RADIOLOGICAL CHARACTERIZATION AND ASSESSMENT STUDY OF A COAL SLAG USED FOR ABRASIVE BLASTING

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16. Abstract (Limit: 200 words) A bag of coal slag, identified as Sure-Shot was subjected to radiological characterization by gamma and alpha spectrometry analysis. An exposure rate of 30 to 50 microroentgen/hour was measured at about 1 inch from the surface of the 100 pound bag of the slag. Major radionuclides detected by gamma and alpha spectrometry were those in the naturally occurring uranium decay series and potassium-40. Gamma spectrometric analysis indicated a total activity of about 195 picocuries per gram of coal slag which could present a risk for gamma exposure. The radionuclide concentrations found in the coal slag were greater by a factor of about eight than those normally found in soil. Inhalation and external exposure were pathways which presented commercial and residential risks in excess of the Superfund upper limit of 1x10(-4). The authors recommend that users of coal slag abrasive blasting material survey areas where slag material is present, including a physical survey and radiation measurements for areas and personnel. The users should also provide required training and monitoring for workers that are in areas required to be labeled as restricted areas. All appropriate measures should be taken to minimize occupational radiation exposures and emissions of radioactive abrasive blasting material off site.

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ABSTRACT

An unopened bag of coal slag used for abrasive blasting was submitted by the National Institute for Occupational Safety and Health (NIOSH) to the National Air and Radiation Environmental Laboratory (NAREL) for radiological characterization by gamma and alpha spectrometry analysis. It is not known how representative this bag of coal slag is of the universe of coal slag that is being used for abrasive blasting, but there is no reason to believe that it is unusual. A survey with a microR meter measured an exposure rate of 30-50 microRoentgen/hr (μR/hr) at about 1 inch from the surface of the 100-lb bag containing the coal slag.

Major radionuclides detected by gamma and alpha spectrometry were those in the naturally occurring U-238, U-235, and Th-232 decay series and K-40. Results of the gamma spectrometry analysis indicated a total activity of about 195 picoCuries per gram (pCi/g) of coal slag that present a risk for gamma exposure. Based on the gamma and alpha spectrometry analysis, an estimated 125 pCi/g of alpha emitters were concentrated in the coal slag that presented a risk for internal exposure due to inhalation and ingestion. Gamma and alpha spectrometry indicated that the radionuclide concentrations found in the coal slag were greater by a factor of about 8 than those normally found in soil. These results confirm somewhat lower, but similar, levels measured in a study conducted by NAREL at a shipyard in Pascagoula, MS in 1981. In that study, above background gamma and alpha activity in shoreline soil were attributed to the use of the coal slag abrasive blasting material at the shipyard.

The following conclusions were made based on the results of the present study:

1. The coal slag abrasive blasting material contains 38 significant radionuclides consisting of the U-238, U-235, and Th-232 series and K-40, which all occur naturally, but have been concentrated (enriched) in the coal slag.

2. The only exposure pathways that presented a commercial and residential risk in excess of the Superfund upper limit of 1×10^{-4} (i.e., 1 person in a population of 10,000 would develop cancer) were inhalation and external exposure with risks of 2.7×10^{-4} and 6.2×10^{-4} for commercial and residential inhalation, respectively, and 3.3×10^{-4} and 1.4×10^{-4} for commercial and residential external exposure, respectively. These pathways were also the major contributors to the overall commercial and residential risks which were 6.1×10^{-4} and 7.7×10^{-4}, respectively.

3. Workers who are abrasive blasting with coal slag or are near those operations are not expected to be over-exposed to external radiation levels above 5 REM/yr (0.5 REM/yr for workers under the age of 18). The Superfund risk limit does not apply to occupational exposures; nevertheless, workers could be exposed to risk in excess of 1×10^{-4} when abrasive blasting or when near abrasive blasting operations using coal slag.

4. For the coal slag analyzed and the presented exposure assumptions, many abrasive blasting areas must be identified as radiation "restricted areas."

5. For the coal slag analyzed and the presented exposure assumptions, many abrasive blasting areas must be posted as "airborne radioactivity areas."

6. For the coal slag analyzed and the presented exposure assumptions, most storage areas and rooms must be posted with signs that read "CAUTION RADIOACTIVE MATERIALS."

7. For the coal slag analyzed and the presented exposure assumptions, most containers must have durable, clearly visible labels that read "CAUTION RADIOACTIVE MATERIALS."

8. The ALARA principle should be applied to minimize risk on and off site to radiation from coal slag.

9. Site specific studies should be conducted to ensure that residential risk levels are not in excess of the Superfund risk limit of 1×10^{-4} and to determine occupational exposures due to coal slag.

