FINAL

Assessment of Variations in Radiation Exposure in the United States

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Prepared for:

U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
1310 L Street, N.W.
Washington, DC 20005

Ken Czyscinski
Work Assignment Manager

Prepared by:

John Mauro, PhD, CHP
Nicole M. Briggs
S. Cohen & Associates
6858 Old Dominion Drive
Suite 301
McLean, VA 22101

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APPENDICES

1.0 INTRODUCTION AND SUMMARY

In accordance with Task 4 of Work Assignment 1-02, Contract EP-D-05-002, SC&A, Inc., has compiled information and developed a database on the nationwide variations in annual radiation exposures due to various sources of radiation in the environment. These sources include terrestrial radiation, cosmic radiation, indoor radon, internal emitters, nuclear weapons testing fallout, diagnostic medical procedures, and consumer products. The radiation exposures described in this report, along with the databases provided in the appendices, provide information that can be used to compare the radiation exposures that different segments of the U.S. population are experiencing due to background radiation, which, for the purposes of this report, is defined to include both natural background radiation and ubiquitous sources of man-made radiation. All exposures are presented in terms of effective dose equivalent (EDE[1]), as opposed to individual organ dose, in order to facilitate inter-comparisons among the different sources of background radiation.

Of particular interest to this report is the substantial geographic variability of exposures to radon and terrestrial and cosmic radiation. In order to characterize the degree of geographic variability of exposure to these sources of background radiation, this report draws primarily upon reports and databases prepared and compiled by the Environmental Protection Agency (EPA), the National Academy of Sciences (NAS), the National Council on Radiation Protection and Measurement (NCRP), and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). These reports provide information that allows comparisons of U.S exposures among different regions, among states, and, to a degree, among counties and cities. It is also noteworthy that exposure to indoor radon varies substantially among individual homes and also within a given home in terms of whether residents reside primarily in the basement, the first floor, or the second floor of a home. In addition, external exposure to background radiation also varies significantly depending on the structural material used to build a home, i.e., stone versus brick versus wood frame.

Because of the variability of background radiation exposures within and among homes, and the variability of background radiation within a given region, state, and county, generalizations regarding background exposures within a given geographical location, as provided in this report, must be used with a degree of caution. Specifically, though a household or group of households are located within a given geographic region of the U.S., as described in this report, it does not necessarily mean that those households are in fact experiencing the indicated radiation exposures. The geographic variability in background exposures as presented in this report is best interpreted as generally representative of a given geographical location, but not necessarily applicable to a given home.

Because exposure to radon and terrestrial and cosmic radiation together account for the majority of the background radiation exposures in the U.S (i.e., over 70%) and are also responsible for the geographic variability in exposures, this report emphasizes these sources of exposures. The contribution from internal emitters, nuclear weapons testing fallout, diagnostic medical

[1] The effective dose equivalent is the radiation dose to any organ or by any type of radiation (i.e., alpha, beta, gamma, neutron) that is equivalent in terms of health risk to a uniform whole-body exposure to external gamma radiation. For example, a dose to the lung of 1 rem is equivalent to 0.12 rem to the whole body in terms of health risk.

procedures, and consumer products are discussed separately. Doses from these pathways are not area-specific and are not included in the geographic-based tables provided in the appendices.

The accepted value for the average background radiation dose from natural and man-made sources to people living in the United States is 360-mrem/year effective dose equivalent (EDE) (BEIR 1990). Figure 1 presents a breakdown of the sources of background radiation and the average annual EDEs associated with those sources, as described by the Committee on the Biological Effects of Ionizing Radiations in their 1990 publication. This figure illustrates that the dose from exposure to indoor radon (200 mrem/year EDE) represents over 50% of the total dose. The "other" section in Figure 1 includes per capita[2] doses due to occupational exposures of radiation workers, exposures to the public from emissions from nuclear fuel cycle facilities, and fallout. Of these minor sources of background radiation exposures, only fallout is discussed in this report, due to its ubiquitous nature.

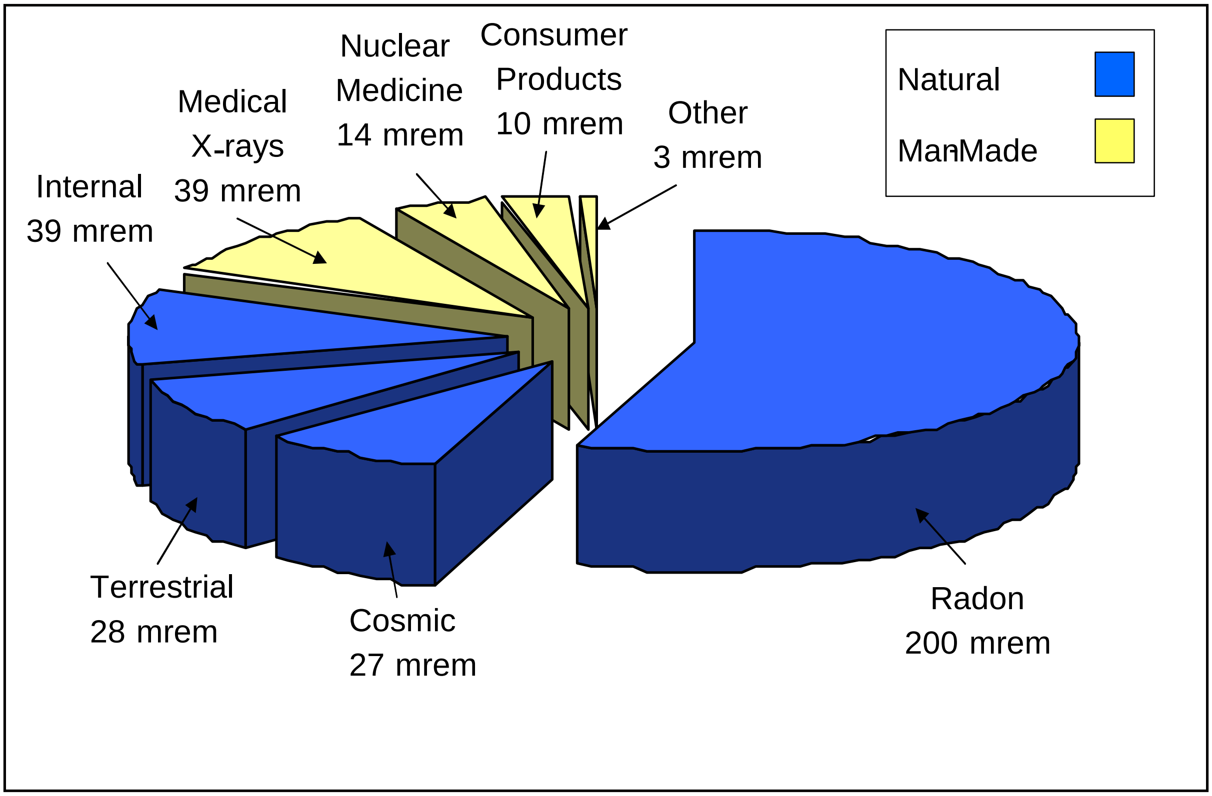

Figure 1. Sources of Radiation Exposure to the U.S. Population
(derived from Figure 1-1 of BEIR 1990)

The U.S. Department of Energy (DOE) has estimated that the average background dose to the people living near the proposed site of the Yucca Mountain Repository in Amargosa Valley, Nye County, Nevada, is slightly above the U.S. average at 400 mrem/year EDE. DOE has also determined that the maximum dose incurred by people in Amargosa Valley due to the proposed repository will be an additional 260 mrem/year EDE, bringing the total background dose to 660 mrem/year EDE. This incremental dose is not expected to occur until approximately 300,000 years after the repository has closed. As a means of comparison, DOE notes that there

[2] Per capita refers to the doses averaged over all members of the U.S. population.

are people living in the northeast region of Washington State who could be receiving 1,700 mrem/year EDE from background radiation (OCRWM 2005).

The background radiation database provided in this report was developed in MS Excel and includes estimates of the average doses from terrestrial radiation, cosmic radiation, and indoor radon for different geographic regions in the U.S. and by state. In addition, where the data are available, comparisons among major cities in the U.S. are provided.[3] The dose equivalents for terrestrial and cosmic radiation for each state obtained from Bogen and Goldin (1981) were added to the average dose equivalents for indoor radon derived from the U.S. Environmental Protection Agency (EPA) for each state (EPA 1993a). The indoor radon data, which were originally published in units of pCi/L, were converted to dose by assuming 200 mrem/year EDE per pCi/L of measured indoor radon (NCRP 1987a, Table 2.4). Indoor radon is discussed in greater detail in Section 3 of this report.

The total average annual doses (in units of mrem/year EDE) for each state from cosmic radiation, terrestrial radiation, and indoor radon are presented in Table 1. The values for radon exposure are based on measurements made in 5,694 homes drawn from a survey of 11,423 homes. This population was drawn from an eligible universe of nearly 72 million households out of the 93 million households in the U.S. (EPA 1993a). The radon concentrations represent the average concentration in the living space of each home. Whole-body doses to terrestrial and cosmic radiation take into consideration shielding by the home and self-shielding. Accordingly, the doses represent realistic estimates of the doses experienced by typical residents in each state. Figure 2 presents these natural background dose estimates on a map of the United States.

