3-4	4-5	5-6		
1966		526	15	3				544	
1967		496	17	4	1			518	
1968		393	6					399	
1969		397	2	1				400	
1970		352	15	7	1			375	
1971		426	21	8	2			457	
1972		407	10	6				423	
1973		296	7					303	
1974		472	9					481	72
1975	45	457	6					508	56
1976	31	406	3	1				441	50
1977	20	419	4	1				444	62
1978	68	426	2	1				497	57
1979	27	610	28	10	1	4	1	681	185
1980	106	641	27	10	2			786	153
1981	355	512	49	8				924	204

*In number of workers with dose in each range of measurement; compiled from "Annual Reports of Radiation Exposure for DOE and DOE Contractor Employees," USDOE Office of Nuclear Safety (USDOE 1982).

**Dose was below the measurement limits of dosimeters (approximately 0.001 rem). This category was not reported 1966-1974.

***Sum of measurable doses to all workers monitored. This category was not reported 1966 to 1973.

TABLE II

COMPARISON OF INTEGRATED DOSES
AT DOE WEAPON FABRICATION AND TEST FACILITIES

	Pantex			All WFT Facilities		
Year	Total Monitored	Integrated Dose (person-rem)	Average Dose*	Total Monitored	Integrated Dose (person-rem)	Average Dose*
1974	481	72	0.15	19 026	2244	0.12
1975	508	56	0.11	19 425	1435	0.07
1976	441	50	0.11	15 823	814	0.05
1977	444	62	0.14	16 264	875	0.05
1978	497	57	0.11	18 296	1072	0.06
1979	654	185	0.28	18 409	1248	0.07
1980	786	153	0.19	15 904	869	0.05
1981	924	204	0.22	18 062	973	0.05

*Ratio of person-rem to total monitored yields average dose in rem.

type of work they were doing. Table IV reflects comparisons by task heading.

By far the highest frequency of above-average exposed workers occurred in the manufacturing department, where assembly, disassembly, maintenance, and modification are performed. These workers are in direct contact or close proximity to nuclear explosives packages a major portion of their work day. Their exposure is gradual in well-known radiation fields. Sudden major increases in the radiation field do not occur in this work situation. The quality assurance department personnel, who independently inspect nuclear explosives packages throughout assembly or disassembly, also receive relatively high doses. Their doses, which are similar to those of assembly workers, originate primarily from proximity to nuclear explosives packages.

Of the 27 assembly workers receiving ≥ 1 rem in 1980, 13 worked on the modification program that entered the plant in 1978. Their average whole body dose (neutron and gamma) was 1960 ± 600 (1 std dev) mrem in 1980, compared to 1590 ± 400 mrem for 10 cell assembly workers working on assembly programs. Doses from the modification program were received after shielding fixtures were installed in the cells. Shielding is being provided for incoming assembly programs; however, none was in place until after these 1980 doses were received. Pantex officials believe the shielding applied to the

TABLE III

INTEGRATED DOSE (person-rem) PER FACILITY TYPE
DOE/DOE CONTRACTOR EMPLOYEES AND VISITORS - 1974-1980*

Facility Type	Total Number of Persons Monitored	Total Number of Persons with Measurable Dose	Integrated Dose (person-rem)	Average Dose (rem) Per Person Monitored**	Average Dose (rem) Per Person with Meas. Dose***
Reactor	43 851	28 393	114 52	0.26	0.44
Fuel Fabrication	8 463	7 147	1 853	0.22	0.26
Fuel Processing	18 531	14 359	7 814	0.42	0.53
Weapon Fabrication & Test	123 147	62 515	8 556	0.07	0.14
Accelerator	31 774	12 977	5 140	0.16	0.39

*Period over which all categories were uniformly reported.
**Based on integrated dose divided by the number monitored.
***Based on integrated dose divided by the number of persons with measurable dose.

