

RADIOLOGICAL ASSESSMENT OF THE POPULATED
AREAS SOUTHWEST OF THE HOMESTAKE MINING
COMPANY URANIUM MILL

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A.0 Introduction

This appendix presents an analysis of the radiological impacts from the Homestake Mining Company's uranium mill on the environment and population within 80 km (50 miles) of the facility. The analysis was based on estimated annual releases of radionuclides, computer modeling using NRC's MILDOS computer program and environmental monitoring data collected by the NMEID. MILDOS models the dispersion of radioactive effluents and calculates the resulting environmental concentrations and the doses received by individuals at specified receptor locations. The input parameters are described in Section A.5. For a complete discussion of the model, refer to the MILDOS manual (1).

The meteorological data used in this assessment was collected at the Anaconda uranium mill (5 miles west of Homestake) by Argonne National Laboratory (4). This data was organized into a joint frequency distribution of wind speed versus direction for each of the Pasquill stability classes (A-F). The Surveillance and Assessment Section currently is operating a weather station at Homestake, but not enough data for an annual average has been collected.

A.1 Sources of Radioactivity and Exposure Pathways

The most significant source of radioactivity in the Grants Mineral Belt (GMB) is naturally occurring background radiation. Table A.17 shows the average annual dose equivalent that a person in the GMB receives from background radiation (13). Diagnostic medical and dental procedures are other sources of radiation to which members of the public are regularly exposed. The combined mean annual bone marrow dose to an adult from these procedures is about 100 mrem (7). The average adult in the GMB, therefore, receives a total annual dose equivalent to bone of about 217 mrem.

There are several sources of radioactive emissions from the milling process.

- (1) The yellowcake drying and packaging stacks are considered to be a single source. U-nat is the major radionuclide released, although others are released to a lesser extent.
- (2) Dumping the ore onto the ore pad is a source of particulate release to the atmosphere.
- (3) The ore pad is a source of both radon and particulates.
- (4) Dumping the ore into the grizzly is a source of particulates.

- (5) Conveying and crushing ore releases radon and particulates to the atmosphere.
- (6) The ore dryer is a minor source of particulate release.
- (7) Tailings are a source of both radon and particulates. There are two tailings piles, the currently used main tailings and the smaller inactive Sapien pile.

Only the U-238 decay chain is considered in this analysis. From soil and air particulate data collected by the NMEID, it is evident that the U-235 and Th-232 chains are much less abundant in the GMB and hence are not a significant source. The pathways of dose to man are shown in Figure A.1 and are listed below:

- (1) Inhalation of radioactive particulates, radon and radon daughters.
- (2) Direct gamma exposure from radionuclides deposited on the ground and airborne radionuclides.
- (3) Ingestion of contaminated water.
- (4) Ingestion of contaminated fruit and vegetables.
- (5) Ingestion of contaminated livestock tissues.

A.2 Environmental Concentrations of Released Radionuclides

Radionuclide concentrations were calculated at 17 locations. These locations are shown in Figure A.2. The calculated concentrations are compared to actual data collected by the RPB in Tables A.1 and A.2. Comparisons are made during the 1978-1980 timestep. Note that predicted MILDOS values do not include natural background, whereas actual data is a combination of mill releases and background. The further away from the mill the receptor is, the higher the percentage of concentration due to natural background or other sources. For instance, background and/or other sources dominate the concentration at Milan.

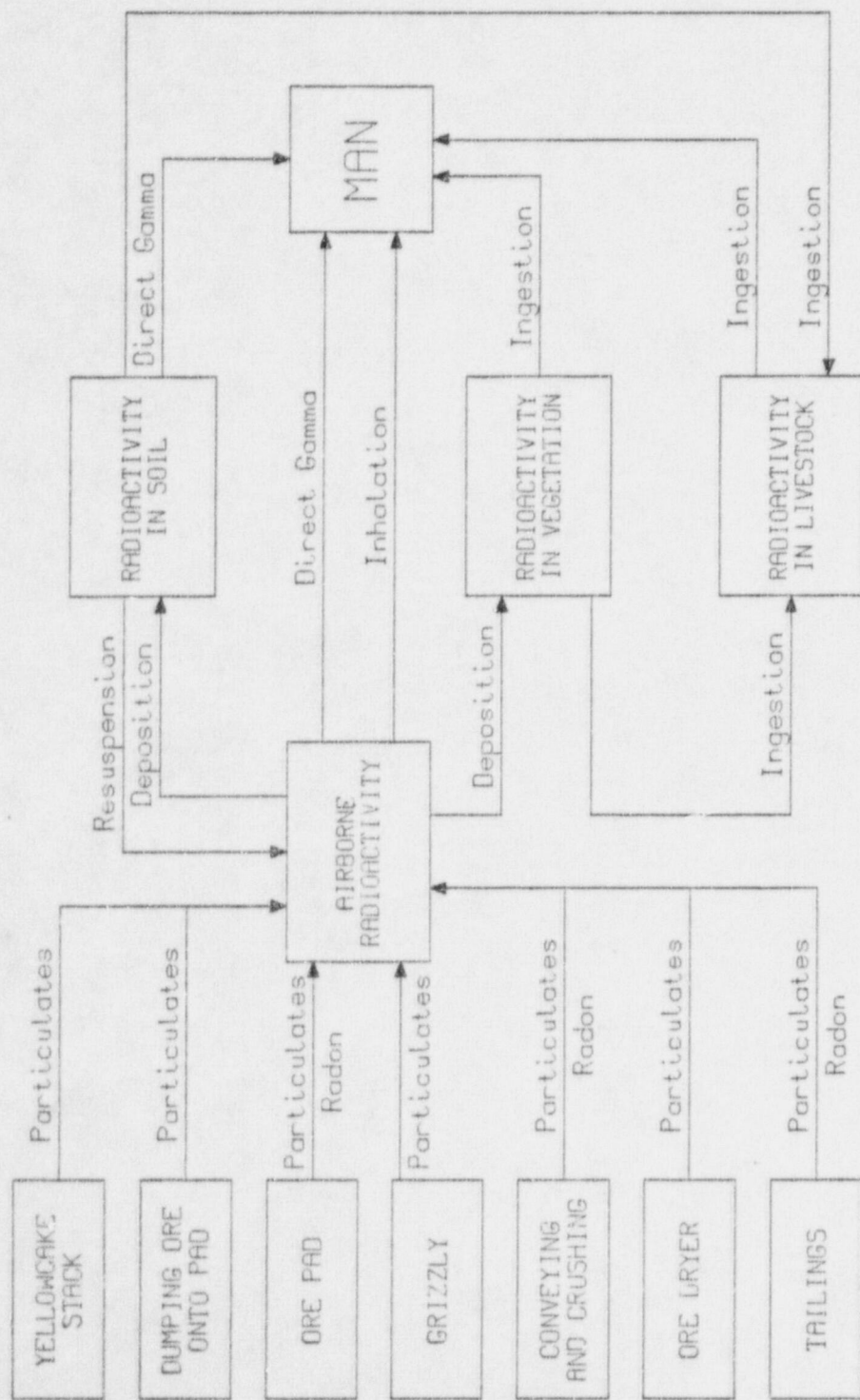
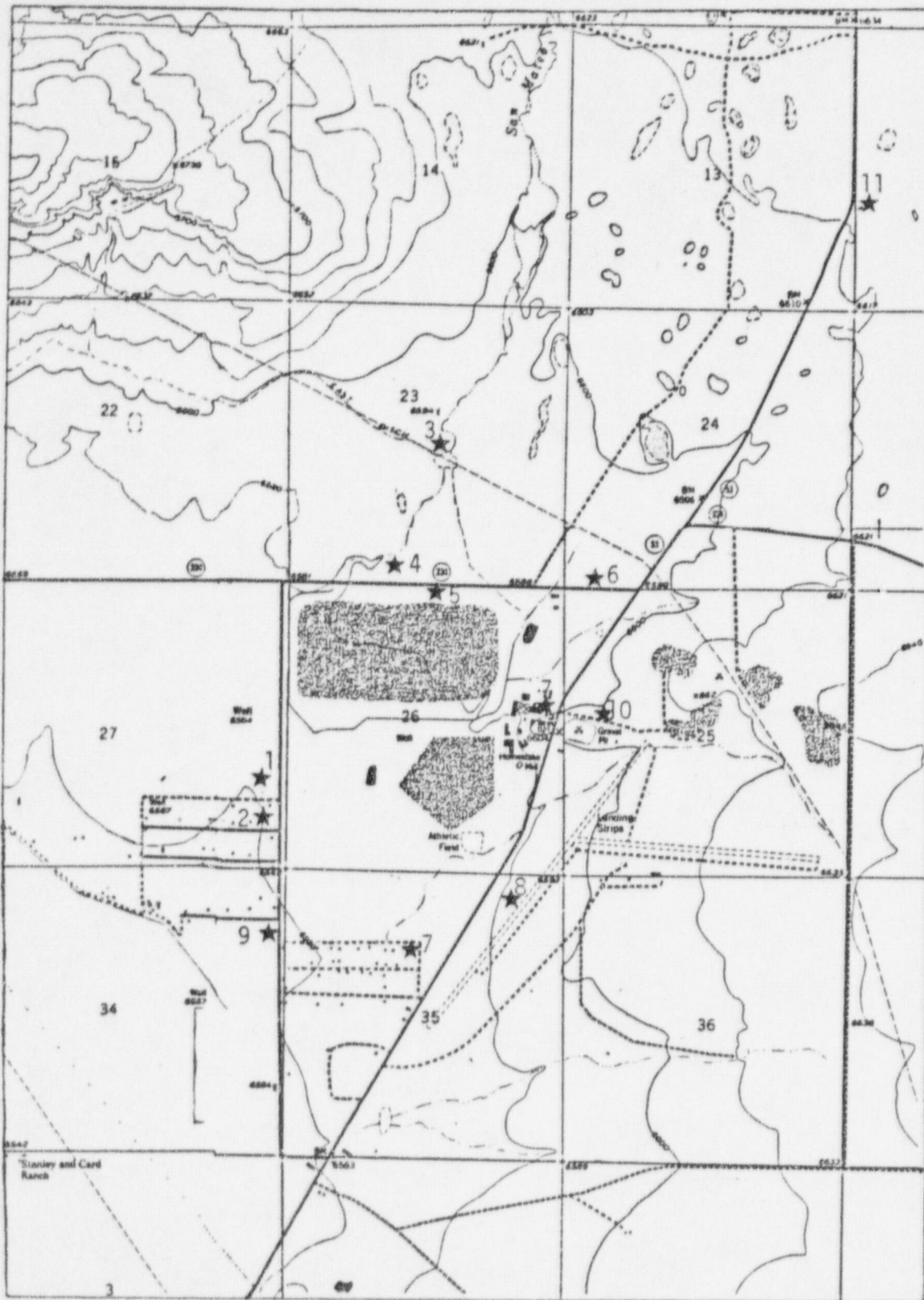