The last row in Table 1 presents the average values. These average values must be used with caution because they do not represent the average exposures associated with all measurements, but represent the average of the average values for each state. For radon exposures, two averages are presented; the average among the state averages for states where we have data, and the value in parenthesis, which is the average of the average values for the 5,694 homes that comprised the survey. The averages in Table 1 are in close agreement with the values presented in Figure 1 for cosmic and terrestrial radiation, but the exposure associated with indoor radon in Figure 1 is substantially lower than the averages in Table 1. The sources of the information used by the BEIR Committee to prepare the values in Figure 1 differ from the sources of the data used to derive the exposures provided in Table 1. As a result, it is not surprising that there are differences among the values, especially for the radon exposures.

[3] The database containing the radon concentration measurements for each home in the survey does not include identifiers that allow sorting the data by city. Conversations with the authors of the report reveal that the original database included the zip code for each house, which would allow sorting the data according to city. However, at the time of preparation of this report, the zip code data was not available, and therefore it was not possible to provide radon levels in homes sorted by city.

Table 1. Total Average Annual Doses (mrem/year EDE) from Cosmic Radiation, Terrestrial Radiation, and Indoor Radon

State	Dose Equivalent (mrem/year)			
	Cosmic	Terrestrial	Radon	Total
Alabama	27.1	22.5	170	219.6
Alaska	26.6	29.2	97	152.8
Arizona	31.5	29.2	250	310.7
Arkansas	27.5	19.1	142	188.6
California	26.8	23.2	126	176
Colorado	47.5	42.6	610	700.1
Connecticut	26.4	32.7	180	239.1
Delaware	26.3	20.1	112	158.4
District of Columbia	26.4	22.7	no data	Not enough data
Florida	26.2	14.3	91	131.5
Georgia	27.6	25.7	273	326.3
Hawaii	26.3	29.2	no data	Not enough data
Idaho	36.8	29.2	342	408
Illinois	27.4	26.6	343	397
Indiana	27.6	28.7	401	457.3
Iowa	28.3	29.2	727	784.5
Kansas	29.2	29.2	474	532.4
Kentucky	27.7	27.8	470	525.5
Louisiana	26.6	14.6	no data	Not enough data
Maine	26.8	29.2	286	342
Maryland	26.4	20.7	476	523.1
Massachusetts	26.4	29.0	228	283.4
Michigan	27.6	29.2	226	282.8
Minnesota	28.5	25.1	383	436.6
Mississippi	26.6	14.6	160	201.2
Missouri	27.6	28.7	350	406.3
Montana	36.3	29.2	no data	Not enough data
Nebraska	29.3	29.2	361	419.5
Nevada	36.6	21.2	164	221.8
New Hampshire	27.3	29.2	378	434.5
New Jersey	26.2	28.0	98	152.2
New Mexico	45.7	33.7	269	348.4
New York	26.5	28.8	223	278.3
North Carolina	27.8	24.4	268	320.2
North Dakota	29.9	29.2	730	789.1
Ohio	27.7	28.0	417	472.7
Oklahoma	29.0	28.8	247	304.8
Oregon	27.4	29.2	99	155.6
Pennsylvania	27.2	23.2	293	343.4
Rhode Island	26.3	27.4	no data	Not enough data
South Carolina	25.9	23.4	no data	Not enough data
South Dakota	30.7	29.2	903	962.9
Tennessee	27.6	25.1	511	563.7
Texas	28.1	18.2	165	211.3
Utah	41.8	29.2	196	267
Vermont	27.3	29.2	no data	Not enough data
Virginia	27.2	21.4	260	308.6

Table 1. Total Average Annual Doses (mrem/year EDE) from Cosmic Radiation, Terrestrial Radiation, and Indoor Radon

State	Dose Equivalent (mrem/year)			
	Cosmic	Terrestrial	Radon	Total
Washington	26.9	29.2	79	135.1
West Virginia	28.9	29.9	197	255.8
Wisconsin	27.8	29.2	293	350
National Average	29.5	26.6	303	359 (294)

Figure 2. Average Annual Natural Background Doses (mrem/year) based on Cosmic Radiation, Terrestrial Radiation, and Mean Indoor Radon Levels

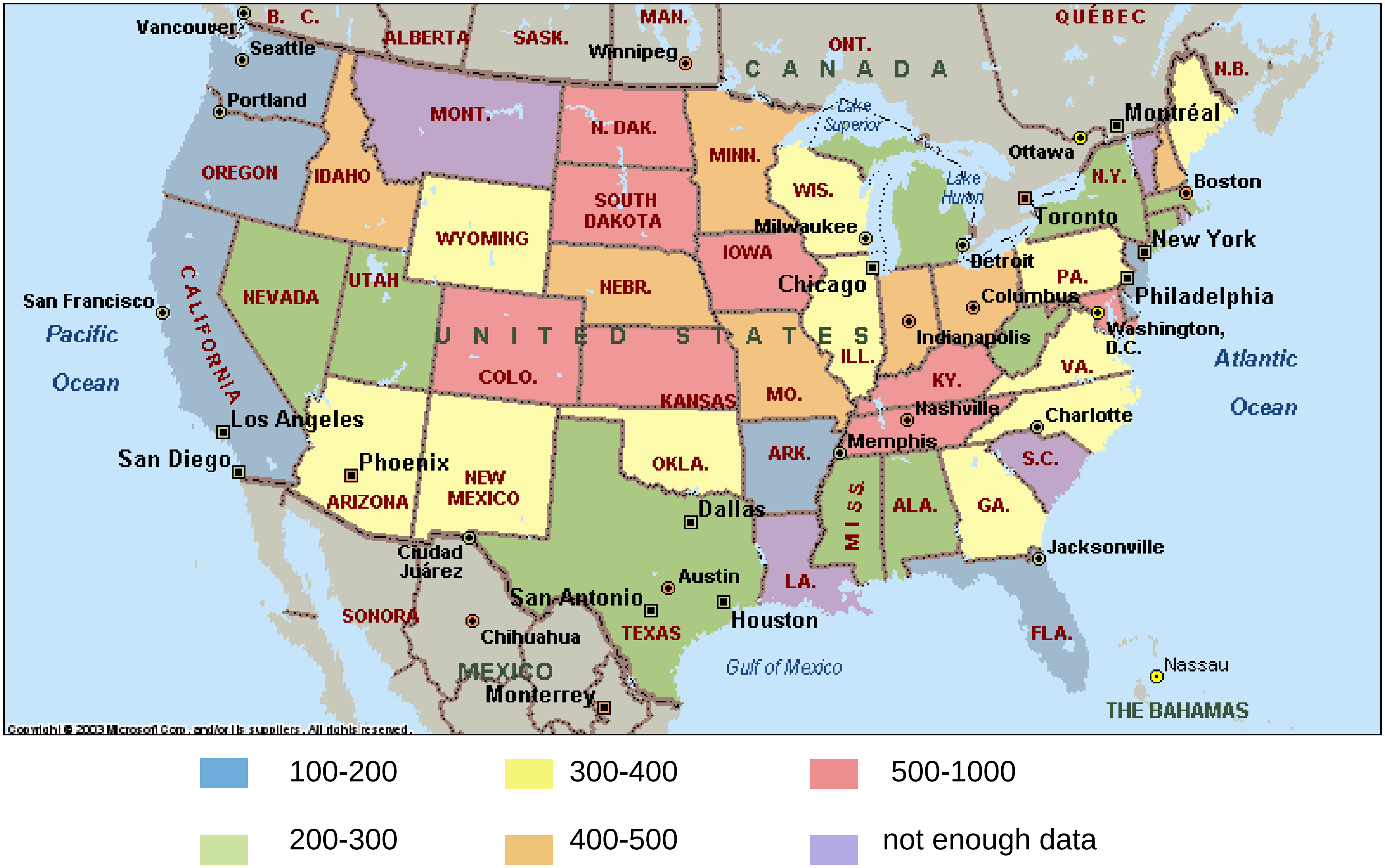

Table 1 reveals that there is variation in average natural background radiation doses throughout the United States, ranging from 131.5 mrem/year in Florida to 962.9 mrem/year in South Dakota, a difference of 831.4 mrem/yr EDE. The estimated average background dose in Nevada of 221.8 mrem/year is toward the low end of this range. Keep in mind that these doses do not include other sources of ubiquitous natural and man-made exposures (i.e., internal, medical, consumer products, and other miscellaneous sources of exposure), which would add approximately an additional 100 mrem/yr to these exposures.

Since the values in Table 1 represent estimates of the average background exposures over each state, smaller locations within each state and individual households have an even wider range of values. Appendix B presents estimates of the maximum doses associated with the average annual radon concentration measurements observed in individual homes. As may be noted, the maximum doses associated with radon measurements made in individual homes ranged from a low of 1,034 mrem/yr for California to a high of 10,581 mrem/yr in South Dakota; a difference of 9,547 mrem/yr EDE.

In addition to the databases provided in Appendices A and B, as summarized in Table 1, SC&A compiled nationwide estimates of the average dose to members of the population from internal emitters, diagnostic medical procedures (including x-rays and nuclear medicine), and Nevada Test Site (NTS) and global fallout. These sources of background radiation are discussed in detail in the sections below, but are not included in Table 1 or the appendices. Appendix C presents population and migration changes in the U.S., and in particular, in the state of Nevada and Nye County, Nevada. The tables in Appendix C illustrate that population shifts occur between areas with high and low levels of background exposure.

Not included in these exposures or described in this report are locations where individuals may be experiencing localized elevated levels of exposures, such as households in the Reading Prong area in Pennsylvania, where some residents were exposed to highly elevated levels of indoor radon, or residents in the vicinity of some uranium mines and mills. This report also does not address the degree to which many locations with elevated exposures to either naturally occurring or man-made radiation have been mitigated. Radon mitigation is discussed further in Section 3. It is worth noting that radon mitigation that has been implemented subsequent to the completion of the National Residential Radon Survey likely reduced the high-end indoor radon concentrations and doses for individual homes in each state as presented in Appendix B. However, the statewide average radon concentrations in the living spaces, as presented in Appendix B, most likely have not been reduced substantially as a result of mitigation, because the number of mitigated homes is extremely small as compared to the total number of homes.