The following recommendations were made:

1. Users of the coal slag abrasive blasting material must survey areas where slag material is present (produced, used, released, or stored) as required by 29CFR1910.96/1926.53. The survey must include a physical survey and radiation measurements for areas and personnel, as appropriate.

2. Users of the coal slag abrasive blasting material must provide the required training and monitoring for workers that are in areas required under 29CFR1910.96/1926.53 to be radiation "restricted areas."

3. Users of the coal slag abrasive blasting materials must ensure that all requirements of 29CFR1910.96/1926.53, such as posting and labelling, are met.

4. Users of coal slag abrasive blasting materials should apply the ALARA principle to the abrasive blasting operations to minimize occupational radiation exposures and emissions of radioactive abrasive blasting material off site.

5. Additional occupational and environmental studies should be performed to more accurately identify pathways of concern, determine doses via those pathways, assess risk associated with the exposures, and measure occupational exposures.

6. Environmental risks greater than 1×10^{-6} but less than 1×10^{-4} require additional study to determine if the ALARA principle is being applied and to determine the feasibility of additional exposure reduction techniques.

7. A comprehensive strategy should be developed to protect workers, the public, and the environment. This could be accomplished by the mutual participation and leadership of appropriate Federal agencies along with industry, labor, and other occupational/environmental stakeholders.

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1.0 INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) requested that the National Air and Radiation Environmental Laboratory (NAREL), a U.S. Environmental Protection Agency laboratory, radiologically characterize a sample of coal slag used for abrasive blasting. It is not known how representative this bag of coal slag is of the universe for coal slag that is being used for abrasive blasting, but there is no reason to believe that it is unusual. NAREL collected samples from a previously unopened 100-lb bag of the abrasive blasting material provided by NIOSH. The collected samples consisted of three 1-gal containers of the material. A survey of the 100-lb bag of material with a microR meter measured 30-50 microRoentgen/hr (μR/hr) of gamma radiation at approximately 1 inch from the bag surface. Samples from each of the 1-gal containers were submitted for gamma spectrometry, gross alpha, gross beta, and radiochemical/alpha spectrometry analysis. These samples were considered to be duplicate samples.

2.0 BACKGROUND

An analysis report furnished by the manufacturer of the blasting material, identified as Sure-Shot, indicated that the coal slag contained less than 0.1 picoCuries/gram (pCi/g) of Co-60 and 3.7±1.1 pCi/g of Ra-226 with no other gamma emitters being detected. The analysis report did not address other alpha and beta emitters.

In December 1981, the Eastern Environmental Radiation Facility (now NAREL) conducted a radiological survey (EPA83) of the Ingalls Shipbuilding Division at Pascagoula, MS. A coal slag abrasive blasting material, identified as Black Beauty, was used at the shipyard. Black Beauty is a trade name for a product manufactured by Reed Minerals. The name "Black Beauty" is often used as a generic term for all coal slag so it cannot be concluded that this coal slag product was manufactured by Reed Minerals. Table 2.1 shows the results of the analysis for that Black Beauty product; it contained about 40 pCi/g of alpha emitters and about 71 pCi/g of gamma emitters. The report concluded that the only radiation levels at the shipyard above background were due to the abrasive blasting material at locations on the shoreline.

Table 2.1. Radiological Results of Black Beauty Abrasive Blasting Material From Ingalls Shipbuilding Division, Pascagoula, MS (December 1981)

Location/Sample Identification	Type of Analysis	Radionuclide[1]	Activity (pCi/g)
Abrasive Blasting Areas/Black Beauty	gamma spectrometry	K-40	13±0.91
		U-238	1.4±0.70
		Pb-214	4.6±0.18
		Bi-214	3.9±0.12
		Th-232	1.4±0.18
	Ra by Rn emanation into Lucas Cell	Ra-226	4.2±0.08 (wet) 5.2±0.10 (ash)
	U by alpha spectrometry	U-238	3.2±0.38 (wet) 3.9±0.47 (ash)
		U-234	2.8±0.34 (wet) 3.4±0.41 (ash)
		U-235	0.29±0.06 (wet) 0.36±0.07 (ash)
	Th by alpha spectrometry	Th-232	0.92±0.09 (wet) 1.1±0.11 (ash)
		Th-228	0.92±0.10 (wet) 1.1±0.12 (ash)
		Th-230	3.0±0.24 (wet) 3.8±0.30 (ash)
		Th-227	0.28±0.06 (wet) 0.35±0.07 (ash)

[1] All radionuclides reported with detectable activity are naturally occurring.