Figure A.1 Exposure Pathways to Man



Figures A.2 MILDOS Receptor Locations - ★ (Locations not shown)

- 12 - Lobo Canyon
- 13 - Milan
- 14 - Grants
- 15 - North Milan
- 16 - Junctions 53-509

Table A.1 Predicted MILDOS vs. Measured^a Air Particulate Concentrations (fCi/m³)

Radionuclide	Receptor Location			
	2	4	10	13
U-Nat ^b	6.7 (22.1)	17.7 (15.4)	193 (25.8)	0.49 (16.6)
Th-230	0.37 (0.90)	3.3 (22.5)	30.9 (29.1)	0.02 (0.44)
Ra-226	0.31 (0.69)	3.1 (11.4)	29.2 (17.5)	0.02 (0.36)

(a) Measured air concentrations are shown in parentheses.

(b) MILDOS calculates only U-238 air concentrations. Therefore, equilibrium was assumed between U-238 and U-234 so that U-Nat equals twice U-238 values.

Table A.2 Predicted vs. Measured Radon Concentrations (pCi/l)

Location (Receptor #)	Predicted	Measured	
		(4/78-3/79)	(4/79-3/80)
2	0.23	1.55	1.41
3	0.30	1.32	0.89
4	0.48	1.92	1.51
5	0.61	2.01	1.89
6	0.89	1.55	1.12
7	0.28	1.18	0.93
8	0.75	1.10	0.84
13	0.02	0.44	0.71
14	0.03	0.36	0.61
16	0.02	1.50	1.69

The general trend for particulates is that upwind stations are somewhat underestimated while downwind stations are overestimated. This may indicate that local wind patterns are not accurately described for the HMC facility by the meteorological data taken at Anaconda. If a background level of 0.2 pCi/l is added to the radon concentrations, downwind estimates are closer to measured values, although upwind sites are still underestimated.

A.3 Dose Commitments to Individuals and Populations

Annual dose commitments were calculated at seventeen locations. However, only ten of these have members of the public living nearby. Table A.3 shows the calculated annual dose commitments at these ten locations. These doses were calculated when the ore thruput was a maximum (2000 tons per day). It was also assumed that 100 percent of the meat in an individual's diet was raised at that receptor. This is an overestimation which means the actual dose from this pathway will be lower than the predicted one. No milk was assumed to be produced in the area.

The New Mexico Radiation Protection Regulations (NMRPR) state that no licensed facility is allowed to release radioactive material in concentrations high enough to deliver in excess of 25 mrem/year to any organ of an individual member of the public (18). However, part 3-300.M specifically excludes contributions from tailings piles, radon and short-lived radon daughters. Therefore, two radiological assessments were done; one with contributions from these sources and one without. From a legal viewpoint, only the assessment without the tailings, radon and radon daughters can be used for determining compliance. However, the assessment presented in Table A.4, presents a more realistic view of the true radiological impact.

Table A.3 Annual Dose Commitments (mrem/year) to Individuals, Excluding Contributions From Tailings, Radon and Radon Daughters

Receptor	Whole Body	Bone	Lung	Liver	Kidney	Bronchi
1	0.27	3.56	6.65	0.20	0.83	0.19
2	0.23	3.01	5.75	0.17	0.70	0.16
7	0.37	4.87	9.25	0.27	1.13	0.26
9	0.18	2.40	4.47	0.13	0.56	0.13
11	0.44	5.09	6.03	0.31	1.07	0.37
12	0.06	0.71	0.85	0.04	0.15	0.05
13	0.01	0.21	0.48	0.01	0.05	0.01
14	0.03	0.47	0.97	0.03	0.11	0.02
15	0.02	0.34	0.76	0.02	0.08	0.02
16	0.03	0.38	0.33	0.02	0.08	0.03

Table A.4 Annual Dose Commitments (mrem/year) to Individuals, Including Contributions from Tailings, Radon and Radon Daughters

Receptor	Whole Body	Bone	Lung	Liver	Kidney	Bronchi
1	2.00	8.75	8.72	1.91	3.13	188
2	1.73	7.34	7.53	1.65	2.67	146
7	2.83	12.1	12.2	2.71	4.39	177
9	1.51	6.06	6.07	1.45	2.28	94.2
11	4.69	20.1	11.7	4.51	7.13	74.2
12	0.98	3.22	2.10	1.01	1.50	30.6
13	0.20	0.50	0.68	0.21	0.29	9.76
14	0.35	1.05	1.33	0.37	0.54	15.6
15	0.29	0.78	1.05	0.29	0.41	13.8
16	0.52	2.05	1.11	0.54	0.86	11.3

As shown in Table A.3, the 25 mrem regulation was not exceeded at any location for any organ. However, the 25 mrem limit would be exceeded on the downwind side of the facility if there was anyone living there. In the undeveloped subdivision of Vista Montano the limit would also be exceeded. It should be noted that while federal regulations (40 CFR 190) exclude radon, New Mexico is the only state that excludes tailings. The largest MILDOS lung dose calculation, excluding radon but including tailings, was 10.2 mrem/yr at receptor 7.

From ?

The cumulative annual population dose commitments for people within 80 km is calculated by the MILDOS code. These doses, calculated during maximum allowable mill throughput, are presented in Table A.5. In accordance with NMRPR part 3-300.M, these doses do not include contributions from tailings, radon or short-lived radon daughters.

Table A.5 Population Dose Within 80 km (person-rem/year)

Pathway	Whole Body	Bone	Lung	Liver	Kidney	Bronchi
Inhalation	0.098	2.236	8.014	0.074	0.578	0
Ingestion	0.232	2.831	0.232	0.244	0.803	0.232
External Gamma	0.836	0.836	0.836	0.836	0.836	0.836

A.4 Radiological Assessment of Nearby Residential Areas

This chapter provides a detailed assessment of the radiological risk to individuals living in the residential areas southwest of the Homestake Mining Company (HMC) uranium mill. The purpose of this assessment is to determine a quantitative estimate of risk from living near this uranium milling facility. The Homestake mill is the only facility in the state with a population (approximately 200 individuals) in close proximity.

Computer modeling was used extensively to calculate environmental concentrations of radionuclides released from the facility and the dose to individuals from these releases. In addition, background levels of radiation in the area were also evaluated. In order to increase the accuracy of the calculated doses, previously collected monitoring data was used in place of modeled concentrations whenever possible. Finally, the risk of radiation induced cancer per year of exposure in the Homestake area was evaluated.

A.4.1 Dose Calculations

The Homestake uranium mill releases measurable amounts of radiation via several pathways. Radon gas emanates from the ore storage pile, the tailings pile and from the ore during the milling process. Dust particles containing radionuclides are also released. Radionuclides from the tailings pile can seep into the ground water or enter the food ingestion pathway leading to man by contaminating water sources, grazing animals or vegetable gardens.