2.0 TERRESTRIAL AND COSMIC RADIATION

This section summarizes the discussion of external terrestrial radiation from UNSCEAR (1993). Appendix A presents a database summarizing the annual radiation doses in each state in the U.S., along with the highest and lowest dose rates for individual cities or locations within each state, as reported by Bogen and Goldin (1981). The cosmic radiation doses range from 26 mrem/year in most coastal regions to 50.4 mrem/year in Wyoming. The terrestrial radiation doses range from 7.4 mrem/year in Orlando, Florida, to 57.4 mrem/year in Denver, Colorado.

EPA has developed a background dose calculator located on their website,[4] which includes location-specific cosmic and terrestrial background calculators. According to this calculator, the cosmic radiation dose experienced at sea level is 26 mrem/year, with incremental increases in dose with increasing elevation. The EPA calculator describes the terrestrial radiation dose as 23 mrem/year for the Gulf Coast and the Atlantic Coast, 90 mrem/year for the Colorado Plateau, and 46 mrem/year for the rest of the country. These values are comparable to the Bogen and Goldin (1981) doses presented in Appendix A.

2.1 Terrestrial Radiation

Terrestrial radiation is radiation from naturally occurring radionuclides in the soil, which include K-40, Th-232, U-238, Rb-87, and U-235 and their progeny. External exposures from terrestrial radiation occur both indoors and outdoors. Houses and buildings provide some shielding from radiation emanating from the soil. However some structures, like those made from concrete, brick, and stone, contain radionuclides and emit radiation. In those instances, the dose received inside the building could exceed that from the outside. The dose from terrestrial radiation is generally higher in areas with more bedrock, like mountainous regions, and lower in sandy, coastal areas. Naturally occurring radionuclides in the soil also result in internal exposures, which are discussed in Section 5 and Section 7.

The data for external terrestrial radiation exposure were obtained from the 1981 Bogen and Goldin report on natural background radiation. Bogen and Goldin estimate the doses to the population of the U.S. from terrestrial radiation by city and also by general region (i.e., non-urban coastal plains and non-urban non-coastal plains). These data are based on the measurements published by Oakley (1972), but corrected for shielding by structures and the human body. Oakley's estimates of terrestrial dose were based on aerial survey measurements.

It is instructive to note that not only are there substantially large differences in the average terrestrial doses among states (e.g., 14.3 mrem/yr in Florida versus 42.6 in Colorado), but there are also large differences in the average terrestrial dose rates among cities within a state. For example, in Colorado, the average terrestrial dose rate in Pueblo is 29.2 mrem/yr, while in Denver it is 57.4 mrem/yr. In Las Vegas, Nevada, the terrestrial dose rate is 12.7 mrem/yr, while in non-urban regions of Nevada it is 29.2 mrem/yr.

The average terrestrial radiation exposures in different regions of the U.S also differ substantially. For example, the EPA dose calculator (see web site cited above) indicates that the

[4] http://www.epa.gov/radiation/students/calculate.html

annual dose rate from terrestrial radiation ranges from 23 mrem/yr in the Gulf Coast and Atlantic Coast to 90 mrem/yr on the Colorado Plateau.

2.2 Cosmic Radiation

Cosmic radiation is radiation that originates from our galaxy (galactic cosmic rays) and from the sun (solar particle radiation). The radiation from both of these sources is affected by the earth's magnetic field. The low-energy radiation is usually deflected by the magnetic field, while the high-energy rays are able to penetrate the atmosphere. The cosmic radiation dose incurred by a person on the earth is dependent upon altitude, latitude, and shielding. For the most part, the dose received from ionizing cosmic radiation at a high elevation is greater than the dose at sea level; and the dose received at high- and mid-latitudes is greater than the dose received at equatorial areas. This "latitude effect" is due to the fact that more low-energy protons reach the atmosphere at the poles than at the equator. Buildings offer some shielding from cosmic radiation. For example, a large concrete building could reduce the cosmic radiation dose by as much as 58% (UNSCEAR, 1993, Annex A, paragraph 23).

SC&A obtained data for cosmic radiation exposure from the 1981 Bogen and Goldin report on natural background radiation. As with the terrestrial radiation dose data, Bogen and Goldin present the doses to the U.S. population from cosmic radiation by city and also by general region. Bogen and Goldin (1981) state that these values are based on the "long-term average cosmic dose equivalent rates at various altitudes" estimated by NCRP (1975).

It is instructive to note that not only are there substantially large differences in the average cosmic radiation doses among states (e.g., 25.9 mrem/yr in South Carolina versus 50.4 mrem/yr in Wyoming), but there are also large differences in the average cosmic radiation dose rates among cities and regions with different elevations. A review of the EPA Dose Calculator reveals that people residing in regions and cities located at sea level experience cosmic ray dose rates of about 26 mrem/yr. As the elevation increases, the cosmic ray dose rate increases according to the following look-up table:

Elevation	Cosmic Ray Dose Rate (mrem/yr EDE)
Sea level	26 mrem/yr
Up to 1000 feet above sea level	Add 2 mrem/yr
1000 to 2000 feet above sea level	Add 5 mrem/yr
2000 to 3000 feet above sea level	Add 9 mrem/yr
3000 to 4000 feet above sea level	Add 15 mrem/yr
4000 to 5000 feet above sea level	Add 21 mrem/yr
5000 to 6000 feet above sea level	Add 29 mrem/yr
6000 to 7000 feet above sea level	Add 40 mrem/yr
7000 to 8000 feet above sea level	Add 53 mrem/yr
Above 8000 feet above sea level	Add 70 mrem/yr

For example, in Denver, Colorado, the average cosmic ray dose rate in Pueblo is 46.5 mrem/yr, while in Leadville, Colorado, which is located above 8000 feet above sea level, the cosmic ray dose rate is 90 mrem/yr.

3.0 INDOOR RADON

This section presents a summary of the data presented in NRC 1999 and EPA 1993a (*The National Residential Radon Survey*). Appendix B presents a database summarizing indoor radon exposures in the U.S derived from the data collected from the *National Residential Radon Survey*.

Radon (Rn-222) is a radioactive gas produced from the decay of radium-226, which is a member of the uranium-238 decay chain. Radon is colorless, odorless, and is found naturally in almost all types of soil. The amount of radon in the soil is dependent upon several factors, including concentration of radium in the soil, the soil's porosity and permeability, and moisture content. Areas with particular types of soil/bedrock (i.e., granite and limestone) have been shown to have higher levels of radon concentrations.

In order for the radon gas to enter a home, there must be a pressure gradient between the inside and the outside of the house. This pressure difference most commonly occurs in the winter, when furnace combustion and rising warm air create a pressure differential, allowing radon to enter the home through cracks in the foundation. Without ventilation, radon can build up inside the home, with the highest concentrations usually recorded in the lower and basement levels. The type and condition of the foundation can also determine if and how much radon will enter and concentrate inside a home. It should be noted that indoor radon levels in buildings and homes in the same geologic area could have very different indoor radon levels. The EPA's safety standard for indoor radon concentrations is 4 pCi/L.

Since the 1980s, the EPA has devoted a tremendous amount of resources to addressing issues of indoor radon. The first major nationwide indoor radon survey was the State/EPA Residential Radon Survey conducted between 1986 and 1992, and involved 60,000 indoor radon measurements taken in 42 states. EPA supplemented this data with measurements taken by independent state surveys, which included Delaware, Florida, Illinois, New Hampshire, New Jersey, New York, Oregon, and Utah. EPA (1993b) states that these surveys are "designed to be comprehensive and statistically significant at the state level." However due to the design of the survey, the averages are not considered statistically significant for many counties. For example, the radon survey performed in New Jersey has thousands of samples for each county, indicating that the mean radon level calculated is likely close to the true mean. If only one or a few samples were taken in a given county, those averages are not likely representative of the true mean for that county. This survey was also limited to measurements collected over a short period of time and was limited to the lowest levels in homes. As a result, the data collected in this first major survey did not represent the average exposures experienced by the U.S. population.

In order to remedy this limitation, EPA performed a supplemental survey that included measurements made in 5,694 homes drawn from a survey of 11,423 homes (EPA 1993a). This population was drawn from an eligible universe of nearly 72 million households out of the 93 million households in the U.S. Measurements were year-long and included the lowest living level for each home, the lowest non-living level, mean radon measurements over all living levels, and measurements made in the lowest level. The results of the survey are presented by region and for each state. SC&A calculated the average radon levels for each state and then assumed a dose rate of 200 mrem/year per pCi/L of measured indoor radon in order to determine the average annual dose for each state (NCRP 1987a, Table 2.4). Appendix B also presents the maximum-recorded radon values for the lowest living level, the lowest non-living level, and the mean overall living levels. The maximum values for a given state do not necessarily come from the same housing unit. For example, the maximum lowest living level reading and the maximum lowest non-living level reading could come from different homes.

It is instructive to note that, in addition to the variability in the average radon dose rates among states (e.g., a low of 79 mrem/yr in Washington as compared to a high of 903 mrem/yr in South Dakota; a difference of 824 mrem/yr), there is large variability in the average radon levels in different living spaces within states. For example, in Iowa, the average radon concentration in the lowest living level in the homes surveyed was 4.43 pCi/L (which corresponds to an annual dose of 886 mrem/yr EDE), while the average radon concentration observed among all the living spaces among the homes surveyed in Iowa was 3.64 pCi/L (which corresponds to a dose rate of about 728 mrem/yr); a difference of 158 mrem/yr.

