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ASSESSMENT OF

RADIATION DOSES AND RESULTING HEALTH RISKS

FROM THE

CONTROLLED-AIR INCINERATOR

by

Thomas Buhl, Ph.D., C.H.P.

LOS ALAMOS NATIONAL LABORATORY

July 1989

EXHIBIT FIVE

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1.0. INTRODUCTION

The radiological impacts from the Controlled Air Incinerator (CAI) were estimated using mathematical models to describe atmospheric dispersion, radionuclide transport, uptake, and metabolism, and to calculate resulting radiation doses. The models calculated radiation doses from exposure to radionuclides released from routine operations. The doses were then used to estimate health effects to the surrounding population that may result from the operation of the CAI.

2.0. EXPOSURE PATHWAYS

Radiation exposures to members of the public from CAI routine operations could potentially occur from airborne releases, liquid releases, and direct radiation. Only exposures through airborne releases, however, present a viable pathway. Exposures from liquid releases and from direct radiation are insignificant, as discussed below, and are not considered further in this assessment.

Because the doses from liquid releases and direct radiation are negligible, doses resulting from airborne emissions are the doses for all pathways. Consequently, doses from airborne releases are the appropriate doses to compare with the U.S. Department of Energy's (USDOE's) Radiation Protection Standard of 100 mrem/yr effective dose equivalent to a member of the public from all pathways (USDOE 1985).

Airborne Releases. Some radioactive airborne emissions are expected to be released from the CAI. These emissions are estimated to be approximately 0.7 µCi/yr of plutonium/americium activity (0.1 µCi/yr of plutonium/americium alpha activity), 15.2 mCi/yr of ^{14}C, and 7.6 mCi/yr of tritium.

Radiation doses resulting from these releases were calculated using the computer code AIRDOS-EPA. This code considers all major pathways of importance at the Laboratory that could result in radiation exposure from airborne releases (see Sec. 3.0).

Liquid Releases. The CAI will have no liquid releases with above-background radioactivity (radioactive liquid effluent) to the environment. All of the radioactive liquid effluents will be sent to the Laboratory's Radioactive Liquid Waste Treatment Plant at Technical Area (TA)-50 to be processed.

This is the same procedure that is currently followed for other liquid radioactive waste at the Laboratory. The environmental impact of the Laboratory's current liquid radioactive waste treatment methods, which involve no off-site liquid transport of radioactivity and no resulting dose to the public, is evaluated in the Laboratory's annual environmental surveillance reports (for an example, see ESG 1988).

Direct Radiation. Operations at the CAI will involve small direct-photon and neutron radiation fields. These external radiation fields will be of primary concern to occupational

exposure. Doses to workers from external radiation have been shown to be less than 100 mrem/yr. Dose rate levels exterior to the CAI in areas accessible to the public will be considerably lower and will continue to decrease rapidly with distance from the facility. These dose levels will not present a viable exposure pathway to the public because of their very low levels, their limited range, the limited exposure time, and the small number of people who would be exposed.

3.0. ESTIMATING RADIATION DOSE FROM ROUTINE OPERATIONS

The computer code AIRDOS-EPA was used to estimate radiation doses resulting from expected routine airborne emissions from the CAI. AIRDOS-EPA uses a Gaussian-dispersion model to calculate annual average concentrations of radionuclides in air. Input data include radionuclide emission rates, stack dimensions, and annual average wind speed, wind direction, and stability class. After calculating air concentrations, AIRDOS-EPA then uses deposition velocity to estimate radionuclide concentrations on soil from ground deposition.

The calculated air and ground radionuclide concentrations are then used in an ecology model to estimate radionuclide intake by humans through inhalation and ingestion and through external radiation exposure. AIRDOS-EPA considers the following pathways:

- inhalation,
- external exposure from cloud submersion,
- external exposure from ground deposition,
- ingestion of contaminated crops,
- ingestion of contaminated meat, and
- ingestion of contaminated milk.

Input data required by the ecology model include detailed descriptions of the area within 80 km of the facility, providing population distribution details and agricultural information, such as number of livestock and area of cultivatable land.

The computer codes PREPAR and DARTAB were run in conjunction with AIRDOS-EPA. PREPAR is a data preprocessor for AIRDOS-EPA that prepares the AIRDOS-EPA data file. DARTAB combines the AIRDOS-EPA calculated radionuclide intake values with dose conversion factors to calculate either the radiation dose to individuals at a given receptor location or the collective dose to the population living within 80 km of the facility.

The codes AIRDOS-EPA, PREPAR, and DARTAB have been extensively documented (Begovich 1981, Moore 1979, Sjoreen 1984). The reader is referred to these documents for a detailed description of the procedures used in each program. The rest of this section discusses the input parameters used in the codes to calculate the doses resulting from operation of the CAI.

3.1. *Radionuclide Emission Rates*

Estimates of the annual radionuclide emission rates for the CAI are based on past operating experience at other incinerators, the expected radionuclide throughput, and the design for the filtration system on the facility. For added conservatism in performing this radiological assessment, radionuclide emissions actually used in the dose calculations were assumed to be 150% of the quantities calculated below.

Table 1 shows the expected radionuclide emissions from the CAI, as well as 150% of these emissions used in performing the dose assessment. The quantity of plutonium/-americium expected to enter the CAI was estimated by the Waste Management Group

TABLE 1

WASTE INPUT INTO AND RADIONUCLIDE EMISSIONS FROM THE CONTROLLED-AIR INCINERATOR

Waste Input

	Expected (g/yr)	150% of Expected (g/yr)
Solid:		
TRU radionuclides	4000	6000
Mixed waste	9.9×10^{7}	1.5×10^{8}
Liquid:		
Mixed waste	2.2×10^{6}	3.4×10^{6}

Radionuclide Emissions

Radionuclide	Projected Annual Emissions (Ci/yr)	150% of Projected Annual Emissions (Ci/yr)
^{3}H	5.1×10^{-3}	7.6×10^{-3}
^{14}C	1.0×10^{-2}	1.5×10^{-2}
^{238}Pu	4.6×10^{-9}	6.9×10^{-9}
^{239}Pu	5.2×10^{-8}	7.9×10^{-8}
^{240}Pu	1.2×10^{-8}	1.8×10^{-8}
^{241}Pu	3.7×10^{-7}	5.6×10^{-7}
^{241}Am	1.1×10^{-9}	1.6×10^{-9}

based on past operating experience. This mass was then distributed among the plutonium/-americium radioisotopes according to the following proportions:

Isotope	Fraction by Weight
^{238}Pu	0.0003
^{239}Pu	0.936
^{240}Pu	0.06
^{241}Pu	0.004
^{241}Am	0.00035

The release fraction for the plutonium/americium particulate emissions was calculated to be 2.25×10^{-10}, based on control equipment efficiencies. These efficiencies are discussed below.

Approximately 1×10^5 kg of wastes containing 0.1 nCi/g of ^3H and 0.1 nCi/g of ^{14}C may be processed by the CAI. These radionuclides are assumed to be released in the incineration of these wastes.

Carbon-14 is assumed to be totally converted to carbon dioxide under incinerator operating conditions and thus would not be subject to removal by the process scrub or filtration systems.

Tritium is assumed to be totally converted to tritiated water vapor (T_2O or HTO) under incinerator operating conditions. One-half is assumed to be entrained in the aqueous scrub solutions and one-half entrained in the off gas as water vapor. The control efficiency is thus 50%.