In order to assess the problem, monitoring programs have been implemented to determine concentrations of nuclides being released. These programs will be discussed in greater detail in the following sections.

(a) Inhalation

An assessment of the risk of inhaling radioactive particulates, radon and radon daughters is made in this section. Radon was measured both indoors and outdoors and the dose from this exposure was calculated. As an aid in determining doses to individuals, the MILDOS computer code (1) was used. The code uses an RBE of 10 and USNRC dose conversion factors (8). It also assumes a non-occupational breathing rate. Parameters such as meteorological data, radionuclide release rates and receptor locations are fed into the code, which then calculates radionuclide concentrations in air at each receptor location. Fifty-year dose commitments (DC-50) per year of exposure (the cumulative dose over a fifty year period from radionuclides remaining in the body from one year of intake) are then derived by multiplying annual intakes by the appropriate dose conversion factors. When available, measured concentrations were used to modify modeled results to ensure that predicted values were more accurate.

Outdoor Radon. Concentrations were measured for a one year period beginning in March 1983 using Passive Environmental Radon Monitors (PERM) supplied by the USEPA Office of Radiation Program, Las Vegas Nevada. Stations were maintained at five locations in Murray and Broadview Acres. An average value and standard error of 1.97 ± 0.18 pCi/l (n=130) was obtained from individual measurements. Of this, 0.35 ± 0.02 pCi/l (n=52) was estimated to be due to natural background (using PERM measurements from the San Mateo and Bluewater areas). Therefore 1.62 pCi/l was due to the HMC milling facility.

George and Breslin measured outdoor background radon and radon daughter concentrations which averaged 83% equilibrium (3). Although this number seems high, it was conservatively used as the equilibrium value for the component of ambient radon assigned to background. To obtain an equilibrium value for radon daughters from the pile, the travel time between the pile and the residential area was estimated. Wind speed data (4) showed that the wind traveling toward the residential areas had an average velocity of 1.16 m/s (2.6 mph). The average distance between the pile and the residential areas is 1.21 km (0.75 miles). Hence, the travel time for ingrowth of radon daughter products is 17 minutes. Pure radon attains 28% equilibrium during this time period, and therefore this equilibrium value was used for the component of ambient radon coming from the tailings pile.

We also assumed that an individual spends 80% of the time indoors and 20% outdoors (22). Working levels are converted to working level months (WLM) by multiplying by the number of hours per year (8760) and dividing by the number of working hours per working month (170). The BEIR III report (7) gives a conversion factor of 6 rem per WLM. This value was used to convert the exposure to dose equivalent per year of exposure in units of rem.

The working levels in outdoor air from natural background were calculated as follows:

$$(0.35 \text{ pCi/l}) (0.01 \text{ WL/pCi/l}) (0.83) = 0.0029 \text{ WL}$$

This converts to an exposure of 0.150 WLM and a dose of 900 mrem. Assuming an occupancy factor of 20% for outdoors results in a dose of 180 mrem.

The exposure from radon daughters due to the mill facility is calculated below:

$$(1.62 \text{ pCi/l}) (0.01 \text{ WL/pCi/l}) (0.28) = 0.0045 \text{ WL}$$

This converts to an exposure of 0.234 WLM and a dose of 1400 mrem. Accounting for time spent outdoors results in a dose of 280 mrem. The total dose for outdoor radon from all sources was therefore $(180 + 280) = 460$ mrem.

Indoor Radon During the same time as outdoor radon measurements, indoor concentrations were measured in Murray Acres at two locations, using the PERM method. An average of the individual measurements (n=49) gave a mean and standard error of 4.86 ± 0.53 pCi/l. In addition to the PERM measurements, Track Etch detectors were placed in five homes in Broadview and Murray Acres, including the two homes which had PERM devices. The annual mean and standard error for all five locations was 4.48 ± 0.80 pCi/l (n=20). Since this value is statistically

identical to the mean observed for PERM units, it would appear that this is a realistic estimate for the average indoor radon concentrations for community homes. As a further confirmation, indoor working levels were measured at one of the homes in Murray Acres. Twenty measurements during the period of 10/83 through 11/84 gave a mean and standard error of 0.027 ± 0.002 WL. If a 51% equilibrium is assumed, this corresponds to 5.3 pCi/l. This value is statistically identical to the PERM and Track Etch average radon values.

There appears to be no physical mechanism that could concentrate radon inside a home to levels above outdoor values because it is a chemically inert gas (much the same as nitrogen molecules in the atmosphere). Therefore, it was assumed that indoor radon from the HMC facility would be equal to outdoor concentrations from the same sources. 1.62 pCi/l was assumed to be from the milling facility and $(4.86 - 1.62) = 3.24$ pCi/l was from background and indoor structural sources. This value is higher than those measured in five local background structures, which averaged 1.84 ± 0.15 pCi/l. Of these five, two were located in Grants and one each in Milan, Bluewater and San Mateo. Two of these were in schools, two were in private homes and one was located in an office building. This background average value (1.84 pCi/l) converts to 0.009 WL assuming 51% equilibrium. This can be compared to a mean indoor background working level value of 0.0057 as reported by George and Breslin (3) for 29 control homes in Grand Junction, Colorado. Thus, the elevated value of 3.24 pCi/l cannot be completely explained by background. The increase could be due to homes placed on soil contaminated with wind blown tailings, from elevated radon in water released in the home or from building materials that contain radium. However, no data currently exist to substantiate any of these contentions.

George and Breslin measured indoor (first floor) radon and radon daughter concentrations. An average 51% equilibrium value was derived from this data set and used for all indoor calculations. Background indoor working levels were thus calculated as follows:

$$(3.24 \text{ pCi/l}) (0.01 \text{ WL/pCi/l}) (0.51) = 0.0165 \text{ WL}$$

This converts to an exposure of 0.850 WLM and a dose commitment of 5100 mrem. Assuming an indoor occupancy factor of 80% (22) leads to a dose of 4080 mrem.

Indoor working levels due to the milling facility were calculated below:

$$(1.62 \text{ pCi/l}) (0.01 \text{ WL/pCi/l}) (0.51) = 0.0083 \text{ WL}$$

This value results in a dose of 2050 mrem including the 80% occupancy factor. The total dose from indoor radon from all sources is therefore 6130 mrem.

Table A.6 provides a summary of dose commitment resulting from exposure to radon released from the tailings pile and natural background sources. These doses are conservatively calculated assuming 100% occupancy. If an individual does spend several hours a day away from home, his dose would be lowered accordingly. However, there are people that do spend nearly all their time at home.

Table A.6 Summary Of Dose Commitments to the Bronchial Epithelium from Major Radon Sources (mrem/yr).

SOURCE	INDOOR	OUTDOOR	TOTAL
Background and Indoor Sources	4080	180	4260
Milling Facility	2050	280	2330
Total	6130	460	6590

Particulates

Fifty year dose commitments to various organs per year of exposure from inhalation of radioactive particulates were obtained by using the MILDOS computer modeling program. These doses were then modified to take into account measured particulate air concentrations which are shown in Table A.7. U-238 and U-234 were assumed to be in equilibrium. Data was taken over a time period of one year, from August 1978 thru August 1979. The DC-50 values from inhalation of measured air particulate concentrations are shown in Table A.8.

Table A.7 Radionuclide Concentrations in Air (fCi/m³)^c

Location	U-Nat	Th-230	Ra-226	Pb-210
Murray Acres	22.06	0.90	0.69	21.96
San Mateo (background)	0.35	0.18	0.15	10.71
HMC Facility ^a	21.71	0.72	0.54	11.25
Fraction due to HMC Facility ^b	0.984	0.800	0.783	0.512

- a) HMC Facility equals Murray Acres minus San Mateo.
- b) Fraction equals HMC Facility divided by Murray Acres.
- c) fCi = femtocurie or 10⁻¹⁵ curies.

Table A.8 Fifty Year Dose Commitments Per Year of Exposure to Individual Organs (mrem) from Inhalation of Background and HMC Facility Air Particulate Concentrations at Murray Acres

Radionuclide	Whole Body	Bone	Lung	Liver	Kidney
U-238	0.10	1.8	11.4	0.0	0.40
U-234	0.12	1.9	12.9	0.0	0.46
Th-230	0.12	4.2	2.0	0.24	1.19
Ra-226	0.02	0.2	3.1	3.0×10^{-5}	8.5×10^{-4}
Pb-210	0.10	3.1	11.3	0.78	2.56
Total	0.46	11.2	40.7	1.02	4.61
MILDOS Prediction	0.17	3.95	13.3	0.14	1.03
Ratio (Total/Mildos)	2.71	2.84	3.06	7.29	4.48

Background radionuclide concentrations in air were also measured at San Mateo, some 15 miles to the northeast. By subtracting these values from the concentrations at Murray Acres, the contribution from the milling facility can be estimated. The percent of the concentration due to the facility is found by dividing the milling facility contribution by the total (Table A.7). This ratio is then applied to the doses in Table A.8 to obtain the doses from the facility. These are shown in Table A.9.