Recently EPA published the report, *National Radon Results: 1985 to 2000*, by Gregory and Jalbert (2004), which examines the current state of radon mitigation and public awareness. Gregory and Jalbert (2004) report that, since the beginning of the EPA radon research effort in the mid-1980s, the amount of public awareness regarding radon, as well as the number of homes being mitigated, has increased dramatically. Since the start of the EPA/State Residential Radon Survey in the mid-1980s, 800,000 homes that had indoor radon levels of 4 pCi/L or more have been mitigated. Mitigation generally involves installation of a vent fan that removes the radon gas from the home. In 2003, approximately 80,000 homes have been mitigated. The indoor radon data presented in Appendix B is taken from the National Residential Radon Survey, which was completed in 1993. Therefore, the data presented here do not reflect the large mitigation effort that has taken place during the last 10-15 years.

4.0 NUCLEAR WEAPONS TESTING FALLOUT

4.1 Nevada Test Site and Global Fallout

In recent years, the radiation dose from fallout is only a small fraction of the total background dose. However, since the historical doses to fallout have been comprehensively studied, a brief discussion of fallout is presented here. The U.S. population receives radiation doses from fallout generated from two sources: (1) U.S. nuclear weapons tests performed at the NTS, and (2) tests performed outside the U.S. The fallout created by these two categories of tests differs in several important ways. Table 2 summarizes the differences described in CDC/NCI (2001).

Table 2. Characteristics of Nevada Test Site Fallout vs. Global Fallout

	NTS fallout	Global fallout
Yield	Low-yield tests	High-yield tests
Radioactive cloud	Lower layers of atmosphere	High layers of atmosphere
Time to fallout deposition	Days	Months to years
Radionuclides	Short-lived, I-131	Long-lived, Cs-137
Geographical distribution	Decreased with distance from NTS	Evenly distributed over U.S.

Fallout from high-yield global tests is evenly distributed over the entire United States and consists of long-lived radionuclides like Cs-137. The fallout from low-yield detonations at the Nevada Test Site, however, consisted of short-lived radionuclides, most importantly I-131, and were deposited in greater concentrations in the areas surrounding NTS.

4.2 Estimates of Current Fallout Dose to U.S. Population

Estimates of the dose to the U.S. population from nuclear weapons testing fallout have been presented in two comprehensive studies by the Centers for Disease Control and Prevention (CDC) and the National Cancer Institute (NCI). The 1997 study performed by the NCI titled *Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests* describes the doses to the thyroid from exposure to I-131 following the NTS nuclear weapons tests. The 2001 joint effort by the CDC and the NCI titled *A Feasability Study of the Health Consequences to the American Population from Nuclear Weapons Tests Conducted by the United States and Other Nations* expands on the 1997 NCI report and presents estimates of cumulative doses incurred by the U.S. population through the year 2000 from exposures to 43 radionuclides from both NTS and global fallout. The CDC/NCI report describes the doses on a county-by-county basis from both external radiation from deposited radionuclides, and internal doses from ingestion of radionuclides in water and food. Although both of these studies contain a tremendous amount of research and information pertaining to historical doses to fallout, they do not describe the present individual dose from fallout exposure. Given all of this information, SC&A has decided that the best estimate for the current dose from fallout comes from NCRP (1987b). At the time of this study in 1987, the NCRP estimated that the dose from fallout to the U.S. population was less than 1 mrem/year EDE.

5.0 INTERNAL EXPOSURES

This section summarizes the discussion of internal exposures from NCRP (1987b). Human beings receive radiation exposures from naturally occurring radionuclides contained in food, air, and water. This section focuses on ingested radionuclides, since the predominant inhaled radionuclide is radon, which has already been discussed in Chapter 4. Due to the large amount of potassium in the body, the major source of internal exposure is potassium-40 (K-40). Potassium-40 is contained in food, but since potassium is under homeostatic control,[5] changes in diet do not affect the levels of K-40 in the body. Rubidium-87 is metabolically similar to potassium, but it is not under homeostatic control. Exposures from Pb-210 and Po-210 are due to dietary intake and smoking. Smokers have been shown to have 2–3 times higher concentrations of Pb-210 and Po-210 in their lungs and ribs than non-smokers. Other ingested radionuclides that cause internal exposures include uranium, Th-232, Th-230, Th-228, Ra-226, and Ra-228, which are mostly found in drinking water. Table 2 summarizes the doses incurred from intake of radionuclides. The approximate internal dose equivalent from all naturally occurring radionuclides is 340 μSv/year (34 mrem/year). This value is compatible with the BEIR (1990) value of 39 mrem/year.

Table 3. Summary of Annual Dose Equivalents from Naturally Occurring Radionuclides in the Body (from Table 7.17 of NCRP 1987b)

Radionuclide	Dose equivalent in soft tissues μSv/year (mrem/year)
C-14	10 (1)
K-40	180 (18)
Rb-87	3 (0.3)
U-238 series	4.6 (0.46)
Th-230	0.1 (0.01)
Ra-226	3 (0.3)
Pb-210 - Po-210	140 (14)
Th-232	0.1 (0.01)
Ra-228 - Th-228	1.5 (0.15)
Total	**342 (34)**

[5] Elements under homeostatic control are maintained at constant levels in the body, regardless of the amount of that element that is ingested or taken into the body.

6.0 DIAGNOSTIC MEDICAL EXPOSURES

Most of the available epidemiological data on annual patient doses of radiation from diagnostic procedures in the U.S., which include x-rays and nuclear medicine, comes from data collected prior to the mid-1990s. NCRP (1989) concluded that the average annual EDE for the U.S. population is 40 mrem (0.40 mSv) from diagnostic x-ray exposures, and 14 mrem (0.14 mSv) from diagnostic nuclear medicine procedures. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimates in Annex C, Section 305, of its 1993 publication that the per capita EDE from all diagnostic medical examinations to individuals living in health care level I countries (which include the U.S. and Western Europe) is 1.1 mSv per year (110 mrem). However, the world of diagnostic imaging has changed dramatically in the past decade.

In recent years, some smaller studies have looked at current trends in doses for various procedures, particularly the rapidly increasing use of computed tomography (CT). According to the National Center for Health Statistics (Robb 2004), an estimated 65 million CT scans were performed in 2002, representing an increase of about 700% over the past decade. The use of diagnostic radiological procedures for children has increased, particularly of CT. It is estimated that children aged 0–15 years accounted for 11% of all CT scans in 1999 (Mettler et al. 2000).

While the use of diagnostic radiological procedures has increased, the dose per examination has generally remained the same over the past decade for particular procedures, although some studies have shown variations (both increases and decreases). These variations usually result from differences in practitioners or facility procedures. Different practitioners may use varying amounts of radiation for a particular examination based on their training and experience (Robb 2004). For example, a study at the Mayo Clinic (Ngutter et al. 2003) found that the total collective EDE decreased from 2,030 person-Sv (203,000 person-rem) in 1988 to 1,817 person-Sv (181,700 person-rem) in 1997, but showed both substantial increases and decreases in EDE for various procedures. Improvements in technology lowered the EDE for some procedures. Such improvements include (1) pulsed-progressive fluoroscopy that typically decreases the radiation dose by a factor of two or more, (2) better detectors, and (3) a change in CT scanners. Other changes increased the EDE, such as (1) a preference for darker films, (2) a change from dual emulsion to single emulsion films in mammography, (3) a change from two posterior-anterior (PA) chest views to one PA view and one lateral view (which gives approximately twice the radiation dose of a PA) for increased diagnostic value, and (4) a new radiopharmaceutical resulting in twice the dose. Organizations such as the Conference of Radiation Control Program Directors (CRCPD), as well as individual states, are looking to minimize radiation exposure from diagnostic radiological procedures by publishing guidance on radiation exposure norms for entrance skin doses that seek to keep the patient dose as low as reasonably achievable, while obtaining the necessary diagnostic information (CRCPD 2003).

In addition, the proportion of the total collective EDE for all radiological diagnostic procedures changes based on the mix of procedures. For example, Mettler et al. (2000) notes that while CT scanning represented only 11% of the procedures in 1997, it accounted for almost 70% of the total effective dose from all diagnostic radiology procedures for that year. It is estimated that one abdominal CT scan has a radiation equivalence of 100 or more chest x-rays (Robb 2004). The U.S. Food and Drug Administration, Center for Devices and Radiological Health, estimates that effective doses from diagnostic CT procedures range from 1 to 10 mSv (100 to 1,000 mrem) (FDA 2002), while chest x-rays result in EDEs of approximately 0.1 mSv (10 mrem). Some procedures, such as cardiovascular, cardiac, tumor, and thyroid scans, may expose patients to effective doses as high as 30 mSv (3,000 mrem) (Ngutter et al. 2003). However, estimates of the effective dose from a diagnostic CT procedure can vary by a factor of 10 or more depending on the type of CT procedure, patient size, and the CT system and its operating technique (FDA 2002).

Another new trend in diagnostic radiological procedures is the increase in the number of patients who have had more than one scan in their lifetime. The University of New Mexico study (Mettler et al. 2000) found that in 1997, 39% of patients having CT scans of the head had experienced a prior head CT, and 33% of those having an abdominal or pelvic CT had received prior examinations.

Table 3 provides data on EDE for various radiological diagnostic procedures from two representative studies. It should be noted that the doses listed in Table 3 are whole-body EDEs. The doses to the individual target organs will be much greater.