TABLE IV

ABOVE-AVERAGE EXPOSURE FREQUENCY BY TASK

Dept.	Work Description	Number of Above-Average Exposed Workers
324	Production stores (vault workers)	6
350	Manufacturing	47
374	Production control	1
422	Nondestructive testing	5
443	Quality assurance evaluation	4
444	Quality assurance	18
555	Electronic shop	1
930	Assembly engineering	1
960	Industrial engineering	1
		84

modification program reduced gamma dose rates by approximately 90% and neutron dose rates by approximately 50%. Several design changes reduced radiation sources within the nuclear explosives package.

Until the completion of the epidemiological study of Pantex workers now in progress, the question of health effects being induced among Pantex workers can be addressed only on a hypothetical basis. Fatal cancer is hypothesized to be caused by low-level radiation. Actual increases in cancer mortality have never been measured at low average annual doses such as those received by Pantex workers. The reason for the lack of measurements at this level is twofold: first, the induction rate is low and, second, the normal or usual incidence of cancer in any group of people is such that 15 to 17% of those now alive will eventually die of cancer even if they do not receive radiation exposure above normal background.

Dose response models published by the National Academy of Science (BEIR III 1980) offer a method for projecting the number of cancer deaths (above the normal incidence) caused by radiation such as x rays, gamma rays, and neutrons. The BEIR III analysis is based primarily on radiation with low-linear energy transfer (LET) capability; therefore, it is considered an appropriate reference for the Pantex worker, whose exposure is predominantly to low-LET radiation [approximately 3:1 gamma and x ray (low-LET) to neutron (high-LET) dose].

For the purposes of these estimates, the worker population was assumed to be all men; actually, women make up 13% of the work force exposed to radiation. Radiation-induced cancer incidence is higher in women than in men (approximately double), particularly in incidence of breast, thyroid, and lung cancer. This higher incidence would not alter these estimates unless the fraction of women in the work force increased markedly in future years. This increase is not expected since the percentage of women in the work force has remained steady in the range of 12 to 15% over the past 6 yr. The estimates for the male population in the age bracket 20 to 65 yr were summed in Tables V-16 and V-19 of BEIR III to yield deaths from all cancer types. Continuous dose to 1 rad/yr (equivalent to 1 rem/yr for low-LET radiation) would induce 2728 to 4634 cancer deaths per million population or 1.6 to 2.7% of the normal incidence. (The lower end of the range given here and later in this section is based on the absolute projection model; the upper end, on the relative projection model. These models are described in detail in the BEIR III report.) Normal incidence in the age group 20 to 65 yr is 171 500 cancer deaths per million population not occupationally exposed (17%).

Potential cancer incidence at Pantex was estimated using the annual average integrated dose of 181 person-rem received by the worker population over the period 1979 to 1981. This estimate, obtained by multiplying 181 person-rem by the risk (2728 or 4634 deaths per million), indicates 0.5 to 0.8 deaths might be attributable to job-related radiation exposure in the population (797 average). This can be restated as a probability of 0.5 to 0.8 that one radiation-induced death might occur. Similarly, the probability of a death in the above-average exposed group of 39 workers was estimated to be 0.2 to 0.4 by multiplying their 2 rem/yr average dose by 2728 or 4634 per million and by 39 persons. These estimates assume conservatively that these workers would continue to receive dose at this rate for their entire working lives. Examination of the data shows only 9 workers (Group B) in 84 continued to receive over 1 rem/yr late in their careers. In conclusion, these estimates indicate that one radiation-induced cancer death might result from job-related radiation exposure at Pantex. In this case, the incidence of cancer would be raised only slightly for the Pantex worker (0.8/797 or 0.1%).