Furthermore, the dose due to background airborne radionuclides is found by subtracting the doses in Table A.9 from those in Table A.8. These doses for whole body, bone, lung, liver and kidney are 0.07, 2.45, 6.97, 0.43 and 1.51 mrem/yr. respectively.

Table A.9 Fifty Year Dose Commitments Per Year of Exposure to Individual Organs from the HMC Milling Facility (mrem)

Radionuclide	Whole Body	Bone	Lung	Liver	Kidney
U-238	0.10	1.77	11.22	0.0	0.39
U-234	0.12	1.87	12.69	0.0	0.45
Th-230	0.10	3.36	1.60	0.19	0.95
Ra-226	0.02	0.16	2.43	2.3x10 ⁻⁵	6.7x10 ⁻⁴
Pb-210	0.05	1.59	5.79	0.40	1.31
Total	0.39	8.75	33.73	0.59	3.10

(b) Water Consumption

Assumptions: Fifty year dose commitments were calculated per year of exposure for all pertinent target organs using the following assumptions.

*Target Organs: total bone, endosteum, red marrow, liver, kidney and lung.

*F₁ uptake to blood factors are shown below and were taken from an Oak Ridge National Laboratory report by Dunning et al., 1981 (9) and International Commission on Radiological Protection reports 2(10) and 30(11). It should be noted that some investigators think the F₁ uptake factor for uranium may be as high as 0.2 from dietary data of occupationally exposed persons (24).

U-238, U-234	0.05	ICRP 30
Th-230	0.0002	ICRP 30
Ra-226	0.2	ICRP 30
Pb-210	0.08	ICRP 2
Po-210	0.10	ICRP 30

*A bone distribution factor of 5 was used for Th-230.

*Average daily water intake for Homestake area residents was determined by a survey conducted by the New Mexico Office of Epidemiology to be 32.7 oz/day (0.97 liters/day). In 1977, Homestake started providing bottled water to nearby residents. Prior to this, local wells were the major source of drinking water.

Even though Homestake provides bottled water, some residents continue to use well water, as determined by interviews with local residents.

*Since only natural uranium water concentrations were available, U-238 and U-234 were assumed to be in equilibrium.

*Dose conversion factors (DCF) used were also taken from the report by Dunning et al., 1981 (9) and are summarized in Table A.10. However, Dunning used an RBE of 20 for alpha emitters. To be consistent with the RBE of 10 that has been used throughout this report, we have divided Dunning's values by 2.

Table A.10 Dose Conversion Factors For All Target Organs (Rem/uCi)

Target Organ	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210
Total Bone	3.5	3.9	0.6	21.5	10.5	0.26
Endosteum	1.4	1.8	8.0	10.0	4.8	0.12
Red Marrow	0.10	0.12	0.5	1.1	0.5	0.27
Liver	6.70E-3	7.90E-3	1.09E-2	0.30	0.7	0.8
Kidney	0.75	0.85	2.16E-3	0.30	0.47	4.7
Lung	7.65E-3	8.60E-3	2.28E-3	0.30	0.15	0.26

Water Concentrations: There are 95 wells in the communities in question and 92 were sampled (97%). Of the sampled wells, 64 (70%) were alluvial and 28 (30%) non-alluvial. Non-alluvial wells had lower concentrations because they are deeper and hence less easily contaminated by surface sources. Mean yearly natural uranium concentrations are shown below in Table A.11. Concentrations were obtained by averaging all alluvial well water values reported by HMC, EID and others in the 1981 water discharge permit. All HMC U₃O₈ values were converted to natural uranium units of ug/l.

Table A.11 Uranium Concentration in Alluvial Well Water (ug/l)

Year	(n)	Mean	(s)	(sem) ^a	(% CV) ^b
1975	4	2430	2227	1114	92
1976	27	768	1806	348	235
1977	53	1620	3352	460	207
1978	68	1184	2885	350	244
1979	47	1652	3887	567	235
1980	40	1690	3426	542	203
1981	77	1320	2585	295	196
1982	116	924	1261	117	136
1983	35	737	1137	192	154

(a) Standard error of the mean.

(b) Percent coefficient of variation.

The overall mean and standard error for uranium during all nine years was 1235 ± 121 ug/l with an n=467.

Natural uranium concentrations were also averaged for non-alluvial wells using data reported in the 1981 water discharge permit for HMC. The overall mean and standard error for 96 samples collected from 28 wells from 1976 to 1983 was 93 ± 35 ug/l. This average value is approximately 13 times lower than the average for alluvial wells. However, there was evidence of contamination in non-alluvial wells sampled during 1982 and 1983, with a high value of 2730 ug/l detected. The average without those values indicating contamination was 33 ug/l, which may be a reasonable estimate of natural background levels in the local area.

Thorium-230, lead-210 and polonium-210 have recently been measured in alluvial wells in Broadview and Murray Acres. These values are shown in Table A.12. Radium-226 values were averaged from all data presented in the HMC Groundwater Discharge Plan.

Table A.12 1983 Thorium-230, Radium-226, Lead-210 and Polonium-210 Concentrations in Alluvial Well Water from Broadview and Murray Acres (pCi/l).

Radionuclide	n	Mean	s(a)	(sem)
Th-230	4	0.2	0.1	0.07
Ra-226				
Alluvial	314	1.2	0.9	0.05
Non-Alluvial	49	0.7	0.6	0.08
Pb-210	4	6.8	4.6	2.3
Po-210	4	15.7	17.4	8.7

(a) s = standard deviation and sem = standard error of the mean

Dose Calculations: Using the overall uranium mean concentration of 1235 ug/l (836 pCi/l) and previously stated assumptions, 50 year dose commitments per year of exposure were calculated for U-238 and U-234, Th-230, Ra-226, Pb-210, and Po-210. Individual DC-50 values were calculated and listed in a table for each target organ in rem/yr using the following generic relationship:

$$DC-50 = \frac{(\text{concentration})(0.97 \text{ liters})(365 \text{ d})(\text{uCi})(DCF) (1000 \text{ mrem})}{(\text{day}) (\text{year}) (10^6 \text{ pCi}) (\text{rem})} = \frac{\text{mrem}}{\text{year}}$$

Table A.13 Fifty Year Dose Commitments Per Year of Exposure from Radionuclides in Drinking Water (mrem)

Target Organ	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Total
Total Bone	518	577	0.21	9.1	25.3	1.5	1131
Endosteum	207	259	0.55	4.2	11.6	0.65	483
Red Marrow	14	17	3.6E-2	0.47	1.2	1.5	34
Liver	0.97	1.2	7.5E-4	0.13	1.7	4.5	8
Kidney	111	126	1.6E-4	0.13	1.2	25.9	264
Lung	1.1	1.3	1.6E-4	0.13	0.35	1.5	4

Using the highest average reported natural uranium concentration of 8550 ug/l (5788 pCi/l) taken in Broadview Acres from a single domestic well during the period of 1977-1982, DC-50 values were calculated for the maximally exposed individual. These values can be obtained from Table A.13 by multiplying total rem/year values by (8550/1235). The total dose to bone, the organ receiving the highest dose, per year of exposure for this individual was 7.6 rem.

(c) Meat and Vegetable Consumption

Since vegetable gardens are utilized within the study area and receive alluvial well water, some residents could receive a dose through consumption of vegetables contaminated by radionuclides in water and by direct airborne foliar deposition. Similarly, meat products may accumulate radionuclides since animals may graze on pasture contaminated by both irrigation water and direct airborne foliar deposition.

First, consider the air deposition pathway. Radionuclides deposit on vegetation and are consumed directly by man or indirectly through the meat pathway. MILDOS calculates doses from these pathways. The dose conversion factors used by MILDOS include a 50% reduction in radionuclide concentration from washing and cooking. The calculated doses were modified to reflect measured air concentrations, using the ratio of measured/predicted DC-50 values reported in Table A.8. The NRC reports that 145.5 kg of vegetables are consumed by an average individual per year (8). However, only part of the total would be grown locally. Healy (22) reports that an average gardener produces 80 kg/yr. The MILDOS predicted values are therefore modified by (80/145.5)=0.55. Locally produced meat is conservatively assumed to account for half of the meat in an individual's diet. The predicted doses from vegetable consumption are shown in Table A.14.

Table A.14 Fifty Year Dose Commitments Per Year of Exposure to Individual Organs from Air Deposition on Vegetables and Pasture Grass (mrem)

Organ	Vegetables	Meat
Lung	0.41	0.06
Bone	4.55	0.67
Whole Body	0.41	0.06
Liver	0.85	0.16
Kidney	1.64	0.30

Now consider the contribution from irrigation. Assume that irrigation water is applied at a rate of $0.072 \text{ l/m}^2\text{-hr}$. The following equation* from Reg. Guide 1.109 (5) was used to calculate radionuclide concentrations in vegetation due to uptake from irrigation water.

$$C_{iv} = (C_{iw}) (I) (r) (1 - \exp(-X_{ei} t_e)) / Y_v X_{ei}$$

where C_{iw} = the concentration of radionuclide i in irrigation water;

I = the average irrigation rate;

r = the fraction of deposited activity retained on crops;

X_{ei} = the effective removal rate of radionuclide i from the crops;

t_e = the time period that crops are exposed to irrigation water;

Y_v = the agricultural productivity.