In the future, new technologies will continue to change the amount of diagnostic radiation to which patients are exposed. For example, according to CRCPD (2001), CT technologies require multiple scans to be delivered in preparation for the procedure, adding to the patient’s exposure. As the use of such technologies increases, the impacts from multiple scans in one examination must be considered. Changes may also come as international studies show exposure differences between countries. Herzog and Rieger note that in the U.S., exposure parameters are generally set to achieve much higher doses (to reduce image noise) than in Europe, where the emphasis is on reducing patient radiation exposure (Herzog and Rieger 2004). All of these studies indicate that present average EDE from diagnostic procedures (x-rays and nuclear medicine) could have exceeded the previously accepted per capita value of 53 mrem/year.

It is worth repeating that in the year 2002, 65 million CT scans were performed, which represents a sizable fraction of the U.S. population. As indicated in Table 4, the exposures associated with these scans are on the order of several hundred mrem EDE per scan, and many people receive multiple scans. These exposures are comparable to the exposures due to natural background radiation, and, in some cases, greatly exceed exposures to natural background.

Table 4. Total Effective Dose Equivalent of Various Types of Diagnostic Procedures

Procedure	Dose in mSv EDE (mrem EDE)	
	UNM Health Center practices in 1998 and 1999 (Mettler 2000)	**Mayo Clinic practices in 1997 (Ngutter 2001)**
Radiography		
Head and neck	0.22 (22)	
C-spine	0.20 (20)	
T-spine	0.80 (80)	
L-spine	1.27 (127)	
Chest	0.08 (8)	
Abdomen	0.56 (56)	
Upper GI and SB	2.44 (244)	
Barium enema	4.06 (406)	
Kidney/bladder	1.58 (158)	
Pelvis	0.44 (44)	0.7 (70)
Hip	0.83 (83)	0.6 (60)
Extremities	0.01 (1)	
Mammography	0.1 (10) (estimated)	0.7 (70)
Intravenous Pyelogram (for kidneys, ureters, bladder)		5.7 (570)
Computed Tomography		
Head	1.50 (150)	1.6 (160)
Chest	5.40 (540)	5.6 (560)
Abdomen/pelvis	3.10 (310)	6.8/7.9 (680/790)
Other (neck, spine, etc.)	3.00 (300) (estimated)	
Angiography		
Neurology		3.5 (350)
Cardiac		27.9 (2790)
Vascular		13.8 (1380)
Fluoroscopy		
Chest		6.3 (630)
GI		2.9 (290)
Iodine contrast		3.7 (370)

7.0 CONSUMER PRODUCTS

This section briefly summarizes the discussion of exposures from consumer products from NCRP 1987c. The U.S. population is exposed to radiation from various products that include, but are not limited to, radon in domestic water supplies (usually wells and other ground-water supplies), building and construction materials, mining and agricultural products, natural gas heaters and ranges, electronics, and smoke detectors. The estimated total EDE from consumer products is 60-130 μSv/year (6-13 mrem/year), with the majority of that dose due to radon in domestic water supplies (10-60 μSv/year). Radon can enter the home through the water supplies during activities such as bathing, toilet flushing, dishwashing, and laundering. The National Research Council's 1999 publication on radon in drinking water states that radon in water tends to be an issue for those using private wells and those in mountainous regions. SC&A has determined that any radon released into the home through the water supply would have been captured by the National Residential Radon Survey.

REFERENCES

Bogen, K.T. and Goldin, A.S. 1991. *Population Exposures to External Natural Radiation Background in the Unites States*. U.S. Environmental Protection Agency, ORP/SEPD-80-12.

Centers for Disease Control and Prevention and the National Cancer Institute. (CDC/NCI). 2001. *A Feasability Study of the Health Consequences to the American Population from Nuclear Weapons Tests Conducted by the United States and Other Nations*.

Committee on the Biological Effects of Ionizing Radiations (BEIR). 1990. *Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V*. Washington, DC: National Academy Press.

Conference of Radiation Control Program Directors (CRCPD). 2001. *QA Collectible: Computed Tomography Fluoroscopy*. Committee on Quality Assurance in Diagnostic X-Ray (H-7). <http://www.crcpd.org/PDF/CTFluroscopy.pdf> (March 3, 2005).

Conference of Radiation Control Program Directors (CRCPD). 2003. *Patient Exposure and Dose Guide—2003*. Publication E-03-2.
< http://www.crcpd.org/Pubs/ESERePublished/Apr03.pdf,> (March 3, 2005).

Gregory, B and P. P. Jalbert. 2004. *National Radon Results: 1985 to 2003*. <http://www.epa.gov/radon>

Herzog, P. and C. Rieger. 2004. "Risk of cancer from diagnostic x-rays." *The Lancet* l363(9406).

Mettler, Jr., F., P. Wiest, J. Locken, and C. Kelsey. 2000. *CT scanning: patterns of use and dose*. Journal of Radiological Protection. 20:353–359.

National Council on Radiation Protection and Measurements (NCRP). 1975. *Natural Background Radiation in the United States*. NCRP Report No. 45. Bethesda, MD.

National Council on Radiation Protection and Measurements (NCRP). 1987a. *Ionizing Radiation Exposure of the Population of the United States*. NCRP Report No. 93.

National Council on Radiation Protection and Measurements (NCRP). 1987b. *Exposure of the Population of the Unites States and Canada from Natural Background Radiation*. NCRP Report No. 94.

National Council on Radiation Protection and Measurements (NCRP). 1987c. *Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources*. NCRP Report No. 95.

National Council on Radiation Protection and Measurements (NCRP). 1989. *Exposure of the U.S. Population from Diagnostic Medical Radiation.* NCRP Report No. 100.

NRC 1999, National Research Council, *Risk Assessment of Radon in Drinking Water, Committee on Risk Assessment of Exposure to Radon in Drinking Water*, Board on Radiation Effects Research, Commission on Life Sciences, National Research Council, National Academy Press, Washington, D.C. 1999.

Ngutter, L., J. Kofler, C. McCollough, R. Vetter. 2001. *Update on patient radiation doses at a large tertiary care medical center*. Health Physics. 81(5):530–535, November 2001. Erratum in *Health Physics*, 84(3):388–389, March 2003.

Oakley, D.T. 1972. *Natural Radiation Exposure in the United States*. U.S. Environmental Protection Agency. ORP/SID 72-1.

Office of Civilian Radioactive Waste Management (OCRWM). 2005. *Facts About Radiation*. Yucca Mountain Project Factsheet. DOE/YMP-0403, January 2005. http://www.OCRWM.DOE.GOV/factsheets/DOEYMP0403.SHTML.

Robb, M. 2004. *Like One Hundred X-Rays? Study Suggests Many Referring Physicians Don't Grasp or Explain to Patients the Radiation Exposure Involved with CT*. Radiology Today. < http://www.radiologytoday.net/archive/rt_071904p22.shtml> (March 3, 2005).

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 1993. *Sources and Effects of Ionizing Radiation*. Report to the General Assembly, with Annexes. United Nations: New York.

U.S. Environmental Protection Agency (EPA). 1993a. *National Radon Database, Volume 6: National Residential Radon Survey*, EPA 402-R-93-013, January 1993.

U.S. Environmental Protection Agency (EPA). 1993b. *EPA Map of Radiation Zones*, 402-R-93-021.

U.S. Food and Drug Administration (FDA). 2002. *What are the Radiation Risks from CT?* Center for Devices and Radiological Health < http://www.fda.gov/crdh/ct/risks.html,> (March 3, 2005).

APPENDIX A
COSMIC AND TERRESTIAL RADIATION DOSES BY STATE AND REGION
(from Bogen and Goldin, 1991)

Table A-1. Cosmic and Terrestrial Radiation Doses By State and Region

State*	Dose Equivalent (mrem/year) Shielded		
	Cosmic	Terrestrial	Total
Alabama	27.1	22.5	49.7
NU-NCP	27.9	29.2	57.1
Mobile	26.1	14.6	40.7
Alaska	26.6	29.2	55.7
Arizona	31.5	29.2	60.7
NU	35.5	29.2	64.7
Phoenix	28.5	29.2	57.7
Arkansas	27.5	19.1	41.1
NU-NCP	30.1	29.2	59.2
Pine Bluff	26.5	14.6	41.3
California	26.8	23.2	50.0
NU	28.0	29.2	57.2
San Francisco	26.2	17.7	43.8
Colorado	47.5	42.6	90.1
Denver	46.5	57.4	103.9
Pueblo	42.6	29.2	71.8
Connecticut	26.4	32.7	59.1
Norwalk	26.1	44.8	70.9
Hartford	26.1	26.8	52.9
Delaware	26.3	20.1	46.3
Wilmington	26.3	23.2	49.5
NU-CP	26.2	14.6	40.8
District of Columbia	26.4	22.7	49.0
Florida	26.2	14.3	40.4
Gainesville	26.4	14.6	41.0
Orlando	26.2	7.4	33.6
Georgia	27.6	25.7	53.3
Atlanta	28.4	36.6	65.0
Savannah	26.1	14.6	40.7
Hawaii	26.3	29.2	55.5
Idaho	36.8	29.2	65.9
Illinois	27.4	26.6	54.0
Bloomington	27.9	29.2	57.0
Chicago	27.3	24.7	52.0
Indiana	27.6	28.7	56.3
Muncie	28.1	29.2	57.3
Evansville	26.9	29.2	56.0
Iowa	28.3	29.2	57.5
NU	28.6	29.2	57.8
Cedar Rapids	27.6	29.2	56.8
Kansas	29.2	29.2	58.4
NU	29.7	29.2	58.9
Kansas City	27.7	29.2	56.9
Kentucky	27.7	27.8	55.6
Lexington	28.2	29.2	57.3
NU-CP	26.8	14.6	41.3
Louisiana	26.6	14.6	40.8
Shreveport	26.5	14.6	41.1
New Orleans	26.1	14.6	40.6