3.0 EXPERIMENTAL DESIGN, ANALYSIS, AND ANALYSIS RESULTS

3.1 Sample Preparation

From the 100-lb bag, NAREL Sample Preparation received three 1-gal containers of coal slag mineral abrasive blasting material, identified as Sure-Shot. The samples were initially screened for gross beta/gamma activity using a Geiger/Mueller tube. After initial screening, 400-mL aliquots from each 1-gal container were placed in 400-mL containers. Each aliquot was weighed, dried at

60°C, reweighed, and then analyzed by gamma spectrometry (See Section 3.3).

3.2 Wet Sieving/Hydroclassification and Sedimentation

After performing gamma spectrometry analysis, the separate aliquots were combined into one sample. Using wet sieving or a vertical-column hydroclassification method (+100-μm) and a column sedimentation method (-100/+10-μm and -10-μm), the sample was divided into the three particle-size fractions.

Wet sieving (SCA91b) is a physical size separation technique which uses American Standard Testing of Materials (ASTM) standard sieves. For this study, the sieves used were 1.19 mm (16 mesh) and 0.100 mm (140 mesh). When sieving was used, these two fractions were recombined to produce the +100-μm fraction.

Vertical-column hydroclassification (SCA91c) is a method used for separating material by particle size and density. This technique is based on Stoke's Law which states that the settling velocity of a particle in liquid depends upon the second power of the effective diameter of the particle and the first power of the density of the particle and the density and viscosity of the liquid. By adjusting the flow rate of the water stream in the direction opposite to the settling particles, a separation based on the effective particle size can be made if the densities of the particles remain constant or differ only slightly.

Column sedimentation (SCA91a) is a method for separating fine particles by size using the particle settling rate in a static water column. This method is also based on Stoke's Law and is similar to vertical-column hydroclassification. The particles are distributed throughout a column of water and allowed to stand for a period of time sufficient to allow particles of a specific effective diameter to settle a measured distance. The process is repeated, up to eight times, to achieve a separation.

The resulting fractions were dried at 60°C, weighed, and analyzed for gamma and alpha (U, Th, Ra, Pu) emitting radionuclides (See Sections 3.3 and 3.4) and percent by dry weight of each particle-size fraction. The weights and activities for these size fractions are shown in Appendix A.

The purpose for dividing the sample into the three particle-size fractions was to determine the percentage of the sample that was resuspendable (-100 μm) and respirable (-10 μm). The percent by dry weight for the resuspendable (-100 μm) and respirable (-10 μm) particle-size fractions was about 1.68% and 0.07%, respectively. Therefore, for every gram of the whole coal slag released to the air, only about 0.0007 g will be of respirable size. Note that the whole coal slag has not yet been used for abrasive blasting. Naturally, when the coal slag is used for abrasive blasting, the amount of respirable size particles released to the air per weight of whole coal slag will be much larger. NIOSH has measured coal slag air concentrations as high as 72.7 mg/m^3 (NIOSH81). However, this study was not designed to quantify the respirable amount released to the air during abrasive blasting.

3.3 Gamma Spectrometry

Each aliquot of whole coal slag and particle-size fraction was analyzed for gamma emitting radionuclides using high-purity germanium detectors (EPA80). The aliquots and the particle-size fractions were counted for 1000 min or less, depending on the amount of activity present. The major radionuclides identified in the samples were those in the U-238, U-235, and Th-232 series and K-40. Appendix A contains the gamma analyses results. The gamma spectrometry results show that the gamma emitting radionuclide concentrations were greater than those normally found in soil by a factor of about 8 (MYR83). The total gamma activity in the abrasive blasting material was about 195 pCi/g.

3.4 Alpha Spectrometry

Each aliquot of whole coal slag and particle-size fraction had a representative 1-g aliquot removed and solubilized in hot acid mixtures. Uranium, thorium, and plutonium were separated by extraction and/or ion-exchange, coprecipitated with lanthanum fluoride carrier, and analyzed by alpha spectrometry (EPA84). Radium was analyzed using the ingrowth of Rn, i.e., Rn emanation into a Lucas Cell (EPA84) for counting. Appendix A contains the alpha analyses results. The alpha spectrometry results show that the alpha emitting radionuclide concentrations are greater than those normally found in soil by a factor of about 8 (MYR83). The total alpha activity in the abrasive blasting material was about 125 pCi/g.

3.5 Gross Alpha and Gross Beta

Gross alpha and beta analyses (EPA84) were performed on most samples, aliquots, and particle-size fractions for radiation protection purposes and to determine dilution ratios for radiochemical separation and analysis. Appendix A contains the gross alpha and gross beta analyses results.