V. SKIN DOSE

Skin doses were recorded from dosimeter readings in 79 cases of the 84 above-average exposed workers. Skin dose generally accompanies whole body dose because of low-energy gamma rays from ^{241}Am in the radioactive material components of nuclear weapons packages. Minor skin doses have resulted from beta radiation from ^{238}U. Maximum measured skin dose to any individual was 4890 mrem accumulated prior to 1980; maximum in 1980 was 4290 mrem. None of the skin doses of the 84 above-average exposed workers approached the limits stated in Appendix A. However, accidental overexposure of limited skin areas of other workers has been described in incident reports. The worst of these incidents, which occurred in 1974, was a facial exposure to x rays from a x-ray diffractometer. The localized nature of the beam prevented dose measurement by dosimetry. This dose was estimated to be on the order of 3000 rem.

Its cause was attributed to unauthorized defeating of interlocks by the worker. In a 1976 incident, a quality inspector received 7.9-rem skin dose from an unknown source. Each incident was formally investigated and corrective steps were taken where they could be identified.

Incidents of skin overexposure occurring at no greater frequency than this indicate a reasonably sound control program. However, the incidents described above and several investigations related to possible overexposures indicated needed improvements in the Pantex dosimetry program. These improvements were initiated in 1980 with the acquisition of the present system.

VI. INTERNAL DOSES

Small internal doses from tritium leaking from containers have occurred and are reported each year. None of these doses have approached annual dose limits. Radiation doses from other internally deposited radioactive materials were reported to be zero among the 786 active employees (1980), 209 inactive employees (those with previous radiation exposure no longer in radiation work), and 706 employees who have terminated their employment at Pantex. An incident involving weapon accident debris brought to Pantex potentially could have caused internal deposition of plutonium. Follow-up bioassay monitoring of involved persons indicated no intake occurred. Internal doses to workers at Pantex can be expected to remain low, provided radioactive materials continue to be processed at other locations and are handled only in sealed containers at Pantex.

VII. EFFECT OF ALARA ACTIVITIES

A working group was established at Pantex in 1977 (MHSM 1977) to coordinate policies and activities directed at achieving personnel and environmental ALARA doses as provided in DOE Order 5480.1, Chapter XI (USDOE 1980A; MHSM 1982). The Pantex ALARA Working Group has responded to this policy by (1) making workers aware of management's commitment to ALARA, (2) reviewing ALARA activities within divisions, (3) attempting to assess the effects of ALARA activities, and (4) setting goals of reduced occupational doses. Training of radiation workers in procedures to minimize dose has been ongoing.

Recently, an administrative limit of 2.5 rem/yr whole body dose has been instituted (MHSM 1981B). Worker doses in 1981 did not exceed this limit. An administrative goal of 1 rem/yr has been established for DOE workers working in new facilities or on new processes (USDOE 1981). This goal is intended primarily to encourage new achievements in design engineering.

Specific ALARA activities within the manufacturing division were (1) provision of lead-loaded aprons for assembly workers; (2) shielded tooling at each assembly station, which reduced gamma radiation by approximately 90% and neutron radiation by 50%; and (3) radiation safety presentation (review) for all workers. Assessment of the effect of ALARA activities was attempted and has been difficult because of the increased exposures accompanying the workload increase in 1979 (Kouba 1980). Although management has made a reasonable effort to promote ALARA activities, experience over several more years will be necessary to fully assess their effect.

VIII. SUMMARY

Radiation dosimetry and incident records at the Pantex Plant have been reviewed to provide an assessment of the occupational radiation control program there. This review and plant visits indicate that doses received by Pantex workers are routinely well within established DOE guidelines; the control program is considered adequate. Doses increased in 1979, concurrent with a workload increase, and have remained consistent with the workload through the period 1979 to 1981. Whole body doses to Pantex workers are consistently lower than doses to workers at other DOE facilities such as nuclear reactors, accelerators, fuel fabrication, and fuel processing plants.

A new administrative limit of 2.5 rem/yr was successfully observed in 1981. A still lower administrative goal of 1 rem/yr has been adopted for DOE workers working in new facilities or on new processes. These steps are both evidence of an active ALARA program at Pantex.

REFERENCES

ANSI 1982: "Criteria for Testing Personnel Dosimetry Performance," American National Standards Institute Standard ANSI N.13.11 (June 1982).