For example substituting the appropriate values for uranium leads to the following:

$$C_{iv} = \frac{(836 \text{ pCi/l}) (0.072 \text{ l/m}^2\text{-hr}) (0.2) (1 - \exp(-0.05/d) (90d))}{(2 \text{ kg/m}^2) (0.0021/\text{hr})} = 2834 \text{ pCi/kg}$$

We now obtain the total uranium ingested per year from this pathway.

$$(2834 \text{ pCi/kg})(80 \text{ kg/yr})(10^{-6} \text{ uCi/pCi}) = 0.227 \text{ uCi/yr}$$

*The entire equation is not presented, since the other terms were not needed for this calculation.

Fifty year dose commitments from this amount of ingested uranium were obtained by using a dose conversion factor (DCF) for each organ. Since we assumed that U-234 is in equilibrium with U-238, we averaged their DCF's. Similarly, DC-50s from ingested thorium, radium, lead and polonium were obtained and are presented in Table A.15.

Table A.15 Fifty Year Dose Commitments Per Year of Exposure from Irrigation of Vegetables and Pasture Grass (mrem)

Organ	Uranium	Thorium-230	Radium-226	Lead-210	Polonium-210	Total
Total Bone	840	0.16	7.0	19.4	1.1	868
Endosteum	363	0.43	3.3	8.9	0.5	376
Red Marrow	25	2.7E-2	0.4	0.9	1.1	27
Liver	2	5.9E-4	9.8E-2	1.3	3.4	7
Kidney	182	1.2E-4	9.8E-2	0.9	20	203
Lung	2	1.2E-4	9.8E-2	0.3	1.1	4

The dose to the maximally exposed individual from the irrigation pathway can be calculated using the same ratio (8550 ug/l per 1235 ug/l) that applied to the drinking water pathway. The total bone dose would then be 5.8 rem.

(d) External Gamma

Annual dose commitments were calculated from the external gamma pathway by the MILDOS code. Four locations in Murray and Broadview Acres were averaged together. The code considered gamma rays coming from two sources: airborne radionuclides and ground deposited nuclides. The predicted dose only included contributions from the mill, i.e. no dose from natural background sources were included. Because the source is external, each organ received the same dose commitment. Contributions from the two sources were nearly equal and the total external gamma was 1.34 mrem/yr from the pile. In addition, the gamma dose from direct shine from the pile was estimated to be less than one mrem/yr and hence not a significant source.

(e) Summary of Doses

In the preceding sections, the doses that Murray and Broadview Acres residents received, both from the HMC mill and from natural background, were calculated. A summary of these doses is presented below.

Dose Commitment Due to the HMC Milling Facility

Table A.16 presents a summary of the dose commitment received by Murray and Broadview Acre residents that is due to the HMC milling facility. Dose to the lung comes primarily from radon inhalation while dose to other organs is dominated by the water pathway and therefore the ingestion of uranium.

Table A.16 Summary of Fifty Year Dose Commitments per Year of Exposure Due to the Milling Facility (mrem)

Pathway	Lung ^a	Liver	Kidney	Total Bone	Endosteum
Radon	2330	---	---	---	---
Particulates	33.7	0.59	3.1	8.75	---
Drinking Water	4	8	264	1131	483
Meat/Vegetables	0.45	0.20	1.87	5.05	---
Irrigation	4	7	203	868	376
External Gamma	1.34	1.34	1.34	1.34	1.34
TOTAL	2373	17.1	473	2014	860

(a) Radon and its daughters actually deliver the dose to the bronchial epithelium.

As a comparison to Table A.16 values, the BEIR III report (7) gives a value of 10 mrem to the active bone marrow from a single chest x-ray.

Dose Commitment From Natural Background

Table A.17 summarizes the dose commitments from natural background within the Grants Mineral Belt. The average dose commitment to the whole body was 127 mrem while the lung received a larger dose, primarily due to inhalation of radon daughters. Bone received a higher dose than the whole body because of internal sources. Other internal organs received slightly less, due to shielding by the body.

Table A.17 Estimated Annual Dose Commitment Rate (mrem/yr) from Background Radiation in the Grants Mineral Belt^a

Radiation Source	Whole Body	Bronchial Epithelium	Bone	Liver	Kidney
Cosmic ^b	60	60	60	60	60
Cosmogenic	1	1	1	1	1
External Terrestrial ^c	45	33	33	33	33
Internal Terrestrial	21	21	45	21	21
Inhalation	--	2501 ^d	--	--	--
TOTAL	127	2616	139	115	115

(a) Data was taken in part from NUREG/CR-0597 (13) to construct this table.

(b) Assumed 10% reduction due to structural shielding at an elevation of 6500 ft. (7).

(c) Assumed 20% reduction for structural shielding and 20% for shielding by the body (7).

(d) Of the 2501 mrem inhalation dose to the bronchial epithelium, 180 mrem is from exposure to outdoor radon and 2320 mrem is from indoor radon.

Dose to Maximum Exposed Individual

A worst case exposure to milling sources (not including background) from several pathways has been calculated for a hypothetical individual living in Murray or Broadview Acres. These were obtained by calculating the dose that would result from exposure to the highest measured value. In the case of particulates, measurements were taken at only one location and hence the maximum case is the same as the average case. Similarly, since only two indoor PERM radon stations were considered, the monitoring case was assumed to be identical to the average case. In addition, the maximum outdoor radon PERM average was 2.56 pCi/l which was similar to the average value of 1.97 pCi/l. By adding worst case doses for each pathway, the total dose to the lung, bone, liver and kidney was 2400, 13650, 43 and 2960 mrem, respectively.

Minimum Dose

The minimum dose that an individual in Murray or Broadview Acres could receive from milling sources can be estimated using the following assumptions:

- * The individual drinks only bottled water.
- * He does not eat any vegetables or livestock grown in the area.
- * He spends 50% of his time away from home.

The only pathways that would apply to such an individual are inhalation of radon, radioactive particulates and external gamma exposure. These doses would only be 50% of what was previously calculated because of the shorter exposure time. Thus, the bronchial epithelium would receive 1182 mrem per year of exposure, other organs would receive less than 5 mrem.

A.4.2 Risk Analysis

In the previous section dose commitment estimates to various target organs from several exposure pathways were calculated. This section presents estimates of incremental risk of cancer death resulting from exposure to radiological effluents released from the HMC milling facility and from natural background sources. Each target organ was treated separately since they have varying sensitivities to radiation. Risk coefficients taken from the BEIR III report (7) are listed in Table A.18 below in units of lifetime risk of cancer mortality per 10^6 person-rem.

Table A.18 Summary of Risk Coefficients Used
(Risk/10⁶ person-rem)

Target Organ	Risk Coefficient
Total Bone ^a	1.9
Endosteum	14.0
Liver	30.0
Kidney	5.5 ^b
Bronchial Epithelium/ Lung	16.7-166.7 ^c

(a) Total bone and endosteum risk coefficients taken from the BEIR III report for a 7000 g bone were modified to give average skeletal doses for a 5000 g bone by multiplying BEIR coefficients by 5000/7000.

(b) The risk coefficient for kidney was obtained by taking a ratio of low LET risk rate coefficients for kidney and liver reported in the BEIR III report and multiplying by the high LET risk coefficient for liver.

(c) This range for bronchial epithelium risk coefficients (risk/10⁶ person-rem) was obtained from the following estimates reported in the literature.

Evans	(6)	16.7
Jacobi	(14)	16.7-83.3
NCRP 78	(26)	21.7
NCRP 77	(25)	33.3
UNSCEAR	(15)	33.3-75.0
USNRC	(8)	60.0
BEIR III	(7)	143.0
Archer	(16)	166.7

The USEPA (17) has endorsed the BEIR III estimate of 143.0 for a lung risk coefficient, which was derived from uranium miner data. Since uranium miner's breathing rates are twice that for an average individual (8), this risk estimate should be reduced by a factor of two. However, the unattached fraction of RaA is nearly twice as high in an average home (7%) than in a mine (4%) (23). Therefore the BEIR III estimate was not corrected for differential breathing rates. The NCRP has also reported risk coefficient estimates of 21.7-33.3 for lung. Using the recently reported NCRP 78 age dependent risk coefficients of 21.7 (26), an age average risk estimate of 22.8 was derived using the actual age distribution for Murray and Broadview Acres. Due to the broad range of risk coefficients reported for the bronchial epithelium by various authors, committees and agencies, it was not possible to select a single best estimate. A range of values was therefore used for all lung and total risk calculations to best reflect the current uncertainties in risk estimates.