Table A-1. **Cosmic and Terrestrial Radiation Doses By State and Region**

State*	Dose Equivalent (mrem/year) Shielded		
	Cosmic	Terrestrial	Total
Maine	26.8	29.2	55.9
NU	26.9	29.2	56.1
Portland	26.1	29.2	55.3
Maryland	26.4	20.7	47.1
NU-NCP	27.2	29.2	56.4
NU-CP	26.2	14.6	40.8
Massachusetts	26.4	29.0	55.4
Worchester	27.0	34.0	61.0
Pittsfield	28.3	17.9	46.2
Michigan	27.6	29.2	56.7
Jackson	28.1	29.2	57.3
Detroit	27.3	29.2	56.5
Minnesota	28.5	25.1	53.6
NU	29.3	29.2	58.5
Minneapolis	27.8	20.0	47.8
Mississippi	26.6	14.6	41.2
Jackson	26.7	14.6	41.3
Biloxi	26.1	14.6	40.7
Missouri	27.6	28.7	56.3
NU-NCP	28.0	29.2	57.2
NU-CP	26.8	14.6	41.4
Montana	36.3	29.2	65.5
NU	36.6	29.2	65.8
Billings	34.9	29.2	64.1
Nebraska	29.3	29.2	58.5
NU	29.8	29.2	59.0
Omaha	28.4	29.2	57.5
Nevada	36.6	21.2	57.8
NU	41.9	29.2	71.1
Las Vegas	31.1	12.7	43.8
New Hampshire	27.3	29.2	56.5
NU	27.6	29.2	56.8
Manchester	26.4	29.2	55.6
New Jersey	26.2	28.0	54.2
NU-NCP	26.7	29.2	55.8
Atlantic City	26.1	14.6	40.7
New Mexico	45.7	33.7	79.4
Albuquerque	44.3	44.5	88.8
NU	46.3	29.2	75.5
New York	26.5	28.8	55.3
Binghamton	27.9	29.2	57.1
Albany	26.1	16.1	42.1
North Carolina	27.8	24.4	52.2
Asheville	31.6	29.2	60.8
Wilmington	26.1	14.6	40.7
North Dakota	29.9	29.2	59.1
NU	30.1	29.2	59.2
Fargo	28.0	29.2	57.2
Ohio	27.7	28.0	55.7
Mansfield	28.6	29.2	57.8
Cincinnati	27.2	19.3	46.5

Table A-1. **Cosmic and Terrestrial Radiation Doses By State and Region**

State*	Dose Equivalent (mrem/year) Shielded		
	Cosmic	Terrestrial	Total
Oklahoma	29.0	28.8	57.8
Oklahoma City	28.8	29.2	58.0
NU-CP	27.0	14.6	41.6
Oregon	27.4	29.2	57.6
NU	28.4	29.2	58.8
Portland	26.2	29.2	55.4
Pennsylvania	27.2	23.2	50.4
Pittsburgh	27.7	33.3	61.0
NU	27.7	14.6	42.3
Rhode Island	26.3	27.4	53.6
NU	26.5	29.2	55.6
Providence	26.2	26.8	53.0
South Carolina	25.9	23.4	50.7
Columbia	26.6	43.7	70.3
Charleston	26.1	14.6	40.7
South Dakota	30.7	29.2	59.9
NU	30.9	29.2	60.1
Sioux Falls	29.3	29.2	58.4
Tennessee	27.6	25.1	52.7
Knoxville	28.0	38.4	66.4
Memphis	26.6	14.6	41.2
Texas	28.1	18.2	46.3
El Paso	37.7	29.2	66.9
Galveston	26.1	12.6	38.7
Utah	41.8	29.2	71.0
NU	44.8	29.2	74.0
Salt Lake City	40.2	29.2	69.4
Vermont	27.3	29.2	56.5
Virginia	27.2	21.4	48.7
NU-NCP	28.8	29.2	58.0
Norfolk	26.1	12.5	38.5
Washington	26.9	29.2	56.1
Spokane	28.7	29.2	57.9
Seattle	26.3	29.2	55.5
West Virginia	28.9	29.9	58.8
Wheeling	27.4	44.1	71.5
Charleston	27.3	29.2	56.5
Wisconsin	27.8	29.2	57.0
NU	28.2	29.2	57.4
Green Bay	27.3	29.2	56.5
Wyoming	50.4	29.2	79.6

Source: Table A-2 of Bogen and Goldin 1981
NU = Non-Urban CP = Coastal Plain
NCP = Not Coastal Plain
*For each state, the statewide values are given, followed by the city or region with the highest total cosmic + terrestrial dose, followed by the he city or region with the lowest.

APPENDIX B
AVERAGE INDOOR RADON LEVELS AND DOSES BY STATE
(from U.S. EPA 1993a)

Table B-1. **Average Indoor Radon Levels and Doses By State**

State	# Housing units	Average annual indoor radon levels (pCi/L per year)			Maximum recorded radon levels (pCi/L per year)			Average Annual Doses (mrem/yr) 200 mrem/year per pCi/L	
		Lowest level of living space	Lowest level of non-living space	Average of all the living space	Lowest level of living space	Lowest level of non-living space	Average of all the living space	Average for state based on average value for the entire living space	Maximum Dose based on maximum value for the entire living space
Alabama	156	0.88	0.92	0.85	7.69	7.69	7.69	170	1538
Alaska	31	0.56	0.63	0.48	2.73	2.73	1.98	97	397
Arizona	62	1.27	1.33	1.25	4.12	4.12	4.12	250	824
Arkansas	60	0.71	0.71	0.71	5.25	5.25	5.25	142	1050
California	254	0.67	0.68	0.63	5.17	5.17	5.17	126	1034
Colorado	70	3.39	4.59	3.05	13.14	16.32	13.14	610	2629
Connecticut	88	1.36	1.56	0.90	7.04	7.04	5.52	180	1105
Delaware	62	0.64	1.21	0.56	6.55	8.58	4.48	112	895
Florida	112	0.46	0.47	0.45	2.96	2.96	2.96	91	591
Georgia	141	1.52	2.63	1.37	10.74	105.77	9.28	273	1856
Idaho	65	1.86	1.92	1.71	6.10	6.10	6.10	342	1219
Illinois	365	2.05	2.55	1.72	33.61	33.61	24.29	343	4858
Indiana	254	2.18	3.08	2.00	13.08	24.59	9.68	401	1935
Iowa	87	4.43	5.43	3.64	20.54	20.54	15.83	727	3166
Kansas	99	2.79	3.35	2.37	11.17	11.17	9.07	474	1813
Kentucky	118	2.84	3.18	2.35	41.34	41.34	25.12	470	5023
Maine	41	1.60	5.00	1.43	7.51	50.54	6.24	286	1248
Maryland	141	2.82	3.59	2.38	20.05	39.15	19.77	476	3955
Massachusetts	134	1.69	2.18	1.14	21.96	21.96	12.93	228	2586
Michigan	83	1.38	1.94	1.13	9.19	13.61	3.43	226	1086
Minnesota	39	2.26	3.07	1.92	6.20	7.69	5.06	383	1011
Mississippi	142	0.82	0.84	0.80	4.37	4.37	4.37	160	875
Missouri	59	2.06	2.68	1.75	8.66	12.63	7.72	350	1544
Nebraska	69	2.02	2.21	1.81	11.36	11.36	9.22	361	1843
Nevada	74	0.94	0.94	0.82	23.38	23.38	14.53	164	2905
New Hampshire	92	2.14	4.18	1.89	17.53	68.36	17.62	378	3525
New Jersey	289	0.60	0.84	0.49	10.10	12.24	8.63	98	1726
New Mexico	98	1.36	1.36	1.35	8.36	8.36	8.36	269	1672

Table B-1. **Average Indoor Radon Levels and Doses By State**

State	# Housing units	Average annual indoor radon levels (pCi/L per year)			Maximum recorded radon levels (pCi/L per year)			Average Annual Doses (mrem/yr) 200 mrem/year per pCi/L	
		Lowest level of living space	Lowest level of non-living space	Average of all the living space	Lowest level of living space	Lowest level of non-living space	Average of all the living space	Average for state based on average value for the entire living space	Maximum Dose based on maximum value for the entire living space
New York	343	1.39	2.05	1.12	18.65	19.42	13.41	223	2681
North Carolina	48	1.58	1.70	1.34	8.75	8.75	6.78	268	1355
North Dakota	47	3.96	6.10	3.65	13.65	17.81	13.65	730	2731
Ohio	444	2.35	2.91	2.09	22.39	22.39	21.00	417	4199
Oklahoma	48	1.26	1.28	1.24	5.77	5.77	5.77	247	1153
Oregon	53	0.50	0.50	0.49	1.99	1.99	1.58	99	316
Pennsylvania	426	1.85	2.44	1.47	25.59	55.25	25.59	293	5118
South Dakota	65	5.51	8.01	4.52	83.62	83.62	52.90	903	10581
Tennessee	84	2.74	3.58	2.55	10.56	23.56	8.86	511	1773
Texas	213	0.83	0.82	0.83	11.32	11.32	11.32	165	2264
Utah	53	1.16	1.23	0.98	4.96	4.96	4.18	196	836
Virginia	88	1.40	1.80	1.30	6.13	10.00	5.56	260	1113
Washington	41	0.41	0.41	0.40	5.79	5.79	5.73	79	1146
West Virginia	93	1.08	1.43	0.98	8.14	8.14	5.29	197	1057
Wisconsin	319	1.76	2.57	1.46	10.92	13.62	8.50	293	1701
Wyoming	44	1.56	1.72	1.30	4.64	4.64	4.13	260	826

APPENDIX C

POPULATION AND MIGRATION CHANGES IN THE UNITES STATES

(based on data from the US Census Bureau)

APPENDIX C: POPULATION AND MIGRATION CHANGES IN THE UNITES STATES

The following tables present current population and migration data and patterns for each state in the country. All of the population and migration data presented in this appendix were obtained from tables published on the US Census Bureau's website (www.census.gov).