BEIR III 1980: "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, 1980," Committee on the Biological Effects of Ionizing Radiations, National Academy Press, Washington, DC (1980).

Kouba 1980: S. Kouba, "Analysis of Radiation Exposures of Personnel Assigned to the W68 Program During the Period October 1978 through June 1980," Mason and Hanger, Silas Mason Co., Inc., report (September 1980).

MHSM 1977: Standard No. 322, "As Low As Practicable (ALAP) Exposure Working Group," Mason and Hanger, Silas Mason Co., Inc. (1977).

MHSM 1981B: Standard No. 321, "Standards for Radiation Protection," Mason and Hanger, Silas Mason Co., Inc. (August 21, 1981).

MHSM 1982: Standard No. 322, "As Low As Reasonably Achievable (ALARA) Exposure Working Group," Mason and Hanger, Silas Mason Co., Inc. (1982).

PNL 1982: P. L. Roberson, "DOE Intercomparison Program," Pacific Northwest Laboratories, memorandum to R. E. Alexander (June 25, 1982).

University of Michigan 1982: J. K. Miklos, "Results of Test No. 3 in Dosimetry Performance Program," memorandum to R. E. Alexander (July 13, 1982).

USDOE 1980A: DOE Order 5480.1, Chapter XI, "Requirements for Radiation Protection" (August 1980).

USDOE 1981: DOE Draft Order 6430, "General Design Criteria Manual" (June 1981).

USDOE 1982: Thirteenth Annual Report of Radiation Exposure for DOE and DOE Contractor Employees-1980, USDOE, EP-0040 (February 1982).

Acquavella 1982: J.F. Acquavella, L.D. Wiggs, R. J. Waxweiller, D. G. Macdonell, and G. S. Wilkinson, "Supplementary Documentation for an Environmental Impact Statement Regarding the Pantex Plant: Occupational Work Force Mortality Study," Los Alamos National Laboratory report LA-9445-PNTX-Q (December 1982).

APPENDIX A

PLANNED OCCUPATIONAL EXPOSURE LIMITS FOR NUCLEAR EXPLOSIVES WORKERS

(Prior to August 1981)

Individuals directly involved in fabrication and test of nuclear explosives may be exposed to sources of ionizing radiation so long as the values below are not exceeded.

	rem per Calendar Quarter	rem per Year
Whole body, head, trunk, active blood-forming organs, lens of eyes, or gonads	1.25+(3)	5
Hands, feet, ankles	18.75+(25)	75
Skin of whole body	5	15
Forearms	10	30

Note: Plus (+) means the quarterly guidelines for whole body and extremities may be exceeded provided that the quarterly whole body dose does not exceed 3 rem or the quarterly extremities dose does not exceed 25 rem.

APPENDIX B

PLANNED OCCUPATIONAL EXPOSURE GOALS FOR NUCLEAR EXPLOSIVES WORKERS (After August 1981)

Planned occupational exposure to ionizing radiation (not including natural background or medical examinations) in excess of guidelines below should not be permitted.

	rem per Calendar Quarter	rem per Year
Whole body, head, trunk, active blood-forming organs, lens of eyes, or gonads	0.8	2.5
Hands, feet, ankles	12.5	37.5
Skin of whole body	2.5	7.5
Forearms	5	15

APPENDIX C

MAJOR SOURCES OF RADIATION AT PANTEX PLANT

Source Description	Radiation
^{60}Co radiography	Gamma
Radiography machines	x ray
Van de Graaff accelerator	x ray and neutron
1 MeV/250 kVp x-ray machine	x ray
Image intensifier	x ray
Cabinet x-ray machine	x ray
X-ray machine	x ray
Linatron 2000	x ray
^{60}Co radiography	Gamma
Linatron 2000X	x ray
Fluoroscopic inspection	x ray
Flash x-ray machine	x ray
Nuclear component vaults	Gamma and neutron
Nuclear explosives	Gamma and neutron

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