Using the previously listed lifetime risk coefficients and total dose commitment estimates for each target organ, estimates for total risk from the tailings facility and natural background were calculated and summarized in Table A.19 below.

Table A.19 Summary of Lifetime Risk Estimates Per Year of Exposure For Tissues At Risk From Natural Background and the HMC Milling Facility

Source	Risk Estimates ^a				
	Lung	Bone	Liver	Kidney	Range ^b
Tailings Facility	40-396	3.8	0.5	2.6	47-403
Natural Background	44-437	0.3	3.5	0.6	48-441
Total	84-833	4.1	4.0	3.2	95-844

(a) Estimates are in units of chances per million for a premature cancer death per year of exposure.

(b) Calculated using the range of risk coefficients as reported in footnote c of Table A.18.

As can be seen in Table A.19, the risk for lung dominated all other tissues at risk. If a hypothetical person lived in the communities in question for the average residence time (8.6 years) then the total risk from the tailings facility would be from one chance in 2475 to one chance in 290 of contracting a fatal cancer.

A survey of the population did not identify excessive levels of cancer as compared to national cancer mortality rates. However it should be noted that this population may have been quite mobile with exposed persons moving to other locations and therefore were not included in the survey results. Also the average residence period (8.6 years) would not be long enough to exceed the latent period for many types of cancer expected. The BEIR III report (7) states that "the latent period from radiation exposure to death from lung cancer is generally 10 years or more, with excess cases appearing in some populations 50 years or more after the beginning of exposure." In addition, the population of 200 persons would not be sufficient to observe an excess number of cancer mortalities. If all 200 community residents were exposed to radioactive emissions from the tailings facility for the average residence time of 8.6 years then 0.08-0.69 premature cancers would be expected from this source.

Since there is a possibility that the exposed population will obtain access to Milan water within the near future, the total risk estimate was therefore considered following elimination of the water ingestion pathway. If this pathway were eliminated it would result in greatly reduced dose commitments to total bone, liver and kidney. However, the total dose to lung was almost unaffected and therefore the total lifetime risk estimate range of 1/21,300 to 1/2480 per year of exposure was only reduced to 1/25,200-1/2530 from all exposure pathways. A minimally exposed person who spends 50% of his time away from home would, however, reduce his lifetime risk estimate range by a factor of two or 1/50,700 to 1/5075 per year of exposure due to decreased inhalation of radon and particulates.

The maximally exposed individual would have a calculated lifetime risk very close to the risk for the average exposed individual of one chance in 2590 per year of exposure. The maximum and average risk estimates were very close since the maximum and average radon concentrations were very close and dose to lung from radon dominated the total risk estimate. There is a possibility that some community residents could incur radiation exposure in addition to those presented in this report as a result of employment at HMC. Occupational exposures were, however, not considered in this report.

In addition to the previously discussed cancer, an estimate of the risk for induction of leukemia can be derived. Using a risk coefficient of $4E-6$ /person-rem from the BEIR III report (7) and a total estimated red bone marrow dose of 61 mrem from Tables A.13 and A.15 a risk of 0.25 chances per million per year of exposure is calculated. If all 200 community residents received the average red bone marrow dose for 8.6 years, 0.0004 leukemias would be expected.

As a further clarification of potential risk to the exposed population, various authorities have established working level limits as shown in Table A.20. These limits are divided into three categories: required remedial action, remedial action may be necessary and no action required. Table A.20 values can be compared to the measured average radon value of 4.86 pCi/l which converts to 0.025 WL assuming 51% equilibrium and the 0.029 WL measured directly at the nearest resident to the tailings pile. This data suggests that remedial action may be necessary or, according to some of the established limits, be required.

Table A.20 Recommendations and Regulations Concerning Remedial Action Levels for Exposure to Radon Daughters

Reference	Remedial Action Necessary	Remedial Action Suggested	No Action Necessary
Surgeon General (27) ^a	0.05WL	0.01-0.05WL	0.01WL
40CFR192(28)	0.03WL	0.02-0.03WL	0.02WL
NCRP77(25)	0.04WL	-	-
EPA(29)	0.02WL	0.009-0.02WL	0.009WL
Canadian(30)	0.02WL	-	-
DOE (31) ^a	0.03WL	0.01-0.03WL	0.01WL
NMRPR (18) ^a	0.03WL (0.01WL ^b)	-	-

(a) These working level limits do not include background levels.

(b) According to NMRPR Part 4-160.E, the concentration limit may be lowered to one third of the limit stated in Appendix A if a suitable sample of the population is exposed.

A.5 MILDOS Input Parameters

The following is a brief description of each input parameter for the MILDOS computer code. See the MILDOS manual for a complete description of each parameter.

FREQ =

Direction	Stability Class A						Total
	0-3	4-6	7-11	12-16	17-25	25	
N	0.3183	0.1194	0.0133	0.0	0.0	0.0	0.4510
NNE	0.1459	0.0663	0.0133	0.0	0.0	0.0	0.2255
NE	0.1061	0.1061	0.0265	0.0	0.0	0.0	0.2387
ENE	0.1592	0.0663	0.0133	0.0	0.0	0.0	0.2388
E	0.0928	0.0265	0.0133	0.0	0.0	0.0	0.1326
ESE	0.0663	0.0265	0.0133	0.0	0.0	0.0	0.1061
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S	0.0133	0.0	0.0	0.0	0.0	0.0	0.0133
SSW	0.0398	0.0133	0.0	0.0	0.0	0.0	0.0531
SW	0.0928	0.0	0.0	0.0	0.0	0.0	0.0928
WSW	0.0928	0.0398	0.0133	0.0	0.0	0.0	0.1459
W	0.1326	0.0265	0.0133	0.0	0.0	0.0	0.1724
WNN	0.1592	0.0928	0.0265	0.0	0.0	0.0	0.2785
NW	0.2653	0.0928	0.0	0.0	0.0	0.0	0.3581
NNW	0.2520	0.0928	0.0	0.0	0.0	0.0	0.3448

Stability Class B

Windspeed (mph)

Direction	0-3	4-6	7-11	12-16	17-25	25	Total
N	0.3316	0.1061	0.0133	0.0	0.0	0.0	0.4510
NNE	0.2255	0.0928	0.0265	0.0	0.0	0.0	0.3448
NE	0.2255	0.0398	0.0	0.0	0.0	0.0	0.2653
ENE	0.2122	0.0398	0.0	0.0	0.0	0.0	0.2520
E	0.1857	0.0531	0.0133	0.0	0.0	0.0	0.2521
ESE	0.0928	0.0265	0.0133	0.0	0.0	0.0	0.1326
SE	0.0531	0.0	0.0	0.0	0.0	0.0	0.0531
SSE	0.0796	0.0133	0.0	0.0	0.0	0.0	0.0929
S	0.1194	0.0	0.0	0.0	0.0	0.0	0.1194
SSW	0.1592	0.0796	0.0265	0.0	0.0	0.0	0.2653
SW	0.1857	0.0265	0.0133	0.0	0.0	0.0	0.2255
WSW	0.1857	0.0663	0.0133	0.0133	0.0	0.0	0.2786
W	0.3846	0.0928	0.0265	0.0	0.0	0.0	0.5039
WNW	0.3448	0.1061	0.0398	0.0	0.0	0.0	0.4907
NW	0.4377	0.1061	0.0398	0.0	0.0133	0.0	0.5969
NNW	0.3581	0.1194	0.0398	0.0265	0.0	0.0	0.5438

Stability Class C

Windspeed (mph)

Direction	0-3	4-6	7-11	12-16	17-25	25	Total
N	0.5836	0.4244	0.1061	0.0133	0.0	0.0	1.1274
NNE	0.5172	0.1326	0.0663	0.0	0.0	0.0	0.7161
NE	0.3448	0.0796	0.0265	0.0	0.0	0.0	0.4509
ENE	0.2255	0.0531	0.0133	0.0	0.0	0.0	0.2919
E	0.3581	0.0796	0.0	0.0	0.0	0.0	0.4377
ESE	0.2785	0.2122	0.0265	0.0	0.0	0.0	0.5172
SE	0.1326	0.2255	0.0265	0.0	0.0	0.0	0.3846
SSE	0.2653	0.1592	0.0133	0.0133	0.0	0.0	0.4511
S	0.2653	0.1459	0.1326	0.0531	0.0133	0.0	0.6102
SSW	0.4244	0.1989	0.0531	0.0	0.0	0.0	0.6764
SW	0.4509	0.1989	0.1194	0.0	0.0	0.0	0.7692
WSW	0.8223	0.2255	0.1592	0.0	0.0	0.0	1.2070
W	0.7958	0.2255	0.1191	0.0	0.0	0.0	1.1407
WNW	0.6897	0.3183	0.1061	0.0133	0.0	0.0	1.1274
NW	0.6499	0.3448	0.1061	0.0133	0.0	0.0	1.1141
NNW	0.4642	0.2785	0.0663	0.0	0.0133	0.0	0.8223