Release Fractions for Particulates. The off-gas emission-control system consists of a water-spray quench column for off-gas temperature reduction, a high-energy venturi scrubber for particulate removal, a packed-column scrubber for acid-gas removal, a primary high-efficiency particulate-air (HEPA)-filter bank consisting of a roughing prefilter and two HEPA filters in series, an activated carbon bed filter, and a secondary HEPA bank consisting of one HEPA filter downstream of the carbon bed.

For the control of particulate releases, the design criteria for the incinerator and off-gas treatment system components are listed below:

Component	Control Efficiency (%)
Primary chamber	95
Secondary chamber (no credit taken)	0
Quench column (no credit taken)	0
Venturi scrubber	95
Packed column (no credit taken)	0
Prefilter off-gas conditioning (no credit taken)	0
First-bank HEPA filter	99.97
Activated carbon filter (no credit taken)	0
Second-bank HEPA filter	99.97

The control efficiencies are typical of systems of this type currently in operation. Based on these control efficiencies, the release fraction for particulates is $[(1 - 0.95)(1 - 0.95)(1 - 0.9997)(1 - 0.9997)] = 2.25 \times 10^{-10}$.

The removal efficiency assumptions are conservative, in that no credit is taken for particulate removal in the secondary chamber, the quench and absorber columns, and one of the two HEPA filters in the first HEPA-filter bank. Laboratory operating experience with the CAI has shown that ash collects in the secondary chamber and in the quench and absorber columns. Scrubber solutions also collect fly ash. It is currently not possible, however, to quantify the removal efficiencies of these systems.

3.2. Meteorological Input Data and Dispersion Modeling

Annual average integrated air concentrations were calculated with the AIRDOS-EPA model using the sector-averaged Gaussian-dispersion equation. The 3-year wind rose from TA-50 (Table 2) provided the meteorology data used in the calculations. The design stack height of 12 m (above ground) was used for the releases.

3.3. Dose Conversion Factors

The dose conversion factors used in this assessment for internal and external radiation exposure are listed in Table 3.

Inhalation and Ingestion. Dose conversion factors for internal exposure are taken from the USDOE (1988a) and are based on procedures and factors developed by the International Commission on Radiological Protection (ICRP 1979–1982). These factors (Table 3) give the 50-year dose commitment per unit intake of radioactivity (millirem per picocurie).

The 50-year dose commitment is the total dose that an individual would receive from the intake of a radionuclide (by either ingestion or inhalation) during the 50 years following that intake. Plutonium and americium are retained in the body for long periods of time. Using the dose commitment ensures that the radiation dose includes all of the contributions that could occur after the initial exposure.

The inhalation dose conversion factors are based on the Task Group Lung Model of the ICRP. The factors assume an activity median aerodynamic diameter (AMAD) of 1 μm.

A *Y*-lung solubility classification is used for plutonium and a *W*-lung solubility classification is used for americium. Radionuclide uptake fractions in the gastrointestinal tract are those used by the ICRP for these lung solubility classifications: 0.00001 for plutonium and 0.001 for americium.

Tritium is assumed to be present as tritiated water; ^{14}C, as carbon dioxide.

TABLE 2

TA-50 WIND ROSE 1985–1987

Stability A:

Direction	Wind Speed (m/s) 0.0–1.75	1.75–3.25	3.25–5.5	5.5–8.5	8.5–11.0	11.0+	Total
N	0.0012	0.0002	0.0000	0.0000	0.0000	0.0000	0.0015
NNE	0.0018	0.0006	0.0000	0.0000	0.0000	0.0000	0.0023
NE	0.0039	0.0016	0.0000	0.0000	0.0000	0.0000	0.0055
ENE	0.0051	0.0028	0.0000	0.0000	0.0000	0.0000	0.0078
E	0.0064	0.0032	0.0000	0.0000	0.0000	0.0000	0.0096
ESE	0.0055	0.0026	0.0000	0.0000	0.0000	0.0000	0.0082
SE	0.0052	0.0032	0.0000	0.0000	0.0000	0.0000	0.0084
SSE	0.0037	0.0021	0.0000	0.0000	0.0000	0.0000	0.0059
S	0.0024	0.0017	0.0000	0.0000	0.0000	0.0000	0.0041
SSW	0.0013	0.0011	0.0000	0.0000	0.0000	0.0000	0.0024
SW	0.0011	0.0005	0.0000	0.0000	0.0000	0.0000	0.0016
WSW	0.0010	0.0005	0.0000	0.0000	0.0000	0.0000	0.0015
W	0.0009	0.0005	0.0001	0.0000	0.0000	0.0000	0.0015
WNW	0.0005	0.0005	0.0000	0.0000	0.0000	0.0000	0.0011
NW	0.0005	0.0003	0.0000	0.0000	0.0000	0.0000	0.0008
NNW	0.0006	0.0003	0.0000	0.0000	0.0000	0.0000	0.0010
Total							0.0632

Stability B:

Direction	Wind Speed (m/s) 0.0–1.75	1.75–3.25	3.25–5.5	5.5–8.5	8.5–11.0	11.0+	Total
N	0.0004	0.0002	0.0000	0.0000	0.0000	0.0000	0.0006
NNE	0.0005	0.0005	0.0000	0.0000	0.0000	0.0000	0.0009
NE	0.0012	0.0015	0.0001	0.0000	0.0000	0.0000	0.0028
ENE	0.0013	0.0024	0.0001	0.0000	0.0000	0.0000	0.0038
E	0.0015	0.0029	0.0000	0.0000	0.0000	0.0000	0.0044
ESE	0.0014	0.0027	0.0000	0.0000	0.0000	0.0000	0.0041
SE	0.0013	0.0031	0.0001	0.0000	0.0000	0.0000	0.0045
SSE	0.0011	0.0022	0.0000	0.0000	0.0000	0.0000	0.0033
S	0.0007	0.0017	0.0001	0.0000	0.0000	0.0000	0.0025
SSW	0.0003	0.0008	0.0001	0.0000	0.0000	0.0000	0.0012
SW	0.0003	0.0006	0.0002	0.0000	0.0000	0.0000	0.0011
WSW	0.0002	0.0004	0.0003	0.0000	0.0000	0.0000	0.0010
W	0.0002	0.0004	0.0002	0.0000	0.0000	0.0000	0.0007
WNW	0.0001	0.0004	0.0001	0.0000	0.0000	0.0000	0.0006
NW	0.0001	0.0004	0.0001	0.0000	0.0000	0.0000	0.0006
NNW	0.0001	0.0002	0.0001	0.0000	0.0000	0.0000	0.0004
Total							0.0326

TABLE 2 (Cont)

Stability C:

Direction	Wind Speed (m/s) 0.0–1.75	1.75–3.25	3.25–5.5	5.5–8.5	8.5–11.0	11.0+	Total
N	0.0007	0.0008	0.0002	0.0000	0.0000	0.0000	0.0017
NNE	0.0011	0.0015	0.0009	0.0001	0.0000	0.0000	0.0036
NE	0.0018	0.0050	0.0013	0.0000	0.0000	0.0000	0.0081
ENE	0.0015	0.0049	0.0010	0.0000	0.0000	0.0000	0.0074
E	0.0018	0.0054	0.0007	0.0000	0.0000	0.0000	0.0078
ESE	0.0016	0.0043	0.0007	0.0000	0.0000	0.0000	0.0066
SE	0.0017	0.0063	0.0005	0.0000	0.0000	0.0000	0.0086
SSE	0.0013	0.0064	0.0010	0.0000	0.0000	0.0000	0.0087
S	0.0010	0.0049	0.0023	0.0000	0.0000	0.0000	0.0083
SSW	0.0007	0.0022	0.0025	0.0000	0.0000	0.0000	0.0054
SW	0.0006	0.0019	0.0025	0.0002	0.0000	0.0000	0.0052
WSW	0.0004	0.0012	0.0025	0.0004	0.0000	0.0000	0.0044
W	0.0003	0.0011	0.0029	0.0002	0.0000	0.0000	0.0046
WNW	0.0002	0.0007	0.0017	0.0001	0.0000	0.0000	0.0027
NW	0.0002	0.0006	0.0006	0.0000	0.0000	0.0000	0.0015
NNW	0.0004	0.0005	0.0002	0.0000	0.0000	0.0000	0.0010
Total							0.0855

Stability D:

Direction	Wind Speed (m/s) 0.0–1.75	1.75–3.25	3.25–5.5	5.5–8.5	8.5–11.0	11.0+	Total
N	0.0104	0.0087	0.0029	0.0003	0.0000	0.0000	0.0224
NNE	0.0072	0.0070	0.0032	0.0007	0.0000	0.0000	0.0181
NE	0.0067	0.0094	0.0044	0.0007	0.0000	0.0000	0.0212
ENE	0.0048	0.0046	0.0022	0.0000	0.0000	0.0000	0.0116
E	0.0052	0.0062	0.0019	0.0000	0.0000	0.0000	0.0133
ESE	0.0045	0.0059	0.0015	0.0001	0.0000	0.0000	0.0119
SE	0.0048	0.0067	0.0026	0.0002	0.0000	0.0000	0.0144
SSE	0.0048	0.0104	0.0093	0.0015	0.0000	0.0000	0.0261
S	0.0055	0.0151	0.0321	0.0116	0.0003	0.0001	0.0647
SSW	0.0050	0.0149	0.0303	0.0098	0.0004	0.0000	0.0603
SW	0.0068	0.0156	0.0236	0.0079	0.0004	0.0000	0.0544
WSW	0.0073	0.0102	0.0112	0.0074	0.0006	0.0001	0.0367
W	0.0079	0.0103	0.0112	0.0088	0.0017	0.0002	0.0401
WNW	0.0075	0.0100	0.0115	0.0101	0.0018	0.0005	0.0414
NW	0.0079	0.0073	0.0086	0.0047	0.0007	0.0003	0.0294
NNW	0.0080	0.0072	0.0026	0.0007	0.0000	0.0000	0.0185
Total							0.4845

TABLE 2 (Cont)

Stability E:

Direction	Wind Speed (m/s) 0.0–1.75	1.75–3.25	3.25–5.5	5.5–8.5	8.5–11.0	11.0+	Total
N	0.0053	0.0054	0.0005	0.0000	0.0000	0.0000	0.0111
NNE	0.0030	0.0020	0.0002	0.0000	0.0000	0.0000	0.0052
NE	0.0019	0.0013	0.0001	0.0000	0.0000	0.0000	0.0033
ENE	0.0009	0.0005	0.0000	0.0000	0.0000	0.0000	0.0014
E	0.0010	0.0007	0.0001	0.0000	0.0000	0.0000	0.0017
ESE	0.0009	0.0004	0.0001	0.0000	0.0000	0.0000	0.0014
SE	0.0009	0.0006	0.0002	0.0000	0.0000	0.0000	0.0017
SSE	0.0011	0.0013	0.0005	0.0000	0.0000	0.0000	0.0029
S	0.0015	0.0052	0.0035	0.0000	0.0000	0.0000	0.0102
SSW	0.0017	0.0079	0.0053	0.0000	0.0000	0.0000	0.0149
SW	0.0028	0.0106	0.0038	0.0000	0.0000	0.0000	0.0173
WSW	0.0034	0.0115	0.0044	0.0000	0.0000	0.0000	0.0194
W	0.0049	0.0139	0.0036	0.0000	0.0000	0.0000	0.0224
WNW	0.0044	0.0099	0.0076	0.0000	0.0000	0.0000	0.0219
NW	0.0052	0.0094	0.0033	0.0000	0.0000	0.0000	0.0180
NNW	0.0050	0.0088	0.0017	0.0000	0.0000	0.0000	0.0155
Total							0.1683

Stability F:

Direction	Wind Speed (m/s) 0.0–1.75	1.75–3.25	3.25–5.5	5.5–8.5	8.5–11.0	11.0+	Total
N	0.0051	0.0023	0.0000	0.0000	0.0000	0.0000	0.0075
NNE	0.0014	0.0004	0.0000	0.0000	0.0000	0.0000	0.0018
NE	0.0010	0.0003	0.0000	0.0000	0.0000	0.0000	0.0013
ENE	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0006
E	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006
ESE	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0006
SE	0.0007	0.0001	0.0000	0.0000	0.0000	0.0000	0.0008
SSE	0.0009	0.0004	0.0001	0.0000	0.0000	0.0000	0.0013
S	0.0015	0.0015	0.0003	0.0000	0.0000	0.0000	0.0032
SSW	0.0025	0.0024	0.0003	0.0000	0.0000	0.0000	0.0052
SW	0.0039	0.0043	0.0001	0.0000	0.0000	0.0000	0.0083
WSW	0.0064	0.0103	0.0003	0.0000	0.0000	0.0000	0.0170
W	0.0091	0.0184	0.0012	0.0000	0.0000	0.0000	0.0287
WNW	0.0081	0.0291	0.0121	0.0000	0.0000	0.0000	0.0493
NW	0.0094	0.0139	0.0019	0.0000	0.0000	0.0000	0.0252
NNW	0.0079	0.0063	0.0002	0.0000	0.0000	0.0000	0.0144
Total							0.1660