3.6 Risk Analysis

A risk analysis was performed for a representative sample using the activity for each radionuclide detected in the whole coal slag. The radionuclide concentrations in the whole coal slag were used (See Table 3.1) since the radionuclide concentrations in the different particle-size fractions were not appreciably different than those in the whole coal slag. Radionuclides not detected due to analytical limitations were given assumed values based upon parent/daughter activities from the natural decay chain. Risk factors were determined using slope factors for each

Table 3.1. Radionuclide Levels in Whole Coal Slag Used for Risk Analysis

Uranium Series	Nuclide Level (pCi/g)	Actinium Series	Nuclide Level (pCi/g)	Thorium Series	Nuclide Level (pCi/g)
U-238	17.4±2.89	U-235	0.493±0.039	Th-232	2.15±0.447
Th-234	17.4±2.89	Th-231	0.493±0.039	Ra-228	1.87±0.090
Pa-234m	17.4±2.89	Pa-231	0.861±0.058	Ac-228	1.87±0.090
U-234	17.4±2.89	Ac-227	0.861±0.058	Th-228	1.81±0.424
Th-230	14.8±1.61	Th-227	0.802±0.163	Ra-224	1.81±0.424
Ra-226	18.6±0.60	Ra-223	0.698±0.175	Rn-220	1.81±0.424
Rn-222	18.6±0.60	Rn-219	0.698±0.175	Po-216	1.81±0.424
Po-218	18.6±0.60	Po-215	0.698±0.175	Pb-212	1.92±0.047
Pb-214	13.5±0.080	Pb-211	0.698±0.175	Bi-212	1.92±0.047
Bi-214	12.9±0.080	Bi-211	0.698±0.175	Po-212	1.23±0.047
Po-214	12.9±0.080	Tl-207	0.698±0.175	Tl-208	0.612±0.024
Pb-210	12.9±0.080			Other Nuclides	
Bi-210	12.9±0.080			K-40	14.20±0.320
Po-210	12.9±0.080			Pu-239	0.189±0.122

radionuclide from the Health Effects Assessment Summary Tables for fiscal year 1992 (HEAST92). The risk factor for ingestion of Rn-219 and Rn-220 is zero, due to the fact that ingestion of these short-lived radionuclides is negligible. Assumptions were made for intake and exposure periods.

Table 3.2 presents a summary of the risk for developing cancer associated with each exposure pathway for the whole coal slag and the respirable coal slag. A summary of the risk analysis results and methodology is contained in Appendix B of this report. These risk analyses do take into account respiratory protection for occupational workers; however, the general public would not be using respiratory protection. Note that the total commercial risk by all pathways is 6.1×10^{-4}; the total residential risk of 7.7×10^{-4} is of a similar magnitude. In the USEPA Superfund program, acceptable risk limits for Superfund sites have been established as 1 x 10^{-4} to 1 x 10^{-6} (40CFR300). These risk values are above the upper limit, 1 x 10^{-4}, for Superfund sites. Using more protective, conservative assumptions, the total risk values could be in the 10^{-3} range. HEAST92 risk factors were used for this initial assessment. Similar results were obtained using risk factors from HEAST 1995 (HEAST95) and EPA 402-R-93-076 (EPA94). OSHA does not use risk analysis within its regulation; therefore, this risk analysis should only be used as a decision tool for conducting OSHA compliance-type surveys in occupational environments.

Table 3.2. Summary of Commercial Risk Results by Pathway

EXPOSURE PATHWAY	RISK for Whole Coal Slag
External	3.3 x 10^{-4}
Ingestion	1.1 x 10^{-5}
Inhalation	2.7 x 10^{-4}
Immersion	1.8 x 10^{-8}
TOTAL RISK	6.1 x 10^{-4}

Note: For external exposure, it is assumed that the coal slag material is diluted by a factor of 4. For inhalation exposure, it is assumed that the air breathed has 1.37 mg/m^3 of the respirable coal slag material. For commercial immersion exposure, it is assumed that the air concentration for the coal slag is 13.7 mg/m^3.

3.7 Compliance with OSHA Regulations

The OSHA regulations for ionizing radiation are contained within 29CFR1910.96 and 29CFR1926.53 (29CFR1910). The requirements of 29CFR1926.53 are identical to those in 29CFR1910.96; therefore, only 29CFR1910.96 will be referenced in the following discussions. Two sections which are applicable to the use of this coal slag material during abrasive blasting and transporting are 29CFR1910.96(c), Exposure to Airborne Radioactive Material, and 29CFR1910.96(e), Caution Signs, Labels, and Signals, respectively.

29CFR1910.96(c)(1) states "No employer shall possess, use or transport radioactive material in such a manner as to cause any employee, within a restricted area, to be exposed to airborne radioactive material in an average concentration in excess of the limits specified in Table I of Appendix B to 10 CFR Part 20 (10CFR20, dated 1993). [NOTE: Currently, OSHA enforces referenced parts of 10 CFR 20 as regulated prior to January 1, 1994.] The limits given in Table I are for exposure to the concentrations specified for 40 hours in any workweek of 7 consecutive days. In any such period where the number of hours of exposure is less than 40, the limits specified in the table may be increased proportionately. In any such period where the number of hours of exposure is greater than 40, the limits specified in the table shall be decreased proportionately."