Table C-1 presents the total population and changes in the state populations from the 1990 Census, the 2000 Census, and the most recently published estimate for 2004. By far, Nevada has seen the greatest population increase during the last 14 years, with a 17% increase since 2000 and a 94% increase since 1990. Arizona follows with a 12% increase since 2000 and a 57% increase since 1990. These total population values include births, deaths, and domestic and international migration. The migration column in Table C-1 presents the domestic net migration, which occurred for each state between the years 1995 and 2000. These values are a representation of the moving patterns of Americans during that time. For example, Florida has seen the greatest net infux of people from other parts of the country (607,023) during this time, followed by North Carolina, Arizona, and Nevada. Since we do not know where these individuals are moving from, we cannot predict their potential change in natural background radiation dose. Table C-2 attempts to answer that question by presenting the domestic migration patterns for Nevada and Nye County from 1995 to 2000.

The US Census Bureau has compiled enormous databases that present estimates of the number of people (over age 5) moving from each region, state, and county to every other region, state, and county in the country from 1995 to 2000, which can be obtained from their website[1,2]. Since it would not be practical to present all of that data in this appendix, Table 2 focuses on Nevada and also Nye County. Column 2 of Table C-2 presents the number of people moving to Nevada from each state in this time period. For example, from 1995 to 2000, 1,368 people moved from Alabama to Nevada. Conversely, Column 3 shows that during that time, 958 people moved from Nevada to Alabama. Column 4 presents the net migration into Nevada. The data reveals a general positive influx of people into Nevada from almost every state in the county, with the largest influx from California, New York and Illinois. Columns 5, 6 and 7 present the same data for Nye County. For this county-specific data, SC&A used the US Census Bureau's database "County-by-County Migration Flow files[2]." The total number of people moving into and out of Nye County were summed for each state. This data also reveals that there is a net influx of people into Nye County, with the largest out-of state influx from California, Utah, and Washington. Table C-3 presents some additional population and migration data for Nye County. This table shows that there has been a 112% increase in the total population of the county since 1990, and there is a net domestic migration increase of 6082 people from 1995 to 2000, more than half of which were from another state.

Table C-2 also includes the average natural background dose estimates for each state, taken from Table 1 of the main body of this report. Examination of this data reveals that there is large variability in average natural background radiation doses when moving from state to state.

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[1] US Census Bureau table "State of Residence in 2000 for the Population 5 Years and Over by State of Residence in 1995" http://www.census.gov/population/www/cen2000/phc-t22.html released August 2003.

[2] US Census Bureau County-by County Migration Flow files http://www.census.gov/population/www/cen2000/ctytoctyflow.html, released August 2003.

Table C-1. Total Population Changes and Average Natural Background Doses by State

State	Total Population from Census Bureau							Migration[1]	Average Natural Background Dose (mrem/year EDE)			
	2004 Estimate	2000	1990	Change from 2000 to 2004	Percent change 2000 to 2004	Change from 1990 to 2004	Percent change 1990 to 2004	Domestic 5-yr net migration 1995 - 2000	Cosmic	Terrestrial	Radon	Total
Alabama	4,530,182	4,447,100	4,040,587	83,082	1.9%	489,595	12.1%	25,823	27.1	22.5	170	219.6
Alaska	655,435	626,932	550,043	28,503	4.5%	105,392	19.2%	(30,498)	26.6	29.2	97	152.8
Arizona	5,743,834	5,130,632	3,665,228	613,202	12.0%	2,078,606	56.7%	316,148	31.5	29.2	250	310.7
Arkansas	2,752,629	2,673,400	2,350,725	79,229	3.0%	401,904	17.1%	42,116	27.5	19.1	142	188.6
California	35,893,799	33,871,648	29,760,021	2,022,151	6.0%	6,133,778	20.6%	(755,536)	26.8	23.2	126	176
Colorado	4,601,403	4,301,261	3,294,394	300,142	7.0%	1,307,009	39.7%	162,633	47.5	42.6	610	700.1
Connecticut	3,503,604	3,405,565	3,287,116	98,039	2.9%	216,488	6.6%	(64,610)	26.4	32.7	180	239.1
Delaware	830,364	783,600	666,168	46,764	6.0%	164,196	24.6%	17,383	26.3	20.1	112	158.4
District of Columbia	553,523	572,059	606,900	(18,536)	-3.2%	(53,377)	-8.8%	(45,331)	26.4	22.7	no data	Not enough data
Florida	17,397,161	15,982,378	12,937,926	1,414,783	8.9%	4,459,235	34.5%	607,023	26.2	14.3	91	131.5
Georgia	8,829,383	8,186,453	6,478,216	642,930	7.9%	2,351,167	36.3%	340,705	27.6	25.7	273	326.3
Hawaii	1,262,840	1,211,537	1,108,229	51,303	4.2%	154,611	14.0%	(76,133)	26.3	29.2	no data	Not enough data
Idaho	1,393,262	1,293,953	1,006,749	99,309	7.7%	386,513	38.4%	33,847	36.8	29.2	342	408
Illinois	12,713,634	12,419,293	11,430,602	294,341	2.4%	1,283,032	11.2%	(342,616)	27.4	26.6	343	397
Indiana	6,237,569	6,080,485	5,544,159	157,084	2.6%	693,410	12.5%	21,625	27.6	28.7	401	457.3
Iowa	2,954,451	2,926,324	2,776,755	28,127	1.0%	177,696	6.4%	(33,012)	28.3	29.2	727	784.5
Kansas	2,735,502	2,688,418	2,477,574	47,084	1.8%	257,928	10.4%	(7,792)	29.2	29.2	474	532.4
Kentucky	4,145,922	4,041,769	3,685,296	104,153	2.6%	460,626	12.5%	34,127	27.7	27.8	470	525.5
Louisiana	4,515,770	4,468,976	4,219,973	46,794	1.0%	295,797	7.0%	(75,759)	26.6	14.6	no data	Not enough data
Maine	1,317,253	1,274,923	1,227,928	42,330	3.3%	89,325	7.3%	3,640	26.8	29.2	286	342
Maryland	5,558,058	5,296,486	4,781,468	261,572	4.9%	776,590	16.2%	(19,723)	26.4	20.7	476	523.1
Massachusetts	6,416,505	6,349,097	6,016,425	67,408	1.1%	400,080	6.6%	(54,708)	26.4	29	228	283.4
Michigan	10,112,620	9,938,444	9,295,297	174,176	1.8%	817,323	8.8%	(91,930)	27.6	29.2	226	282.8
Minnesota	5,100,958	4,919,479	4,375,099	181,479	3.7%	725,859	16.6%	29,169	28.5	25.1	383	436.6
Mississippi	2,902,966	2,844,658	2,573,216	58,308	2.0%	329,750	12.8%	26,930	26.6	14.6	160	201.2
Missouri	5,754,618	5,595,211	5,117,073	159,407	2.8%	637,545	12.5%	46,053	27.6	28.7	350	406.3
Montana	926,865	902,195	799,065	24,670	2.7%	127,800	16.0%	(5,166)	36.3	29.2	no data	Not enough data

Table C-1. Total Population Changes and Average Natural Background Doses by State