TABLE 3

DOSE CONVERSION FACTORS

Organ	Ingestion (mrem/pCi)	Inhalation (mrem/pCi)	Air Immersion ([mrem/yr]/[μCi/cm^3])	Ground Surface ([mrem/yr]/[μCi/cm^2])
Plutonium-238				
Effective dose equivalent	5.40×10^{-5}	3.00×10^{-1}	4.41×10^{5}	8.58×10^{2}
Red bone marrow	5.60×10^{-5}	2.40×10^{-1}	5.31×10^{4}	4.51×10^{1}
Lungs	8.42×10^{-7}	1.20	1.18×10^{5}	1.22×10^{2}
Bone surface	6.70×10^{-4}	3.10	2.09×10^{5}	2.05×10^{2}
Lower large intestine wall	2.10×10^{-4}	3.97×10^{-3}	7.77×10^{4}	7.22×10^{1}
Liver	1.50×10^{-4}	6.70×10^{-1}	7.16×10^{4}	2.63×10^{1}
Kidneys	8.42×10^{-7}	3.86×10^{-3}	8.04×10^{4}	2.67×10^{1}
Testes	8.50×10^{-6}	3.89×10^{-2}	4.23×10^{5}	7.55×10^{2}
Ovaries	8.50×10^{-6}	3.90×10^{-2}	7.77×10^{4}	6.96×10^{1}
Plutonium-239				
Effective dose equivalent	5.80×10^{-5}	3.30×10^{-1}	4.11×10^{5}	3.78×10^{2}
Red bone marrow	5.90×10^{-5}	2.80×10^{-1}	1.95×10^{5}	5.58×10^{1}
Lungs	9.45×10^{-7}	1.20	2.42×10^{5}	8.94×10^{1}
Bone surface	7.80×10^{-4}	3.50	4.01×10^{5}	1.47×10^{2}
Lower large intestine wall	2.00×10^{-4}	4.46×10^{-3}	2.03×10^{5}	6.53×10^{1}
Liver	1.60×10^{-4}	7.80×10^{-1}	2.05×10^{5}	4.85×10^{1}
Kidneys	9.45×10^{-7}	4.37×10^{-3}	2.08×10^{5}	4.84×10^{1}
Testes	9.60×10^{-6}	4.44×10^{-2}	4.34×10^{5}	3.46×10^{2}
Ovaries	9.60×10^{-6}	4.43×10^{-2}	1.84×10^{5}	6.00×10^{1}
Plutonium-240				
Effective dose equivalent	5.80×10^{-5}	3.30×10^{-1}	4.32×10^{5}	8.20×10^{2}
Red bone marrow	5.90×10^{-5}	2.80×10^{-1}	5.45×10^{4}	4.43×10^{1}
Lungs	9.45×10^{-7}	1.20	1.21×10^{5}	1.19×10^{2}
Bone surface	7.80×10^{-4}	3.50	2.15×10^{5}	2.00×10^{2}
Lower large intestine wall	2.00×10^{-4}	4.46×10^{-3}	7.98×10^{4}	7.07×10^{1}
Liver	1.60×10^{-4}	7.80×10^{-1}	7.59×10^{4}	2.77×10^{1}
Kidneys	9.45×10^{-7}	4.36×10^{-3}	8.62×10^{4}	2.86×10^{1}
Testes	9.60×10^{-6}	4.44×10^{-2}	4.19×10^{5}	7.24×10^{2}
Ovaries	9.60×10^{-6}	4.44×10^{-2}	8.02×10^{4}	6.84×10^{1}
Plutonium-241				
Effective dose equivalent	9.20×10^{-7}	5.70×10^{-3}	0.00	0.00
Red bone marrow	1.30×10^{-6}	6.30×10^{-3}	0.00	0.00
Lungs	1.95×10^{-8}	1.20×10^{-2}	0.00	0.00
Bone surface	1.60×10^{-5}	7.80×10^{-2}	0.00	0.00
Lower large intestine wall	1.00×10^{-6}	1.09×10^{-4}	0.00	0.00
Liver	3.20×10^{-6}	1.60×10^{-2}	0.00	0.00
Kidneys	1.95×10^{-8}	1.09×10^{-4}	0.00	0.00
Testes	2.10×10^{-7}	1.00×10^{-3}	0.00	0.00
Ovaries	2.10×10^{-7}	1.00×10^{-3}	0.00	0.00

TABLE 3 (Cont)

Organ	Ingestion (mrem/pCi)	Inhalation (mrem/pCi)	Air Immersion ([mrem/yr]/[μCi/cm³])	Ground Surface ([mrem/yr]/[μCi/cm²])
Americium-241				
Effective dose equivalent	4.50×10^{-3}	5.20×10^{-1}	9.50×10^{7}	2.99×10^{4}
Red bone marrow	6.30×10^{-3}	7.40×10^{-1}	3.74×10^{7}	1.08×10^{4}
Lungs	9.71×10^{-5}	8.05×10^{-2}	6.92×10^{7}	2.01×10^{4}
Bone surface	8.10×10^{-2}	9.30	1.27×10^{8}	3.69×10^{4}
Lower large intestine wall	3.12×10^{-4}	1.18×10^{-2}	5.03×10^{7}	1.45×10^{4}
Liver	1.70×10^{-2}	2.00	6.23×10^{7}	1.78×10^{4}
Kidneys	9.72×10^{-5}	1.18×10^{-2}	6.91×10^{7}	1.98×10^{4}
Testes	1.00×10^{-3}	1.20×10^{-1}	1.15×10^{8}	3.54×10^{4}
Ovaries	1.00×10^{-3}	1.20×10^{-1}	5.06×10^{7}	1.46×10^{4}
Hydrogen-3				
Effective dose equivalent	6.30×10^{-8}	9.50×10^{-8}	0.00	0.00
Red bone marrow	6.30×10^{-8}	9.50×10^{-8}	0.00	0.00
Lungs	6.30×10^{-8}	9.50×10^{-8}	0.00	0.00
Bone surface	6.30×10^{-8}	9.50×10^{-8}	0.00	0.00
Lower large intestine wall	6.30×10^{-8}	9.50×10^{-8}	0.00	0.00
Liver	6.30×10^{-8}	9.50×10^{-8}	0.00	0.00
Kidneys	6.30×10^{-8}	9.50×10^{-8}	0.00	0.00
Testes	6.30×10^{-8}	9.50×10^{-8}	0.00	0.00
Ovaries	6.30×10^{-8}	9.50×10^{-8}	0.00	0.00
Carbon-14				
Effective dose equivalent	2.10×10^{-6}	2.40×10^{-8}	0.00	0.00
Red bone marrow	2.10×10^{-6}	2.40×10^{-8}	0.00	0.00
Lungs	2.10×10^{-6}	2.40×10^{-8}	0.00	0.00
Bone surface	2.10×10^{-6}	2.40×10^{-8}	0.00	0.00
Lower large intestine wall	2.10×10^{-6}	2.40×10^{-8}	0.00	0.00
Liver	2.10×10^{-6}	2.40×10^{-8}	0.00	0.00
Kidneys	2.10×10^{-6}	2.40×10^{-8}	0.00	0.00
Testes	2.10×10^{-6}	2.40×10^{-8}	0.00	0.00
Ovaries	2.10×10^{-6}	2.40×10^{-8}	0.00	0.00

In some cases, dose conversion factors were not presented by the ICRP for some organs of interest because of the ICRP's "10% rule": dose factors are given only if the organ dose contributes more than 10% to the effective dose equivalent. Several dose factors not given by the ICRP were needed, however, to estimate health risks resulting from postulated releases. In these cases, dose conversion factors were taken from the set of dose factors calculated by the computer program RADRISK (Dunning 1980). This computer program follows ICRP methodology and produces dose factors very close to those used in ICRP Publication 30 (1979–1982). Dose conversion factors from RADRISK giving the 50-year dose commitment were used in all cases. RADRISK dose factors for plutonium were used for the gonads (inhalation only), lungs (ingestion only), and kidneys and breasts (both inhalation and ingestion).

For demonstrating compliance with 40 CFR Part 61, Subpart H, the U.S. Environmental Protection Agency (EPA) requires that dose conversion factors be calculated by RADRISK using 70-year dose commitments rather than the 50-year dose commitments used by the USDOE. To demonstrate compliance with this regulation, radiation doses from the CAI have been calculated with the RADRISK 70-year dose conversion factors, with approximately the same results as before. To avoid confusion with doses calculated with 50-year dose commitments, these 40 CFR Part 61 results are included in a separate part of this report (Sec. 4.2) and are labeled in the text where they occur.