In addition, 29CFR1910.96(c)(3) states "Exposed as used in this paragraph means that the individual is present in an airborne concentration. No allowance shall be made for the use of protective clothing or equipment, or particle size."

In summary, what these two paragraphs state is that, within a restricted area, the concentrations in Table I of Appendix B to 10 CFR Part 20 cannot be exceeded regardless of the protective clothing or equipment (e.g., respirators) used or the particle size of the airborne coal slag. Table 3.3 shows important examples from Table I of Appendix B to 10 CFR Part 20.

Table 3.3. Selected Radionuclides Air Activity Concentration Levels for Various Airborne Levels Taken from Table I of Appendix B to 10 CFR Part 20*

Nuclide	Air Activity Concentration Limit (10CFR20) (μCi/mL)	Air Activity Concentration for 1 mg/m^3 (μCi/mL)	Air Activity Concentration for 10 mg/m^3 (μCi/mL)	Air Activity Concentration for 50 mg/m^3 (μCi/mL)
Po-212	6×10^{-13}	1.23×10^{-15}	1.23×10^{-14}	6.15×10^{-14}
Po-214	6×10^{-13}	1.29×10^{-14}	1.29×10^{-13}	6.45×10^{-13}
Th-Nat	6×10^{-11}	3.71×10^{-14}	3.71×10^{-13}	1.85×10^{-12}
Th-230	2×10^{-12} (Soluble)	1.48×10^{-14}	1.48×10^{-13}	7.41×10^{-13}
U-Nat	1×10^{-10}	2.81×10^{-14}	2.81×10^{-13}	1.44×10^{-12}

*Air activity limits are less for workers under 18 years of age; Table II of Appendix B to 10 CFR Part 20 contains those limits.

Note that the air activity concentration for Po-214 at 50 mg/m^3 (shaded in Table 3.3) exceeds the air activity concentration limit specified in Table I of Appendix B to 10 CFR 20. Coal slag abrasive blasting areas have been identified by NIOSH (NIOSH81) with airborne concentrations as high as 72.7 mg/m^3 with average concentrations of about 13.7 mg/m^3. In addition, Table I of Appendix B to 10 CFR 20 states that "If the identity and concentration of each radionuclide in the mixture are known, the limiting values should be derived as follows: Determine, for each radionuclide in the mixture, the ratio between the quantity present in the mixture and the limit otherwise established in

Appendix B for the specific radionuclide when not in the mixture. The sum of such ratios for all the radionuclides in the mixture may not exceed "1" (i.e., "unity")."

There are 38 radionuclides present within the coal slag that contribute to the "unity" calculation. Using the radionuclide concentrations in Table 3.1, the sum of the ratios for the radionuclides in the coal slag will exceed "unity" when the airborne concentrations of the coal slag exceed about 15 mg/m^3 as shown in Appendix C. Based on these calculations and the NIOSH measured average airborne concentration of 13.7 mg/m^3 (NIOSH81), many coal slag abrasive blasting areas should be classified as a "restricted area" "by the employer for the purposes of protection of individuals from exposure to radiation or radioactive materials" as specified in 29CFR1910.96(a)(3). In addition, many coal slag abrasive areas should be posted as an "airborne radioactivity area" as specified in 29CFR1910.96(e)(1)(4)(i) when the airborne concentrations exceed "the amounts specified in column 1 of Table I of Appendix B to 10 CFR Part 20."

Within 29CFR1910.96(e) are posting and labelling requirements for areas or rooms and containers in which radioactive materials are stored or contained. Subsection (5)(i) states "Each area or room in which radioactive material is used or stored and which contains any radioactive material (other than natural uranium or thorium) in any amount exceeding <u>10 times</u> the quantity of such material specified in Appendix C to 10 CFR Part 20 shall be conspicuously posted with a sign or signs ...." Subsection (6)(i) states "Each container in which is transported, stored, or used a quantity of any radioactive material (other than natural uranium or thorium) greater than the quantity of such material specified in Appendix C to 10 CFR Part 20 shall bear a durable, clearly visible label ...."

Similar to Appendix B (10 CFR Part 20), Appendix C (10 CFR Part 20) states that "where there is involved a combination of isotopes in known amounts, the limit for the combination should be derived as follows: Determine, for each isotope in the combination, the ratio between the quantity present in the combination and the limit otherwise established for the specific isotope when not in combination. The sum of such ratios for all the isotopes in the combination may not exceed "1" (i.e., "unity")."