State	Total Population from Census Bureau							Migration[1]	Average Natural Background Dose (mrem/year EDE)			
	2004 Estimate	2000	1990	Change from 2000 to 2004	Percent change 2000 to 2004	Change from 1990 to 2004	Percent change 1990 to 2004	Domestic 5-yr net migration 1995 - 2000	Cosmic	Terrestrial	Radon	Total
Nebraska	1,747,214	1,711,263	1,578,385	35,951	2.1%	168,829	10.7%	(15,353)	29.3	29.2	361	419.5
Nevada	2,334,771	1,998,257	1,201,833	336,514	16.8%	1,132,938	94.3%	233,934	36.6	21.2	164	221.8
New Hampshire	1,299,500	1,235,786	1,109,252	63,714	5.2%	190,248	17.2%	27,903	27.3	29.2	378	434.5
New Jersey	8,698,879	8,414,350	7,730,188	284,529	3.4%	968,691	12.5%	(182,829)	26.2	28	98	152.2
New Mexico	1,903,289	1,819,046	1,515,069	84,243	4.6%	388,220	25.6%	(29,945)	45.7	33.7	269	348.4
New York	19,227,088	18,976,457	17,990,455	250,631	1.3%	1,236,633	6.9%	(874,248)	26.5	28.8	223	278.3
North Carolina	8,541,221	8,049,313	6,628,637	491,908	6.1%	1,912,584	28.9%	337,883	27.8	24.4	268	320.2
North Dakota	634,366	642,200	638,800	(7,834)	-1.2%	(4,434)	-0.7%	(25,207)	29.9	29.2	730	789.1
Ohio	11,459,011	11,353,140	10,847,115	105,871	0.9%	611,896	5.6%	(116,940)	27.7	28	417	472.7
Oklahoma	3,523,553	3,450,654	3,145,585	72,899	2.1%	377,968	12.0%	16,887	29	28.8	247	304.8
Oregon	3,594,586	3,421,399	2,842,321	173,187	5.1%	752,265	26.5%	74,665	27.4	29.2	99	155.6
Pennsylvania	12,406,292	12,281,054	11,881,643	125,238	1.0%	524,649	4.4%	(131,296)	27.2	23.2	293	343.4
Rhode Island	1,080,632	1,048,319	1,003,464	32,313	3.1%	77,168	7.7%	3,236	26.3	27.4	no data	Not enough data
South Carolina	4,198,068	4,012,012	3,486,703	186,056	4.6%	711,365	20.4%	132,205	25.9	23.4	no data	Not enough data
South Dakota	770,883	754,844	696,004	16,039	2.1%	74,879	10.8%	(12,468)	30.7	29.2	903	962.9
Tennessee	5,900,962	5,689,283	4,877,185	211,679	3.7%	1,023,777	21.0%	146,314	27.6	25.1	511	563.7
Texas	22,490,022	20,851,820	16,986,510	1,638,202	7.9%	5,503,512	32.4%	148,240	28.1	18.2	165	211.3
Utah	2,389,039	2,233,169	1,722,850	155,870	7.0%	666,189	38.7%	25,296	41.8	29.2	196	267
Vermont	621,394	608,827	562,758	12,567	2.1%	58,636	10.4%	2,254	27.3	29.2	no data	Not enough data
Virginia	7,459,827	7,078,515	6,187,358	381,312	5.4%	1,272,469	20.6%	75,730	27.2	21.4	260	308.6
Washington	6,203,788	5,894,121	4,866,692	309,667	5.3%	1,337,096	27.5%	75,330	26.9	29.2	79	135.1
West Virginia	1,815,354	1,808,344	1,793,477	7,010	0.4%	21,877	1.2%	(10,754)	28.9	29.9	197	255.8
Wisconsin	5,509,026	5,363,675	4,891,769	145,351	2.7%	617,257	12.6%	7,282	27.8	29.2	293	350
Wyoming	506,529	493,782	453,588	12,747	2.6%	52,941	11.7%	(12,527)	50.4	29.2	260	339.6

Sources: US Census 2004 estimate; US Census 2000; US Census 1990 (http://www.census.gov)

[1] Taken from the US Census Bureau's table "Net Migration for the Population 5 Years and Over for the United States, Regions, States, Counties, New England Minor Civil Divisions, and Metropolitan Areas: 2000" http://www.census.gov/population/www/cen2000/phc-t22.html , released August 2003.

Table C-2. Domestic Migration from 1995 to 2000 for Nevada and Nye County and Average Natural Background Doses

1	2	3	4	5	6	7	8	9	10	11
State	Domestic Migration from 1995 to 2000 (Persons over 5 years of age)						Average Natural Background Dose (mrem/year EDE)			
	To Nevada	From Nevada	Net migration for Nevada	To Nye County	From Nye County	Net migration for Nye County	Cosmic	Terrestrial	Radon	Total
Alabama	1,368	958	410	40	2	38	27.1	22.5	170	219.6
Alaska	3,000	1,596	1,404	68	24	44	26.6	29.2	97	152.8
Arizona	23,432	19,374	4,058	318	461	(143)	31.5	29.2	250	310.7
Arkansas	1,596	1,789	(193)	10	55	(45)	27.5	19.1	142	188.6
California	199,125	60,488	138,637	2849	693	2156	26.8	23.2	126	176
Colorado	11,365	9,740	1,625	338	203	135	47.5	42.6	610	700.1
Connecticut	1,577	683	894	40	13	27	26.4	32.7	180	239.1
Delaware	329	252	77	0	0	0	26.3	20.1	112	158.4
District of Columbia	345	301	44	0	0	0	26.4	22.7	no data	Not enough data
Florida	14,850	8,222	6,628	259	143	116	26.2	14.3	91	131.5
Georgia	3,297	2,852	445	31	54	(23)	27.6	25.7	273	326.3
Hawaii	12,079	1,853	10,226	132	30	102	26.3	29.2	no data	Not enough data
Idaho	6,116	6,858	(742)	285	193	92	36.8	29.2	342	408
Illinois	17,570	5,184	12,386	129	111	18	27.4	26.6	343	397
Indiana	3,755	2,418	1,337	82	51	31	27.6	28.7	401	457.3
Iowa	2,616	1,528	1,088	62	28	34	28.3	29.2	727	784.5
Kansas	2,354	2,074	280	41	9	32	29.2	29.2	474	532.4
Kentucky	1,371	1,549	(178)	45	26	19	27.7	27.8	470	525.5
Louisiana	2,999	1,780	1,219	19	14	5	26.6	14.6	no data	Not enough data
Maine	794	324	470	12	0	12	26.8	29.2	286	342
Maryland	2,228	1,054	1,174	0	27	(27)	26.4	20.7	476	523.1
Massachusetts	2,596	1,173	1,423	11	0	11	26.4	29	228	283.4
Michigan	7,867	3,403	4,464	92	52	40	27.6	29.2	226	282.8
Minnesota	4,823	2,414	2,409	54	29	25	28.5	25.1	383	436.6
Mississippi	1,961	1,657	304	23	13	10	26.6	14.6	160	201.2
Missouri	4,770	3,823	947	136	82	54	27.6	28.7	350	406.3
Montana	4,299	2,564	1,735	116	80	36	36.3	29.2	no data	Not enough data
Nebraska	2,504	1,738	766	12	55	(43)	29.3	29.2	361	419.5
Nevada	619,598 [a]	619,598 [a]	-	5987 [b]	3675 [c]	2312	36.6	21.2	164	221.8
New Hampshire	652	501	151	0	0	0	27.3	29.2	378	434.5

Table C-2. Domestic Migration from 1995 to 2000 for Nevada and Nye County and Average Natural Background Doses

1	2	3	4	5	6	7	8	9	10	11
State	**Domestic Migration from 1995 to 2000 (Persons over 5 years of age)**						**Average Natural Background Dose (mrem/year EDE)**			
	To Nevada	**From Nevada**	**Net migration for Nevada**	**To Nye County**	**From Nye County**	**Net migration for Nye County**	**Cosmic**	**Terrestrial**	**Radon**	**Total**
New Jersey	6,531	1,699	4,832	18	0	18	26.2	28	98	152.2
New Mexico	6,499	4,796	1,703	260	172	88	45.7	33.7	269	348.4
New York	17,153	3,558	13,595	94	35	59	26.5	28.8	223	278.3
North Carolina	3,134	2,953	181	43	33	10	27.8	24.4	268	320.2
North Dakota	1,108	706	402	24	18	6	29.9	29.2	730	789.1
Ohio	7,263	3,538	3,725	81	20	61	27.7	28	417	472.7
Oklahoma	3,170	3,255	(85)	81	90	(9)	29	28.8	247	304.8
Oregon	10,024	10,299	(275)	298	195	103	27.4	29.2	99	155.6
Pennsylvania	6,171	2,406	3,765	41	73	(32)	27.2	23.2	293	343.4
Rhode Island	618	387	231	4	0	4	26.3	27.4	no data	Not enough data
South Carolina	1,270	1,517	(247)	18	20	(2)	25.9	23.4	no data	Not enough data
South Dakota	1,798	744	1,054	70	6	64	30.7	29.2	903	962.9
Tennessee	1,944	2,902	(958)	35	11	24	27.6	25.1	511	563.7
Texas	17,576	12,351	**5,225**	228	122	106	28.1	18.2	165	211.3
Utah	14,060	12,739	1,321	566	272	294	41.8	29.2	196	267
Vermont	296	147	149	0	2	(2)	27.3	29.2	no data	Not enough data
Virginia	3,531	3,563	(32)	23	9	14	27.2	21.4	260	308.6
Washington	14,278	11,031	3,247	334	212	122	26.9	29.2	79	135.1
West Virginia	625	569	56	0	0	0	28.9	29.9	197	255.8
Wisconsin	4,651	2,445	2,206	110	34	76	27.8	29.2	293	350
Wyoming	2,785	2,434	351	71	61	10	50.4	29.2	260	339.6
Total	**1,085,721**	**851,787**	**233,934**	**13590**	**7508**	**6082**				

[a] indicates the number of people that moved within and into and out of the state
[b] indicates the number of people that moved to Nye County from a different county in Nevada
[c] indicates the number of people that moved from Nye County to a different county in Nevada
Sources: US Census Bureau table "State of Residence in 2000 for the Population 5 Years and Over by State of Residence in 1995" http://www.census.gov/population/www/cen2000/phc-t22.html released August 2003. US Census Bureau County-by County Migration Flow files http://www.census.gov/population/www/cen2000/ctytoctyflow.html, released August 2003.

Table C-3. Summary of Nye County Population and Domestic Migration

Total Population from Census Bureau							Migration: Domestic Immigrants 1995-2000			Migration: Domestic Outmigrants 1995-2000			Migration
2004 Estimate	2000	1990	Change from 2000 to 2004	Percent change 2000 to 2004	Change from 1990 to 2004	Percent change 1990 to 2004	Total	From same state	From different state	Total	To same state	To different state	Domestic 5 year net migration 1995 to 2000
37,714	32,923	17,781	4791	14.6%	19,933	112%	13,590	5987	7603	7508	3675	3833	6082

Sources: US census 2000; US Census 1990; US Census 2004 Estimate; US Census Bureau County-by County Migration Flow files http://www.census.gov/population/www/cen2000/ctytoctyflow.html, released August 2003.