External Exposure. Dose conversion factors used to estimate doses from cloud submersion and ground deposition are taken from the USDOE (1988b). The cloud submersion factors give the dose rate per unit of radionuclide concentration in air ([mrem/yr]/[μCi/cm^3]). Similarly, the ground deposition dose conversion factors give the dose rate per unit of radionuclide areal concentration on the ground ([mrem/yr]/[μCi/cm^2]).

Doses calculated with these factors assume no shielding from structures and 100% occupancy of the environmental receptor location. Both these assumptions are conservative in that they tend to increase the calculated dose.

3.4. Population Distribution

The population distribution for the area within 80 km of the CAI is given in Table 4. The 80-km region was divided into 9 annular areas and 16 compass directions to give 144 sectors. The 1980 census tract data were then used to estimate the population in each sector. The distribution was updated to 1987, using the growth rates for each county (as published by the U.S. Bureau of the Census [USBC 1987]) to calculate collective dose from 1987 Laboratory operations (ESG 1988). Calculations of collective doses from the CAI were performed for the year 2010 (chosen as a year toward the end of CAI operation). The collective dose calculations for the year 2010 used population projections to 2010 provided by the data bank maintained by University of New Mexico (UNM 1988).

TABLE 4

PROJECTED POPULATION DISTRIBUTION AROUND THE CONTROLLED-AIR INCINERATOR (FOR YEAR 2010)

	Distance from Controlled-Air Incinerator (km)								
	1–2	2–4	4–8	8–15	15–20	20–30	30–40	40–60	60–80
N	304	1 463	539	0	0	0	1 616	0	523
NNE	0	1 568	983	0	0	771	463	2 552	312
NE	0	222	597	805	0	21 499	1 437	1 553	5 212
ENE	0	0	0	0	2 271	5 404	3 622	1 690	2 745
E	0	0	0	97	29	1 992	815	0	1 692
ESE	0	0	0	6 070	0	342	27 1031	450	2 007
SE	0	0	0	932	0	0	62 657	2 860	9
SSE	0	0	0	50	0	0	498	5 089	111
S	0	0	0	20	0	487	939	10 165	0
SSW	0	0	0	0	0	1 249	307	12 593	51 190
SW	0	0	0	0	0	0	481	6 355	0
WSW	0	0	0	0	0	481	478	3 890	316
W	0	0	0	0	0	0	0	250	202
WNW	0	0	0	0	0	0	0	0	4 710
NW	0	931	0	0	0	0	0	2 047	0
NNW	0	2 385	2 508	0	0	0	0	91	89

3.5. Agricultural Profile

Distributions of beef cattle, milk cows, and area under cultivation for the region within 80 km of the Laboratory are shown in Tables 5, 6, and 7. This information is based on agricultural statistics jointly published by the U.S. Department of Agriculture and the New Mexico Department of Agriculture (USDA/NMDA 1987).

The same 144 sectors were used for the agricultural data as for the population distribution. To estimate the cattle distributions, first the area of a county lying in each sector was determined. This area was then multiplied by the number of cattle in the county and divided by the county area to give the total number of cattle in the sector. This procedure was followed for both beef cattle and milk cows.

TABLE 5

NUMBER OF BEEF CATTLE IN EACH SECTOR

	Distance from Controlled-Air Incinerator (km)								
	1–2	2–4	4–8	8–15	15–20	20–30	30–40	40–50	60–80
N	0	0	0	31	76	217	304	869	1217
NNE	0	0	0	31	76	217	304	821	1082
NE	0	0	0	93	76	217	304	773	1217
ENE	0	0	0	155	135	435	541	1063	473
E	0	0	0	155	169	435	541	1836	1217
ESE	0	0	0	54	169	483	608	1932	1149
SE	0	0	0	35	169	483	676	1932	2570
SSE	0	0	0	30	152	483	676	1932	2705
S	0	0	0	0	34	169	304	966	2164
SSW	0	0	0	47	51	145	203	580	1217
SW	0	0	0	39	51	145	203	580	811
WSW	0	0	0	31	51	145	203	580	811
W	0	0	0	39	51	145	203	580	811
WNW	0	0	0	39	51	145	236	464	811
NW	0	0	0	23	51	193	304	695	1217
NNW	0	0	0	31	68	217	304	869	1217

TABLE 6

NUMBER OF MILK COWS IN EACH SECTOR

	Distance from Controlled-Air Incinerator (km)								
	1–2	2–4	4–8	8–15	15–20	20–30	30–40	40–50	60–80
N	0	0	0	3	0	1	1	3	4
NNE	0	0	0	1	0	1	1	4	7
NE	0	0	0	0	0	1	1	3	4
ENE	0	0	0	1	1	2	2	4	8
E	0	0	0	1	1	2	3	6	4
ESE	0	0	[illegible]	1	1	2	3	7	3
SE	0	0	0	3	1	2	3	8	8
SSE	0	0	0	3	1	2	3	8	11
S	0	0	0	1	1	2	2	7	230
SSW	0	0	0	1	1	2	2	7	130
SW	0	0	0	1	1	2	2	7	9
WSW	0	0	0	0	1	2	2	7	9
W	0	0	0	1	1	2	2	7	9
WNW	0	0	0	0	1	2	2	5	9
NW	0	0	0	0	1	1	1	3	4
NNW	0	0	0	0	0	1	1	3	4

The area under cultivation was determined by calculating the total area in each sector and then excluding urban, national monument, national forest, and wilderness areas; state and federal land; and bodies of water. The remaining area was assumed to be under cultivation.

These procedures tended to be conservative in that they are believed to overestimate the present agricultural activity in the 80-km area surrounding the Laboratory. This would increase the estimate of the radiation dose because more food products would be considered by AIRDOS-EPA to be affected by Laboratory activities.

3.6. Other Input Data Used in the Dose Calculations

A listing of the input data used in running AIRDOS-EPA is given in Table 8.

TABLE 7

AREA OF CULTIVATED LAND (m^2) IN EACH SECTOR

	Distance from Controlled-Air Incinerator (km)								
	1–2	2–4	8–8	8–15	15–20	20–30	30–40	40–60	60–80
N	0	0	0	2.1×10^7	1.2×10^7	2.0×10^7	5.5×10^7	7.9×10^7	5.5×10^7
NNE	0	0	0	1.1×10^7	2.4×10^7	9.8×10^6	4.1×10^7	5.9×10^7	0
NE	0	0	0	2.2×10^6	2.7×10^7	4.9×10^7	6.9×10^7	9.8×10^7	1.1×10^8
ENE	0	0	0	1.3×10^7	2.6×10^7	7.9×10^7	1.4×10^7	7.9×10^7	5.5×10^7
E	0	0	0	1.9×10^7	1.7×10^7	5.9×10^7	8.9×10^7	0	0
ESE	0	0	0	0	0	2.0×10^7	5.5×10^7	3.9×10^7	8.2×10^7
SE	0	0	0	0	0	9.8×10^6	2.7×10^7	5.9×10^7	1.1×10^8
SSE	0	0	0	0	0	0	1.4×10^7	5.9×10^7	5.5×10^7
S	0	0	0	0	1.7×10^7	3.9×10^7	8.2×10^7	1.4×10^8	5.5×10^7
SSW	0	0	0	0	0	3.9×10^7	1.1×10^8	3.1×10^8	2.2×10^8
SW	0	0	0	0	0	2.0×10^7	6.9×10^7	3.3×10^8	8.2×10^7
WSW	0	0	0	0	0	0	0	2.4×10^8	8.2×10^7
W	0	0	0	0	0	0	0	7.9×10^7	5.5×10^7
WNW	0	0	0	0	0	0	0	0	1.6×10^8
NW	0	0	0	0	0	0	0	0	4.4×10^7
NNW	0	0	0	2.1×10^7	1.0×10^7	0	6.9×10^6	1.6×10^8	1.1×10^8

