ANALYSIS OF POTENTIAL RADIATION-INDUCED GENETIC AND SOMATIC EFFECTS TO MAN FROM MILLING OF URANIUM

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INTRODUCTION

Potential radiation-induced somatic and genetic effects are among the risks associated with radionuclides released during mining and milling of uranium. These risks are associated with inhalation and ingestion of the radionuclides and external exposure to radiation. Quantification of these risks is a sequential process of estimating rates of release to and dispersion and uptake of radionuclides within the ecosystem, determining the levels of exposures and uptake of the radionuclides by man, calculating radiation doses to organs at risk, and, finally, predicting potential somatic and genetic effects as a function of time and age of the exposed individuals.

Comprehensive methods for computation of each of the sequential steps were previously reported (Momeni et al. 1979, 1983). The dosimetric methods used here were previously applied to analyses of pathways of exposure from the Jackpile-Paguate Uranium Mines in New Mexico, USA (Momeni 1983) and generic analyses of uranium milling in the USA (USNRC 1980). The calculation of potential radiation-induced genetic and somatic effects from mining of uranium was previously reported (Momeni 1983; Momeni et al. 1983). This report constitutes a summary of the analyses of radiation-induced genetic and somatic effects associated with uranium milling using the previously published dosimetric models data (USNRC 1980). The risks were calculated using the PRIM code (Momeni 1983). The risk-analysis method utilized in the PRIM code is based on competitive morality in a dynamically changing population. The birth and death rates are calculated from the lifetable and cohort-component method and are based on 1969-1971 census statistics of the population in the USA. The probabilities of radiation-induced risks are calculated using age-dependent absolute and relative risk models. The risk coefficients were adopted from the National Academy of Sciences report BEIR III (NAS 1980).

PATTERNS OF MORTALITY

The patterns of mortality (i.e., specific death rates as a function of time) for all causes, including spontaneous and radiation-induced neoplasms, were calculated from demographic characteristics of the exposed population. The exposure patterns are for a hypothetical "model" mill processing 1800 tonnes of ore daily and operating continuously for 15 years as described by the U.S. Nuclear Regulatory Commission (USNRC 1980). The processed ore was assumed to have an average specific activity of 460 pCi U-238/g and to be under secular radioactive equilibrium. The exposed population was assumed to be 57 428 persons (USNRC 1980).

Cumulative five-year mortality from spontaneous neoplasms in the exposed population for an observation period of 85 years was calculated (Table 1). For the same period, radiation-induced mortality from the same cancers was predicted

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Table 1. Spontaneous Cancer Mortality for Five-Year Periods
Calculated using PRIM Code†[1]

Time (Years)	CA-1	CA-2	CA-3	CA-4	CA-5	CA-6	CA-7	CA-8	CA-9	CA-10	CAS	CAS/DEATH
5	18.5	96.6	28.8	121.0	39.6	2.6	24.9	24.9	24.9	342.1	724.0	2.07E-01
10	18.9	99.1	29.6	123.9	39.4	2.7	25.5	25.5	25.5	348.8	739.0	2.05E-01
15	20.4	104.8	32.3	134.6	41.8	2.8	28.4	28.4	28.4	373.9	795.7	2.02E-01
20	21.9	109.8	34.8	144.4	44.5	2.9	31.0	31.0	31.0	397.9	849.1	2.00E-01
25	23.2	114.1	37.0	152.7	47.3	3.0	33.3	33.3	33.3	419.0	896.0	2.04E-01
30	24.3	119.3	38.9	160.3	50.3	3.2	35.2	35.2	35.2	440.2	942.1	2.12E-01
35	25.2	125.7	40.6	167.7	53.3	3.3	36.8	36.8	36.8	461.6	987.9	2.16E-01
40	26.1	133.9	42.3	175.7	56.3	3.5	38.2	38.2	38.2	485.1	1037.4	2.10E-01
45	27.2	143.9	44.4	185.2	58.9	3.6	39.6	39.6	39.6	512.3	1094.3	2.20E-01
50	28.6	155.5	47.3	197.7	61.7	3.9	41.7	41.7	41.7	546.9	1166.5	2.25E-01
55	30.7	166.9	51.3	213.5	64.9	4.2	45.0	45.0	45.0	587.7	1254.3	2.32E-01
60	33.2	176.4	55.8	230.5	68.6	4.4	49.5	49.5	49.5	629.1	1346.4	2.34E-01
65	35.4	183.2	59.6	244.8	72.1	4.6	53.7	53.7	53.7	662.8	1423.4	2.32E-01
70	36.8	187.5	62.0	253.9	74.5	4.7	56.5	56.5	56.5	683.7	1472.5	2.29E-01
75	37.4	190.8	63.0	257.8	75.9	4.8	57.5	57.5	57.5	693.5	1495.8	2.27E-01
80	37.6	194.7	63.3	259.6	76.8	4.9	57.4	57.4	57.4	701.2	1510.5	2.26E-01
85	38.1	200.1	64.3	263.8	78.2	5.0	57.6	57.6	57.6	716.3	1538.4	2.29E-01
Total	483.6	2502.2	795.3	3287.1	1004.2	64.0	711.7	711.7	711.7	9001.9	19 273.4	