Stability Class D

Windspeed (mph)

Direction	0-3	4-6	7-11	12-16	17-25	25	Total
N	0.9549	0.5305	0.5305	0.0133	0.0	0.0	2.0292
NNE	0.8223	0.2520	0.1326	0.0265	0.0	0.0	1.2334
NE	0.5305	0.1061	0.0663	0.0	0.0	0.0	0.7029
ENE	0.6499	0.2122	0.0398	0.0133	0.0	0.0	0.9152
E	0.6101	0.2918	0.0133	0.0	0.0	0.0133	0.9285
ESE	0.8886	0.4377	0.2918	0.0	0.0	0.0	1.6181
SE	0.6101	0.7692	0.6101	0.0265	0.0	0.0	2.0159
SSE	0.6764	0.5703	0.4775	0.0796	0.0133	0.0	1.8171
S	0.4907	0.4377	0.1989	0.0663	0.0398	0.0	1.2334
SSW	1.1008	0.5836	0.3316	0.0928	0.0133	0.0	2.1221
SW	1.2069	0.5040	0.5836	0.2653	0.1061	0.0	2.6659
WSW	1.3130	0.7029	0.8488	0.5305	0.1061	0.0	3.5013
W	2.1751	0.6233	0.9019	0.3183	0.0265	0.0	4.0451
WNW	2.0027	0.7162	0.8355	0.2918	0.0133	0.0	3.8595
NW	1.5119	0.7427	0.7029	0.0663	0.0165	0.0	3.0403
NNW	1.4589	0.7825	0.7162	0.0663	0.0	0.0	3.0239

Stability Class E

Windspeed (mph)

Direction	0-3	4-6	7-11	12-16	17-25	25	Total
N	0.6233	0.3979	0.3714	0.0531	0.0133	0.0	1.4590
NNE	0.2785	0.1459	0.1326	0.02645	0.0	0.0	0.5835
NE	0.2387	0.0663	0.0663	0.0133	0.0	0.0133	0.3979
ENE	0.1857	0.0796	0.0265	0.0265	0.0	0.0	0.3183
E	0.2387	0.0928	0.0531	0.0133	0.0	0.0	0.3979
ESE	0.1459	0.2785	0.1724	0.0	0.0	0.0	0.5968
SE	0.2255	0.4377	0.3581	0.0133	0.0	0.0	1.0343
SSE	0.4642	0.7825	1.1804	0.2255	0.0928	0.0133	2.7597
S	0.7560	0.3714	0.6897	0.2122	0.1061	0.0796	2.2150
SSW	1.0477	0.4377	0.4244	0.1194	0.1989	0.0531	2.2812
SW	1.0080	1.0345	0.5172	0.3316	0.2255	0.0	3.1168
WSW	1.2732	0.6366	1.0477	1.0212	0.6101	0.0796	4.6684
W	2.3607	0.8621	1.1804	0.8753	0.3183	0.0	5.5968
WNW	2.2546	1.3263	0.9814	0.4111	0.3316	0.0133	5.3183
NW	1.2997	1.3395	1.0212	0.6101	0.2653	0.0	4.5358
NNW	0.9151	1.5119	0.8886	0.0796	0.0531	0.0	3.4483

Stability Class F

Windspeed (mph)

Direction	0-3	4-6	7-11	12-16	17-25	25	Total
N	0.0265	0.0663	0.0531	0.0	0.0	0.0	0.1459
NNE	0.0133	0.0265	0.0	0.0	0.0	0.0	0.0398
NE	0.0265	0.0133	0.0	0.0133	0.0	0.0	0.0531
ENE	0.0133	0.0133	0.0	0.0	0.0	0.0	0.0266
E	0.0398	0.0	0.0133	0.0	0.0	0.0	0.0531
ESE	0.0	0.0133	0.0	0.0	0.0	0.0	0.0133
SE	0.0	0.0265	0.0398	0.0	0.0	0.0	0.0663
SSE	0.0133	0.0265	0.2122	0.0265	0.0	0.0	0.2785
S	0.1061	0.1724	0.3846	0.0531	0.0265	0.0133	0.7560
SSW	0.2122	0.1194	0.1194	0.0928	0.0265	0.0133	0.5836
SW	0.2785	0.2520	0.2653	0.0663	0.0265	0.0133	0.9019
WSW	0.2520	0.1592	0.3316	0.1194	0.0531	0.0928	1.0081
W	0.2918	0.0928	0.0796	0.0398	0.0133	0.0133	0.5306
WNW	0.4509	0.1326	0.1989	0.1326	0.0928	0.0	1.0078
NW	0.1724	0.1592	0.3714	0.1194	0.0663	0.0	0.8887
NNW	0.0398	0.2653	0.3050	0.0	0.0	0.0	0.6101

IPOP =

Distance (km)	DIRECTION							
	N	NNE	NE	ENE	E	ESE	SE	SSE
1- 2	0	0	0	0	0	0	0	0
2- 3	0	0	0	0	0	0	0	0
3- 4	0	0	0	0	0	0	0	0
4- 5	0	0	0	0	0	0	0	0
5-10	1	1	1	1	1	1	1	1
10-20	1	1	1	1	1	96	1	1
20-30	13	1	1	300	1	1	181	1
30-40	1	1	1	1	1	1	4103	1
40-50	1	1	1	1	1796	289	1020	450
50-60	1	1	1	1	1	1883	1	1
60-70	1	26	1	34	1254	282	1	1
70-80	1	2412	50	35	20	1	1	1

Distance (km)	DIRECTION							
	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 2	0	70	55	20	0	0	0	0
2- 3	0	38	65	49	24	0	0	0
3- 4	0	27	25	27	0	0	0	0
4- 5	0	0	100	15	0	0	0	0
5-10	1710	1	360	1	250	1	1	1
10-20	12312	1	1	1	594	356	1	1
20-30	1	1	1	1	1	445	1	2218
30-40	8	20	120	1	1	1	1	1
40-50	1	1	30	1	1	1	1	1025
50-60	10	4	1	1	1	506	3240	1789
60-70	1	1	1	1	858	1200	1	2200
70-80	1	1	1	1	2624	3942	1	1220

JC = 1, 5x0, 1, 0, 1, 0,

Job control parameters.

IFTODO = 0, 1, 0, 3x1, 4x0,

Calculates doses for only four time steps.

IRTYPE = 10, 15x1,

Prints doses at all receptor locations. Doses at the first location are broken down by pathway.

FRADON = 0., 0., 1., 0.,

All radon in this assessment comes from the Grant's Mineral Belt.

IPACT = 2x0, 1, 3x0, 3x2, 0,

Source 3 (ore pad) used column 1 of PACT. Sources 7-8 (tailings) use column 2.

PACT = 990., 28., 0
990., 396., 0.,
990., 396., 0.
990., 396., 0.

Specific activities of U-238, Th-230, Ra-226 and Pb-210 (pCi/g) in ore (column 1) and tailings (column 2).

SRNS = 62.2, 305.1, 0.,

Radon release rate in pCi/m²-sec for area sources.

FAS = 3x-1

Enables the MILDOS code to generate particulate release rates from the area sources.

NSORCE = 8,

Number of source terms.

SORCE = 0., 0., 13.8, 0., 144, 0048, .0014, 2.44E-4, 0., 1001, 1, 4.2.,
.2, .09, 0., 0., 4x7.76E-3, 0., 1002, 3, 0.,
.28, .05, 0., .028, 4x0., 56.6, 2001, 3, 0.,
.14, .09, 0., 0., 4x7.18E-3, 0., 1003, 2, 0.,
.05, -.09, 3.1, 0., 4x4.66E-4, 31.14, 1004, 2, 0.,
.06, 0., 19.8, 0., 4x.0004, 0., 1005, 2, 0.,
-.73, .26, 30., .688, 4x0., 5738., 2002, 3, 0.,
-.43, -.46, 5., .1849, 4x0., 2306., 2003, 3, 0.,

The first three numbers in each source term are the x, y and z coordinates, with the yellowcake stack at the origin. The fourth number is the area. The fifth through the ninth numbers are curies per year of U-238, Th-230, Ra-226, Pb-210 and Rn-222 respectively, released to the atmosphere. The tenth number is for identification. The eleventh number is the particle size set number and the twelfth is the stack diameter times the exit velocity.

The particulate activity released to the atmosphere from each source was calculated as follows:

- (1) Several assumptions are made in calculating the yellowcake stack source term.

These are:

- a. ore grade is 0.14% (19).
- b. 93% of the uranium in ore is recovered (8).
- c. 0.1% of recovered uranium is lost up the stack (8).

(2000 tons of ore/day) (0.90718 MT/ton) (216 operating days/year)
(0.0014 MT U₃O₈/MT of ore) (10⁶ g/MT) (0.93) (0.85 g U-nat/g U₃O₈)
(3.33x10⁻⁷ Ci/g U-238) (0.001) = 0.144 Ci of U-238/year.