TABLE 8

INPUT VALUES FOR RADIONUCLIDE-INDEPENDENT VARIABLES

Number of nuclides considered	7
Time delay for ingestion of	
pasture grass by animals (hr)	0
stored feed by animals (hr)	0.216×10^4
leafy vegetables by man (hr)	0.336×10^3
produce by man (hr)	0.336×10^3
Removal rate constant for physical loss by weathering (per hr)	0.29×10^{-2}
Period of exposure during growing season to	
pasture grass (hr)	0.72×10^3
crops or leafy vegetables (hr)	0.144×10^4
Agricultural productivity by unit area for	
grass-cow-milk-man pathway (kg/m^2)	0.28
produce or leafy vegetables ingested by man (kg/m^2)	0.716
Fraction of year animals graze on pasture	0.4
Fraction of daily feed that is pasture grass when animal grazes on pasture	0.43
Consumption rate of contaminated feed or forage by an animal (kg/day, dry weight)	0.156×10^2
Transport time from animal feed–milk–man (day)	2
Rate of ingestion of	
produce by man (kg/yr)	0.1760×10^3
milk by man (liters/yr)	0.1120×10^3
meat by man (kg/yr)	0.8500×10^2
leafy vegetables by man (kg/yr)	0.1800×10^2
Average time from slaughter of meat animal to consumption (day)	0.2000×10^2
Fraction of produce ingested (grown in garden of interest)	1
Fraction of leafy vegetables ingested (grown in garden of interest)	1
Period of long-term buildup for radioactivity in soil (yr)	0.1000×10^3
Effective surface density of soil (kg/m^2, dry weight) (assumes 15-cm plow layer)	0.2150×10^3
Ingestion ratio (immediate surrounding area/total within area)	
vegetable	0.7143
meat	0
milk	0

Minimum Fraction of Food Types from Outside Area Listed Below (Actual Fixed Values)

Minimum fraction of foods ingested from outside area	
vegetables	0.65
meat	0.9
milk	0.9
Inhalation rate of man (cm^3/hr)	0.9167×10^6
Buildup time for radionuclides deposited on ground and in water (day)	0.3652×10^5
Dilution factor, water for swimming (cm)	1
Fraction of time spent swimming	0
Muscle mass of animal at slaughter (kg)	0.2000×10^3
Fraction of animal herd slaughtered (per day)	0.3800×10^{-2}
Milk production of cow (liters/day)	0.1100×10^2
Fallout interception,	
fraction for vegetables	0.2
fraction for pasture	0.57
Fraction of radioactivity retained on leafy vegetables and produce after washing	0.5

4.0. RESULTS OF THE DOSE CALCULATIONS

4.1. Calculation of Doses Used in the Environmental Assessment

Maximum Individual Dose. Maximum individual doses from routine emissions were calculated at six receptor locations in the area surrounding the Laboratory. These are representative of where permanent residences are located, and include the communities of White Rock and Los Alamos, as well as individual residences where maximum doses are expected. The receptor locations are shown in Fig. 1.

These locations are at the following distances and directions from the CAI:

	Direction	Distance (m)
Royal Crest Trailer Park	N	1200
Los Alamos	NNE	1800
East Gate	ENE	4420
White Rock	ESE	8500
Pajarito Acres	SE	9150
Bandelier	SSE	7620

The results of the calculations are given in Table 9. The highest annual effective dose equivalent (50-year dose commitment) from routine operations at the CAI is calculated to be 3.6×10^{-4} mrem at the Royal Crest Trailer Park. As discussed earlier, this dose is from all pathways and is less than 0.1% of the USDOE's Radiation Protection Standard of 100 mrem/yr for doses to the public from all pathways.

The maximum individual effective dose equivalent from all pathways from current Laboratory operations was 6.1 mrem in 1987, or 6.1% of the USDOE's Radiation Protection Standard (ESG 1988). This dose occurred at East Gate. The projected additional contribution of 7.3×10^{-5} mrem (50-year dose commitment) to the effective dose equivalent at East Gate from CAI operations (see Table 9) would not significantly increase the current dose.

Collective Dose. The collective effective dose equivalent was estimated for the area within 80 km of the CAI. This dose was estimated to be 0.0015 person-rem (50-year dose commitment). The CAI collective dose is much less than 0.1% of the 61 000 person-rem that is estimated to occur to the same population from natural background radiation. This dose would not add significantly to the 3.5 person-rem collective effective dose equivalent from 1987 Laboratory operations (ESG 1988).

4.2. Calculation of Doses for Comparison with 40 CFR Part 61 Limits

For demonstrating compliance with the radiation dose limit set in 40 CFR Part 61, Subpart H, under the National Emission Standards for Hazardous Air Pollutants program, the EPA requires that doses from airborne emissions be calculated with the computer codes