†[1] CA = Cancer; CA-1 = Leukemia; CA-2 = Lung; CA-3 = Stomach; CA-4 = Intestines; CA-5 = Breast; CA-6 = Bone; CA-7 = Liver + Pancreas; CA-8 = Sex + Urinary; CA-9 = Lymphoma; CA-10 = All Others; CAS = Total of all cancers; death = death from all cancers and ages.

by both the absolute and relative risk models to be less than 0.1 in any consecutive five-year period. Cumulative deaths (85-year integration) from all spontaneous neoplasms were 19 273.4, and from radiation-induced neoplasms were 0.5 and 1.3 as calculated by the absolute and relative risk models, respectively.

The ratios of predicted mortality from radiation-induced neoplasms to mortality from spontaneously induced neoplasms are 2.5×10^{-5} and 6.7×10^{-5} from the absolute and relative risk models, respectively. Based on these analyses, during the first five-year period, spontaneously induced neoplasms represent 20.7% of all deaths, increasing over the 85-year period to 22.9%. Similarly, radiation-induced deaths constitute 1×10^{-5}% of all deaths in the first period, increasing to 3×10^{-3}% over 85 years.

GENETIC EFFECTS

The numbers of radiation-induced dominant and multifactorial genetic disorders were calculated using equilibrium genetic-induction factors of 6.0×10^{-7} and 5.0×10^{-7} disorders per mrem for dominant and multifactorial effects, respectively. The exposure period for males was limited to ages older than 15, and for females to ages younger than 50. The exposure period of female germ cells was assumed to be continuous and cumulative from birth to copulation; for males, exposure of germ cells was assumed to be limited to only 36 days of continuous irradiation prior to copulation. The doses to gonads were normalized on the basis of radiobiological sensitivity by factors 0.8 and 0.2 for females and males, respectively (NAS 1980). The cumulative genetic disorders for the entire population over the 85-year period were predicted to be 8.0×10^{-3} and 6.7×10^{-3} for dominant and multifactorial disorders, respectively. The current incidence of genetic disorders from natural causes in the USA is 10.7% for live born (NAS 1980).

SUMMARY AND DISCUSSION

Potential mortality from natural causes and from radiation exposure conditions typical of those in the vicinity of uranium mills in the western USA was calculated. The exposure conditions were those assumed to exist in the vicinity of a hypothetical model mill as previously described (USNRC 1980). Dose rates to organs at risk were calculated as a function of time using the Uranium Dispersion and Dosimetry Code (Momeni et al. 1979). The changes in population size, birth rates, and radiation-induced and natural mortalities were calculated using the PRIM code (Momeni 1983) and are summarized in Table 2.

The population of the region within a radius of 80 km from the model mill is projected to increase from 57 428 to 75 638.6 during the 85 years of this analysis. Within the same period, the average birth rates for five-year periods increase from 5067.8 to 7436.1. The cumulative deaths within the five-year periods increase from 724 and 3501.8 from spontaneously induced neoplasms and all causes, respectively, to 1538.2 and 6718.2. In comparison to natural causes, radiation-induced mortality is negligible. The highest rate of death from radiation in any five-year period is only 0.2, compared with 1538.2 deaths attributable to spontaneous incidence. The total radiation-induced genetic disorders were much less than unity for the 85-year period of analysis, in contrast with the 10.7% natural incidence of these disorders.

Table 2. Cumulative Deaths from Natural and Radiation-Induced Causes

Time (Years)	Total Population	Total Births	Cancer Deaths: Radiation-Induced: Absolute Risk Model	Cancer Deaths: Radiation-Induced: Relative Risk Model	Cancer Deaths: Natural	All Deaths
5	57 428.0	5067.8	0.0	0.0	724.0	3501.8
10	58 994.0	5491.8	0.0	0.0	739.0	3597.7
15	60 888.1	5829.8	0.0	0.0	795.7	3940.5
20	62 777.4	5765.0	0.0	0.0	849.1	4238.6
25	64 303.7	5501.4	0.0	0.0	896.0	4384.1
30	65 421.0	5443.8	0.0	0.0	942.1	4452.7
35	66 412.1	6211.8	0.0	0.0	987.9	4566.6
40	68 057.3	5994.1	0.0	0.0	1037.4	4935.9
45	69 115.5	6221.4	0.0	0.0	1094.3	4979.4
50	70 357.4	6278.4	0.0	0.1	1166.5	5187.1
55	71 448.7	6397.1	0.0	0.1	1254.3	5412.3
60	72 433.6	6622.8	0.0	0.1	1346.4	5743.9
65	73 312.3	6822.0	0.1	0.1	1423.4	6127.4
70	74 006.9	6973.3	0.1	0.2	1472.5	6432.0
75	74 548.1	7111.7	0.1	0.2	1495.8	6600.6
80	75 059.1	7253.7	0.1	0.2	1510.5	6673.2
85	75 639.6	7436.9	0.1	0.2	1538.4	6718.8

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