Th-230, Ra-226 and Pb-210 are present in HMC yellowcake at 3.3%, 0.95% and 0.10%, respectively, of the U-238 activity (19). Therefore, the yellowcake stack emits 0.0048 Ci of Th-230, 0.0014 Ci of Ra-226 and 1.44E-4 Ci of Pb-210 per year.

- (2) As the ore is dumped onto the ore pad, 0.04 lbs/ton is lost to the atmosphere as dust (20). The specific activity of U-238, Th-230, Ra-226 and Pb-210 in ore is 396 pCi/g (19). It was conservatively assumed that only the fine parts of the ore are lost as dust. Because the specific activity of fines is 2.5 times as high (8), the specific activity of each nuclide in dust is 990 pCi/g. The release rate is therefore:

(0.04 lbs/ton) (453.59 g/lb) (2000 tons/day) (216 operating days/year)
(990 pCi/g) (10⁻¹² Ci/pCi) = 7.76E-3 Ci/year.

- (3) The dusting rate from the ore pad, and hence the radionuclide release, is calculated by MILDOS.

- (4) Dumping ore into the grizzly produces 0.037 pounds of dust per ton of ore (20). The release rate is:

(0.037 lbs/ton) (453.59 g/lb) (2000 tons/day) (216 operating days/year)
(990 pCi/g) (10⁻¹² Ci/pCi) = 7.18E-3 Ci/year.

- (5) Conveying of ore (including transfer points) produces 0.2 lbs/ton of dust. Crushing of ore with 8-9% moisture content produces 0.04 lbs/ton (20). The release rate is:

((0.2+0.04) lbs/ton) (2000 tons/day) (216 operating day/year) (453.59 g/lb) (990 pCi/g) (10⁻¹² Ci/pCi) = 4.66E-2 Ci/year.

However, conveying and crushing operations are conducted in an enclosure with a 99% efficient bag filter (19). Hence only 1% escapes to the atmosphere.

4.66E-2 Ci/year x 0.01 = 4.66E-4 Ci/yr

- (6) The ore dryer operates at 185 MT/hr, but only for 50 hours a year. It is equipped with a 97% efficient dust collector. It is assumed that 1.6 kg of dust per metric ton of ore is released (19). Therefore, the release rate is:

$$(185 \text{ MT/hr}) (50 \text{ hrs/yr}) (1.6 \text{ kg/MT}) (10^3 \text{ g/kg}) (0.03) (990 \text{ pCi/g}) (10^{-12} \text{ Ci/pCi}) = 4.4 \times 10^{-10} \text{ Ci/yr.}$$

- (7) Particulate release from the tailings were calculated by MILDOS.

Radon source terms were calculated as follows:

- (1) The amount of radon available for release to the atmosphere from the ore pad is given by the equation (8):

$$\begin{aligned} R_n &= E(R_a) (DC) T \\ &= 0.2 (396) (0.181) 10 \\ &= 144 \text{ pCi/g of ore} \end{aligned}$$

Where E is the emanation factor,

R_a is the specific activity of radium in ore,

DC is the decay constant for radon,

T is a ten day supply of ore.

The total amount of radon released is therefore:

$$(144 \text{ pCi/g}) (2000 \text{ tons/day}) (216 \text{ operating days/year}) (0.91 \text{ MT/ton}) (10^6 \text{ g/MT}) (10^{-12} \text{ Ci/pCi}) = 56.6 \text{ Ci/year.}$$

- (2) Ore is stored in the fine ore bins sufficiently long for radon to come into equilibrium with radium. The radon emanation factor is 0.2 (8).

$$(0.2) (396 \text{ pCi/g}) (10^6 \text{ g/MT}) (0.91 \text{ MT/ton}) (2000 \text{ tons/day}) (216 \text{ operating days/year}) (10^{-12} \text{ Ci/pCi}) = 31.14 \text{ Ci/year.}$$

- (3) Radon emissions from the main tailings pile are calculated as shown. The pile has an area of 0.688 km². However, 0.228 km² are covered with water and has a radon flux of zero.

$$((1.0 \text{ pCi Rn/m}^2 \text{ - sec}) / (\text{pCi/ Ra/g})) (396 \text{ pCi Ra/g}) (0.460 \text{ km}^2) (10^6 \text{ m}^2/\text{km}^2) (3.15 \times 10^7 \text{ sec/yr}) (10^{-12} \text{ Ci/pCi}) = 5738 \text{ Ci/yr.}$$

- (4) The radon source term for the inactive Sapien pile is shown below. The entire pile was assumed to be dry.

$$\frac{((1.0 \text{ pCi Rn-222/m}^2 \cdot \text{sec}) / (\text{pCi Ra-226/g tailings})) (396 \text{ pCi/g Ra-226})}{(0.1849 \text{ km}^2) (10^6 \text{ m}^2/\text{km}^2) (3.15 \times 10^7 \text{ sec/year}) (10^{-12} \text{ Ci/pCi})} = 2306 \text{ Ci/year.}$$

QAJUST = .935, 1.468, .438, 3x1., 4x0.,
 .935, 1.468, .438, 0., 2x1., 4x0.,
 .935, 1.468, .438, 3x2., 4x0.,
 .935, 1.468, .438, 0., 2x1., 4x0.,
 .701, 1.101, .329, 3x.75, 4x0.,
 .935, 1.468, .438, 0., 2x1., 4x0.,
 .935, 1.468, .438, 3x1., 4x0.,
 .935, 1.468, .438, 0., 2x1., 4x0.,
 .935, 1.468, .438, 3x2., 4x0.,
 .626, 2x.669, 2x0., .669, 4x0.,
 .935, 2x1., 2x0., 1., 0.075, 3x0.,
 3x1., 2x0., 1., 4x0.,
 3x1., 2x0x, 1., 4x0.,
 40x0.,

Source adjustment for each timestep. Each source has two lines, one for particulates and one for radon. The first six sources are directly proportional to the ore processing rate, with particulates from the ore pad being reduced by 15% due to occasional watering. The next three sources show the growth in the tailings piles.

DM = 695.,

The mixing height in meters (4).

FFORI = FFORP = FHAYI = FHAYP = 0.5

Assumes that half of the livestock feed requirements come from local pastures, and the other half is from locally grown stored feed.

FPR = 280., 1150., 1.,

Food production rate of vegetables, meat and milk (kg/yr-km²).

PAJUST = .98, 1.01, 1.04, 3x1.09, 1.14, 3x0,

Population adjustments for each timestep, referenced to 1978 population.

IADD = 17,

The number of receptor locations.

XRECEP = 1.47, -.57, -11.,
 -1.57, -.71, -11.,
 -.69, 1.31, 0.,
 -.87, .74, 0.,
 -.49, .58, 0.,
 .39, .35, 0.,
 -.69, -1.45, -8.,
 -.16, -1.08, 0.,
 -1.54, -1.33, -10.,
 .56, 12., 0.,
 1.95, 2.81, 6.,
 9.76, -1.24, 151.,
 3.10, -7.81, -20.,
 2.43, -9.90, -44.,
 -3.14, -5.24, -11.,
 13.14, 8.71, 90.,
 0.15,, -0.12, 0.

Receptor location coordinates, referenced to the base of the yellowcake stack; x and y are in kilometers and z is in meters.

NSTEP = 7,

The number of timesteps.

TSTART = 1957.0

The mill started operations in 1957.

TSTEP = 21, 3, 4, 4x5, 3x0,

The duration in years of each timestep.

NAS = 1,

First area source, the ore pad.

NODE = 1, 2, 3, 4,

The numbering system for each of the corners.

NNODE = 4,

Total number of nodes.

XS = 190., 360., 190., 360.,

YS = 2x-40., 2x130.,

x and y coordinates of the corners

NAS = 1,

Second area source, the ~~ore~~ main tailings pile.

NODE = 1, 2, 3, 4,
NNODE = 4,
XS = -1400., -70., -1400., -70.,
YS = 2x0., 2x520.,
NAS = 1,

Third area source, the old Sapien pile.

NODE = 1, 2, 3, 4,
NNODE = 4,
XS = -640., -210., -640., -210.,
YS = 2x-670., 2x-240.,

The Sapien pile is not actually rectangular, but by keeping the center point and area the same as they actually area and changing the shape makes it easier to input. The shape does not affect the final conclusions.

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<u>Brown</u>	Sect. Mgr.	<u>MFB</u>	<u>06/21</u>	<u>06/21</u>
<u>Hargis</u>	Bur. Chief	<u>KMH</u>	<u>6/21</u>	<u>6/21</u>
<u>Richard Holland</u>	Dep. Dir.	_____	_____	_____
<u>Denise Fort</u>	Director	_____	_____	_____

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COMMENTS BY DRAFTER OR REVIEWER(S):

This is radiological assessment for release
to the public as part of re-licensing
process for the Homestake uranium mill.