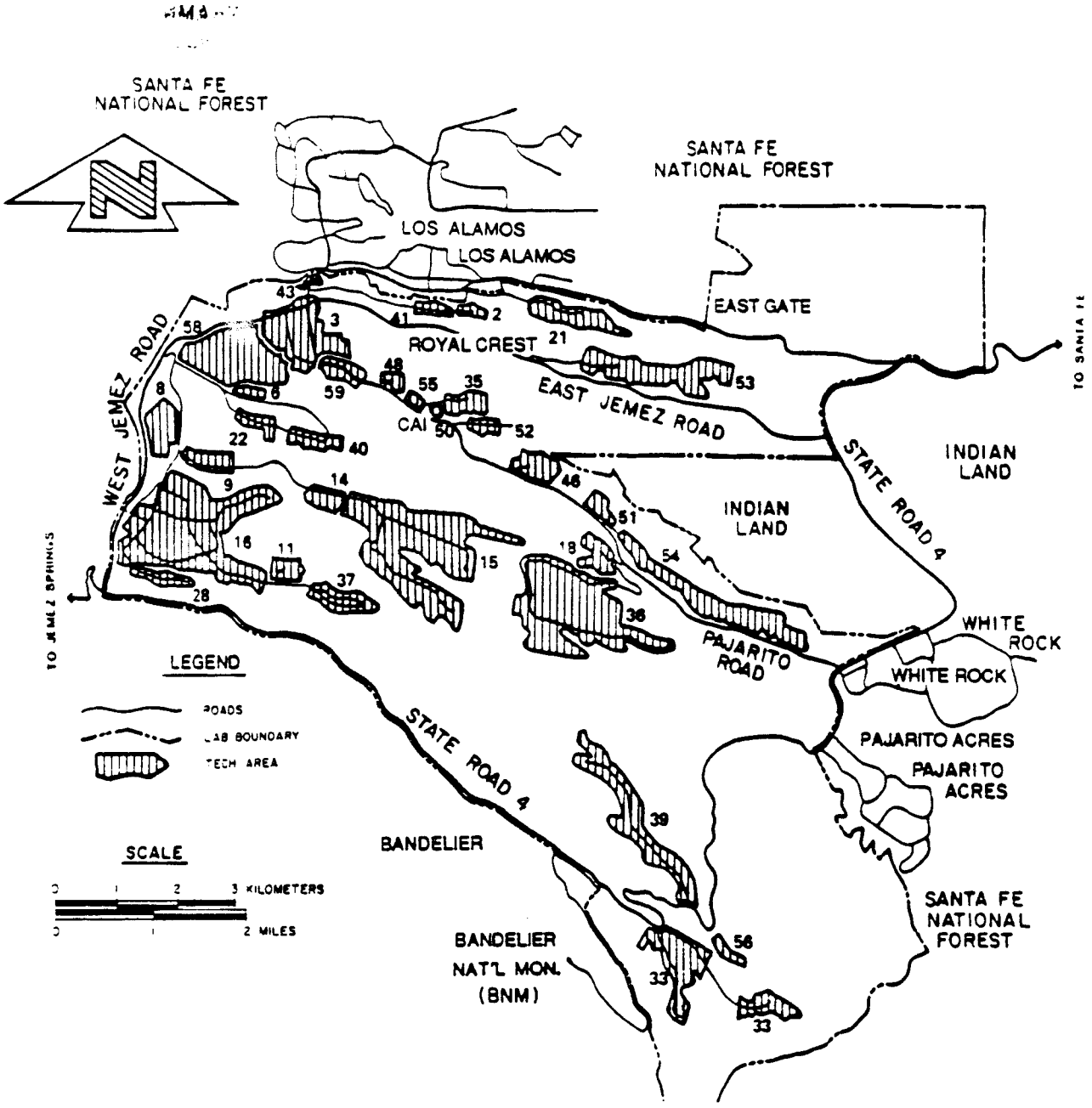

Figure 1.
Receptor locations used for routine releases.

TABLE 9

SUMMARY OF CALCULATED 50-YEAR DOSE COMMITMENTS, CURRENT AND PROPOSED LABORARY OPERATIONS

Doses from the Proposed Controlled-Air Incinerator

Receptor Location	Effective Dose Equivalent (mrem/yr)	Lung (mrem/yr)	Bone Surface (mrem/yr)	Liver (mrem/yr)	Gonads (mrem/yr)
Royal Crest	3.6×10^{-4}	4.0×10^{-4}	5.0×10^{-4}	3.8×10^{-4}	3.5×10^{-4}
Los Alamos	1.9×10^{-4}	2.0×10^{-4}	2.6×10^{-4}	2.0×10^{-4}	1.8×10^{-4}
East Gate	7.3×10^{-5}	8.0×10^{-5}	1.0×10^{-4}	7.7×10^{-5}	7.1×10^{-5}
White Rock	5.5×10^{-5}	6.0×10^{-5}	7.6×10^{-5}	5.8×10^{-5}	5.4×10^{-5}
Pajarito Acres	4.1×10^{-5}	4.4×10^{-5}	5.5×10^{-5}	4.3×10^{-5}	3.6×10^{-5}
Bandelier	3.7×10^{-5}	4.0×10^{-5}	5.0×10^{-5}	3.9×10^{-5}	3.6×10^{-5}

Radiation Protection Standard	100 mrem/yr (above natural background)
Natural background	327 mrem/yr

Doses from 1987 Laboratory Operations

Receptor Location	Effective Dose Equivalent (mrem/yr)	Lung (mrem/yr)	Bone Surface (mrem/yr)	Liver (mrem/yr)	Gonads (mrem/yr)
Royal Crest	0.10	0.13	0.11	0.09	0.13
Los Alamos	0.33	0.39	0.35	0.28	0.22
East Gate	6.1	5.7	6.7	5.3	6.4
White Rock	0.17	0.20	0.18	0.15	0.18
Pajarito Acres	0.12	0.14	0.13	0.10	0.12
Bandelier	0.07	0.08	0.07	0.06	0.07

Collective Dose and Associated Health Risk from the Controlled-Air Incinerator and Current Laboratory Operations

	Collective Effective Dose Equivalent	Incremental Risk of Cancer/yr	Incremental Risk of Genetic Disorder/yr
Controlled-Air Incinerator	0.0015	$(9–27) \times 10^{-13}$	5×10^{-13}
1987 Laboratory operations	3.5	$(3–9) \times 10^{-9}$	4×10^{-9}
Natural background	61 000	$(5–9) \times 10^{-5}$	4×10^{-5}

AIRDOS-EPA and RADRISK (USEPA 1985). The dose conversion factors generated by RADRISK to show compliance are normally 70-year dose commitments rather than the 50-year dose commitments used above.

Radiation Doses for 1987 Laboratory Operations. Regulation 40 CFR Part 61 requires that the radiation dose to a member of the public from airborne emissions from all USDOE operations be limited to 25 mrem/yr to the whole body and 75 mrem/yr to any organ (USEPA 1985). The maximum whole-body dose and organ dose that would occur to the public from all operations at Los Alamos during 1987 were 11 mrem to the whole body and 13 mrem to the lung, as calculated by AIRDOS-EPA/RADRISK using 70-year dose commitments. These doses are 44% and 17%, respectively, of the 40 CFR Part 61 radiation limits. The results of the AIRDOS-EPA/RADRISK calculations are given in Table 10 for the Royal Crest

TABLE 10

SUMMARY OF CALCULATED 70-YEAR DOSE COMMITMENTS, CURRENT AND PROPOSED LABORATORY OPERATIONS, FOR COMPARISON WITH 40 CFR PART 61

	Whole Body (mrem/yr)	Lung (mrem/yr)	Bone Surface (mrem/yr)	Liver (mrem/yr)	Gonads (mrem/yr)
Doses at Royal Crest Trailer Park					
Controlled-Air Incinerator	3.2×10^{-4}	2.0×10^{-4}	1.4×10^{-3}	2.5×10^{-4}	1.3×10^{-4}
Other proposed facilities	5.4×10^{-3}	3.5×10^{-1}	1.8×10^{-2}	3.2×10^{-3}	3.9×10^{-4}
1987 Laboratory operations	0.12	0.39	0.13	0.11	0.12
Total	0.13	0.74	0.15	0.11	0.12
EPA Radiation Limit	25	75	75	75	75
Percentage of EPA Radiation Limit	0.5%	1%	0.2%	0.1%	0.2%
Doses at East Gate					
Controlled-Air Incinerator	6.5×10^{-5}	4.0×10^{-5}	2.8×10^{-4}	5.0×10^{-5}	3.0×10^{-5}
Other proposed facilities	6.9×10^{-3}	6.6×10^{-1}	8.0×10^{-3}	1.2×10^{-3}	4.4×10^{-4}
1987 Laboratory operations	11	13	12	9.5	11
Total	11	14	12	9.5	11
EPA Radiation Limit	25	75	75	75	75
Percentage of EPA Radiation Limit	44%	19%	16%	13%	15%

Trailer Park, the off-site residences where the maximum doses to the public would occur from routine CAI operation, and East Gate, the location where the maximum doses to the public occur from all Laboratory emissions.

The doses for all 1987 Laboratory operations that have been calculated using AIRDOS-EPA/RADRISK (Table 10) differ slightly, but not significantly, from those given earlier in Sec. 4.1 (see Table 9). The principal reason for this difference is not in using 70-year dose commitments instead of 50-year dose commitments but because most of the dose was due to short-lived air-activation products from the Los Alamos Meson Physics Facility. For these radionuclides, there is no difference between the 50- and 70-year dose commitments, and indeed the dose is dominated by cloud submersion rather than inhalation.