Table 3.4 shows that storage areas containing at least 100 lb of coal slag will exceed the limits specified in 10 CFR Part 20, Appendix C for Ra-226, Other Alpha Emitters, and Other Gamma Emitters, individually. The results are similar for 100-lb containers, such as paper bags, except that Po-210 would be added to the list. In fact, storage containers with more than about

Table 3.4. Applicable Container and Storage Limits for Quantity Requiring Labeling from 10 CFR 20, Appendix C

Nuclide(s)	Limit (μCi)	10xLimit (μCi)	Amount per 100-lb (μCi)	% of Limit	% of 10xLimit
Bi-210	1	10	0.585	58.5	5.85
Po-210	0.1	1	0.585	585	58.5
Ra-226	0.01	0.1	0.844	8440	844
Th-Nat plus decay products	100	1000	7.626	7.63	0.763
U-Nat	100	1000	1.273	1.27	0.127
Other Alpha Emitters	0.01	0.1	0.211	2110	211
Other Gamma Emitters	0.1	1	1.667	1670	167
"Unity" Value (excluding Th-Nat and U-Nat)	--	--	--	128.6	12.86

3/4 lb of coal slag should be labelled. In addition, storage areas or rooms with more than about 7.8 lb of coal slag should be posted.

4.0 DISCUSSION OF RESULTS

The radionuclides detected in the abrasive slag material were the U-238, U-235, and Th-232 series radionuclides and K-40 (see Table 3.1). Initial radiological measurements (no greater than 50 μR/hr) of the 100-lb bag indicated that workers are not likely to be externally exposed at levels greater than 5 REM/yr. This conclusion is based on a conservatively estimated high exposure of 100 μR/hr for 50 hr/wk over 50 wk during the year for an exposure of 0.25 REM/yr. However, as the amount of abrasive coal slag increases so will the potential for greater external exposure. When the amounts of coal slag are in excess of 1 Ton, there is the potential for external exposure levels exceeding the OSHA limit of 5 REM/yr. In addition, OSHA regulations are more protective, restrictive for workers under 18 years of age.

Workers under 18 years of age can not receive in excess of 0.125 REM in any quarter (0.5 REM/yr). The estimated external exposure value is 50% of the 0.5 REM/yr OSHA limit for workers under the age of 18. In addition, the OSHA limits were promulgated in 1970, are dated, and should be lowered. For example, the International Commission on Radiological Protection Report 60 (ICRP91) recommends that exposures be maintained to less than 2 REM/yr for working adults.

In the commercial risk analysis (with allowance for respiratory protection), the risks for four exposure pathways and the overall risk were determined (See Table 3.2). As can be seen in Table 3.2, the risk from the ingestion and immersion pathways is 1.1×10^{-5}. This risk is greater than USEPA Superfund lowest allowed risk limit of 1×10^{-6}; however, the risk due to natural background, mostly gamma emitters and radon gas, is in the 10^{-2} range. Therefore, the risk due to the ingestion and immersion exposure pathways is not likely to be a significant increase. However, the ALARA (as low as reasonably achievable) principle would indicate, wherever possible, that immersion exposure to gamma radiation and ingestion of radionuclides should be minimized.

The highest risk is from inhalation of radionuclides and external exposure gamma radiation from coal slag. This total risk of 6.0×10^{-4} is above the 1×10^{-4} limit and is high enough that it is appreciable in calculating the overall risk due to these exposure pathways. The greatest risk, i.e., 3.3×10^{-4}, is due to gamma radiation exposure that is also the major contributor to the overall risk which is 6.1×10^{-4}. The inhalation/external risk and the overall risk are well above the USEPA Superfund allowable highest risk of 1×10^{-4}. Normally, in residential or commercial environments, there are no appreciable airborne concentrations of coal slag or other radioactive particulates. It is possible that, with poor work practices and poor or no respiratory protection for nearby workers, workers could be exposed to risk greater than 1×10^{-4}. However, the USEPA Superfund allowable risk level is for the environmental exposure of the general public; it is not an occupational exposure limit. But, the risk values indicate that users of coal slag abrasive blasting material should perform OSHA compliance-type surveys of blasting areas and provide radiation training and education.

Although not of regulatory occupational concern, risk to the public could be of concern when coal slag is released into residential areas. The residential risk analysis in this report indicates the risk to nearby residents could be 7.7×10^{-4} (See Appendix B) or higher, which is well above the Superfund limit of 1×10^{-4} (i.e., 1 person in a population of 10,000 would likely develop cancer). Site specific studies should be conducted to ensure that residential risk levels are not in excess of the

Superfund risk limit of 1 x 10^{-4}. Users of this coal slag abrasive blasting material should apply the ALARA principle at all times, both on the work site and to emissions from the work site.