The principal reason for the difference in these doses is in the way the dose was estimated. The maximum individual dose at East Gate in Sec. 4.1 was estimated using field measurements of external radiation and radionuclide air concentrations instead of being modeled by AIRDOS-EPA from emission rates and meteorological data. This allowed a more realistic determination of dose based on field data. The programs AIRDOS-EPA/RADRISK overestimate the dose at Los Alamos. This may be partially due to the complex terrain present at Los Alamos, which causes more atmospheric mixing of airborne emissions and consequently reduced air concentrations. These complex terrain features are not taken into account in AIRDOS-EPA.

Radiation Doses from the CAI. To evaluate the effects of CAI operations under 40 CFR Part 61, a separate evaluation of the CAI's emissions was performed using the methods (principally, the 70-year dose commitment) specified by the EPA. The results of this evaluation showed that the resulting doses were small, in agreement with the previous analysis. No significant impact would occur to the maximum-exposed individual from operations at the CAI.

As seen in Table 10, the additional contribution to the total dose from emissions from the CAI is insignificant. At East Gate, estimated CAI doses of 6.5×10^{-5} mrem to the whole body, 4.0×10^{-5} mrem to the lung, and 2.8×10^{-4} mrem to the bone surface would be negligible (<0.1%) when added to the 1987 doses, estimated by AIRDOS-EPA/RADRISK to be 11 mrem, 13 mrem, and 12 mrem, respectively. The expected dose from all Laboratory operations would still be well within the 40 CFR Part 61 radiation limits.

The doses calculated by AIRDOS-EPA/RADRISK at the Royal Crest Trailer Park would be insignificantly changed. The total predicted annual doses to the whole body, lung, and bone surface, from both 1987 Laboratory and projected CAI emissions, would be 3.2×10^{-4} mrem, 2.0×10^{-4} mrem, and 1.4×10^{-3} mrem, respectively. These doses are all less than 1% of their corresponding limits under 40 CFR Part 61.

5.0. ESTIMATES OF HEALTH RISKS FROM IONIZING RADIATION

Potential health risks caused by radiological impacts from CAI operations were estimated using the calculated doses together with risk factors taken from two reports of the Committee on the Biological Effects of Ionizing Radiations (the BEIR Committee) of the National Academy of Sciences/National Research Council (BEIR III 1980, BEIR IV 1988). The evaluation considered the lifetime risk of cancer mortality and genetic disorders.

In calculating risk estimates, it is noted that the small amount of epidemiological data that is available causes the risk estimates to have large uncertainties. The BEIR IV Committee "cautions that the risk estimates derived from epidemiological and experimental animal data should not be considered precise. They are derived from analyses of incomplete data and involve numerous uncertainties" (BEIR IV 1988). Indeed, at the low doses and dose rates to the public that have been estimated for CAI routine operations, no health effects have been observed. Health-effects estimates are based on a linear extrapolation from the high-dose region to this low-dose region. However, health-effects estimates are made in this assessment in order to provide perspective on the radiation doses that have been calculated.

The radiation doses from the plutonium and americium isotopes released from routine operations of the CAI are dominated by high linear-energy-transfer (LET) alpha radiation. The associated health risks were evaluated using the BEIR IV report, which dealt specifically with alpha radiation. In contrast to these radionuclides, tritium and ^{14}C emit low-LET radiation. Health risks from these radionuclides were evaluated using risk factors principally taken from the BEIR III report. The risk factors that were used in estimating the health impacts are given in Table 11.

5.1. Health Risk Factors for Cancer

High-LET Radiation. Following BEIR IV, health risk factors for cancer induced by exposure to plutonium/americium are presented for lung, bone, and liver, but not for other organs. The BEIR Committee stated that the "validity of such risk estimates (to other organs) for transuranic exposures is highly uncertain" (BEIR IV 1988, p. 336). The cancer risk factors are taken directly from the BEIR IV report (BEIR IV, p. 337 for lung and liver, p. 334 for bone). All risk factors were converted from absorbed dose to dose equivalent using a quality factor of 20. The risk factor for bone was converted from risk per average skeletal dose, as given in BEIR IV, to risk per bone surface dose.

Low-LET Radiation. The risk factors for cancer resulting from exposure to low-LET radiation are principally based on those from the BEIR III report. The leukemia risk factor was conservatively based on the linear dose/response model. The risk factor for breast cancer was calculated using the BEIR III risk rate factor for breast cancer, adjusting for competing causes of death through a life table procedure and averaging over all ages.

The lung cancer risk factor was based on BEIR IV, which lowered its estimate of lung cancer from that derived in BEIR III (BEIR IV 1988, p. 8). Because the BEIR III lung cancer

TABLE 11

RISK FACTORS USED TO EVALUATE HEALTH RISKS FROM RADIATION EXPOSURE

Low-LET Radiation

Health Impact	Risk Factor for Low-LET Radiation (per 10^6 person-rem)
Cancer type	
Breast	36
Leukemia	55
Bone	1.4 (for bone surface dose)
Lung	35
Thyroid	1
Liver	15
Total cancers (whole-body radiation)	170–500
Genetic disorder	225[a] (gamete dose)

High-LET Radiation

Health Impact	Risk Factor for High-LET Radiation (per 10^6 person-rem)
Cancer type	
Bone	1.4 (for bone surface dose)
Lung	35
Liver	15
Genetic disorder	600[a] (gamete dose)

[a]Genetic risk factor is in units of risk (per 10^6 person-rem), dose to gametes.

risk estimate for low-LET radiation was based primarily on high-LET radiation (that is, exposure of uranium miners to radon-decay products), this BEIR III risk estimate was revised to agree with the BEIR IV recommendations.

The risk factors for bone and liver cancer are taken directly from the BEIR III report. For the risk of thyroid cancer from low-LET radiation, BEIR III gives the risk of cancer incidence (instead of cancer mortality) to be 4×10^{-6}/rad. If an average incidence/mortality ratio for thyroid cancer of 0.19 is used (BEIR III 1980, p. 220), the risk factor for thyroid cancer mortality becomes 1×10^{-6}/rad.

5.2. Health Risk Factors for Genetic Disorders

Risk factors for high-LET radiation were taken from Table 8-1 of BEIR IV (BEIR IV 1988, p. 379), and factors for low-LET radiation were taken from Table IV-2 of BEIR III (BEIR III 1980, p. 85). Following BEIR IV, a single projection of the genetic risk was obtained from the geometric mean of the risk-range estimates. The BEIR risk estimates, which are given in terms of dose to gametes, were changed to gonadal dose using tables published by the U.S. National Center for Health Statistics (USNCHS 1982) that give the average number of children that an individual is expected to have after a given age. This risk factor for gonadal dose is directly applicable to the collective 50-year gonadal dose commitment calculated by AIRDOS-EPA.

5.3. Health Risks

Health risks from the proposed facility and natural background radiation are summarized in Table 9. Both the average risk of cancer mortality and the risk of genetic disorder to the population living within 80 km of the Laboratory resulting from CAI routine operations are considerably less than 10^{-6}/yr. All risks from these CAI emissions are much less than 1% of the cancer and genetic-disorder risk from natural background radiation.

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