For the coal slag reported in Table 3.3, the coal slag abrasive blasting areas must be identified as radiation "restricted areas" in which the access "is controlled by the employer for purposes of protection of individuals from exposure to radiation or radioactive materials" as required by 29CFR1910.96/1926.53. In addition, coal slag abrasive blasting areas, storage areas, and storage/transportation containers must be assessed as to the necessity for posting and labelling, as required by 29CFR1910.96/1926.53. The results (See Tables 3.3 and 3.4) of this report indicate that most, if not all, coal slag abrasive blasting areas, storage areas, and storage/transportation containers must be posted or labelled, as appropriate.

5.0 CONCLUSIONS

1. The coal slag abrasive blasting material contains 38 significant radionuclides consisting of the U-238, U-235, and Th-232 series and K-40, which all occur naturally, but have been concentrated (enriched) in the coal slag.

2. The only exposure pathways that presented a commercial and residential risk in excess of the Superfund upper limit of 1 x 10^{-4} (i.e., 1 person in a population of 10,000 would develop cancer) were inhalation and external exposure with risks of 2.7 x 10^{-4} and 6.2 x 10^{-4} for commercial and residential inhalation, respectively, and 3.3 x 10^{-4} and 1.4 x 10^{-4} for commercial and residential external exposure, respectively. These pathways were also the major contributors to the overall commercial and residential risks which were 6.1 x 10^{-4} and 7.7 x 10^{-4}, respectively.

3. Workers who are abrasive blasting with coal slag or are near those operations are not expected to be over-exposed to external radiation levels above 5 REM/yr (0.5 REM/yr for workers under the age of 18). The Superfund risk limit does not apply to occupational exposures; nevertheless, workers could be exposed to risk in excess of 1 x 10^{-4} when abrasive blasting or when near abrasive blasting operations using coal slag.

4. For the coal slag analyzed and the presented exposure assumptions, many abrasive blasting areas must be identified as radiation "restricted areas."

5. For the coal slag analyzed and the presented exposure assumptions, many abrasive blasting areas must be posted as "airborne radioactivity areas."

6. For the coal slag analyzed and the presented exposure assumptions, most storage areas and rooms must be posted with signs that read "CAUTION RADIOACTIVE MATERIALS."

7. For the coal slag analyzed and the presented exposure assumptions, most containers must have durable, clearly visible labels that read "CAUTION RADIOACTIVE MATERIALS."

8. The ALARA principle should be applied to minimize risk on and off site to radiation from coal slag.

9. Site specific studies should be conducted to ensure that residential risk levels are not in excess of the Superfund risk limit of 1×10^{-4} and to determine occupational exposures due to coal slag.

6.0 RECOMMENDATIONS

1. Users of the coal slag abrasive blasting material must survey areas where slag material is present (produced, used, released, or stored) as required by 29CFR1910.96/1926.53. The survey must include a physical survey and radiation measurements for areas and personnel, as appropriate.

2. Users of the coal slag abrasive blasting material must provide the required training and monitoring for workers that are in areas required under 29CFR1910.96/1926.53 to be radiation "restricted areas."

3. Users of the coal slag abrasive blasting materials must ensure that all requirements of 29CFR1910.96/1926.53, such as posting and labelling, are met.

4. Users of coal slag abrasive blasting materials should apply the ALARA principle to the abrasive blasting operations to minimize occupational radiation exposures and emissions of radioactive abrasive blasting material off site.

5. Additional occupational and environmental studies should be performed to more accurately identify pathways of concern, determine doses via those pathways, assess risk associated with the exposures, and measure occupational exposures. For example:

   (a) Since the concentrations of the radionuclides detected may vary between different brands, different lot numbers, and other factors, analyses should be conducted on blasting materials of different lots, brands, and types of blasting materials for comparison purposes.

(b) Studies should be conducted in the area of the abrasive blasting operation to determine the protection factor of the respirators used by workers, the transport of airborne blasting material, the density of the materials, time spent in the vicinity of blasting by unprotected workers, more information concerning blasting time and airborne concentrations, types and amounts of material deposited on the ground in residential areas as well as the blasting area, and general external radiation levels around the blasting area and around the residential areas.

(c) Age dependent risk factors may also be studied to assess the effect of living in the vicinity of the site for younger children, who are usually affected more by radiation than adults.

6. Environmental risks greater than 1×10^{-6} but less than 1×10^{-4} require additional study to determine if the ALARA principle is being applied and to determine the feasibility of additional exposure reduction techniques.

7. A comprehensive strategy should be developed to protect workers, the public, and the environment. This could be accomplished by the mutual participation and leadership of appropriate Federal agencies along with industry, labor, and other occupational/environmental stakeholders.

7.0 REFERENCES

10CFR20 10 Code of Federal Regulations, Part 20, Standards For Protection Against Radiation, 1993.

29CFR1910 29 Code of Federal Regulations, Part 1910, Occupational Safety And Health Standards, 1994.

40CFR300 40 Code of Federal Regulations, Part 300, Protection Of Environment, 1994.

EPA80 U.S. Environmental Protection Agency. Prescribed Methods for Measurement of Radioactivity in Drinking Water, Gamma Emitting Radionuclides, Method 901.1. EPA-600 4-80-032, August 1980.

EPA83 U.S. Environmental Protection Agency. Radiological Survey of Ingalls Shipbuilding Division, Pascagoula, Mississippi, and Environs. EPA 520/5-83-022, September 1983.

EPA84 U.S. Environmental Protection Agency. EERF Radiochemistry Procedures Manual. EPA 520/5-84-006, August 1984.

EPA94 U.S. Environmental Protection Agency. Estimating Radiogenic Cancer Risks. EPA 402-R-93-076, June 1994.

HEAST92 U.S. Environmental Protection Agency. Health Effects Assessment Summary Tables. Office of Emergency and Remedial Response, 1992.

HEAST95 U.S. Environmental Protection Agency. Health Effects Assessment Summary Tables. Office of Emergency and Remedial Response, 1995.

ICRP91 ICRP Publication 60, Radiation Protection. 1990 Recommendations of the International Commission on Radiological Protection, Pergamon Press, New York, NY, 1991.

MYR83 Myrick TE, BA Berven, and FF Haywood. Determination of Concentrations of Selected Radionuclides in Surface Soil in the U.S. Health Physics, Vol 45, No 2, pp 631-42, September 1983.

NIOSH81 National Institute for Occupational Safety and Health. Industrial Hygiene Survey, Land and Marine Enterprises, Abrasive Blasting Division, Harvey, LA, February 16-20, 1981.

SCA91a S. Cohen and Associates, Inc. Procedure for Separating Soils by Particle Size-Sedimentation. SCA-405. January 1991.

SCA91b S. Cohen and Associates, Inc. Procedure for Separating Soils by Particle Size - Hand Sieving. SCA-401. January 1991.

SCA91c S. Cohen and Associates, Inc. Procedure for Separating Soils by Particle-Size, Vertical-Column Hydroclassification. SCA-403. January 1991.

APPENDIX A

Radioanalysis Results for NIOSH Coal Slag

NAREL Radiochemical Results For NIOSH Coal Slag Samples

NAREL ID	Sample ID & Date Collected	Gross Alpha pCi/gdry±2σ	Gross Beta pCi/gdry±2σ	226 Ra pCi/gdry±2σ	228 Ra pCi/gdry±2σ
NOSH 93.5321	Coal Slag +100 micron 5/29/93	121±22.9	55.3±6.1	13.8±0.4	4.7±4.5
NOSH 93.5322	Coal Slag -100 mesh/+10 micron 5/29/93	105±19.7	62.5±6.2	12.8±0.3	1.8±3.9
NOSH 93.6064	Coal Slag Composite of 4544,4545, 4546 5/29/93	76.4±17.6	55.5±6.0	13.0±0.3	0.54±4.2

QA For NIOSH Coal Slag Samples

NAREL ID	Nuclide	Original Sample pCi/sample±2σ	Activity Added pCi/sample±2σ	Matrix Spike pCi/sample±2σ	Matrix Spike Duplicate pCi/sample±2σ
NOSH 93.6064	239 Pu	0.019±0.013	3.2±0.3	3.570±0.277	3.900±0.311
	234 U	1.108±0.173	2.3±0.2	3.550±0.299	3.910±0.292
	238 U	1.108±0.174	2.3±0.2	3.520±0.297	4.010±0.298
	230 Th	1.526±0.166	3.05±0.31	4.350±0.405	4.738±0.431
NOSH 93.5321	226 Ra	1.45±0.04	11.6±1.2	12.51±0.10	13.00±0.12
	228 Ra	0.51±0.49	38.8±3.8	32.53±1.62	34.87±1.67

QA For NIOSH Coal Slag Sample

NAREL ID	238 Pu pCi/gdry±2σ	239 Pu pCi/gdry±2σ	234 U pCi/gdry±2σ	235 U pCi/gdry±2σ	238 U pCi/gdry±2σ	227 Th pCi/gdry±2σ	228 Th pCi/gdry±2σ	230 Th pCi/gdry±2σ	232 Th pCi/gdry±2σ	226 Ra pCi/l±2σ	228 Ra pCi/l±2σ
NOSH 93.5322	0.113±0.153 MDA 0.320	0.007±0.076 MDA 0.223	10.438±1.14 MDA 0.299	0.351±0.212 MDA 0.328	11.184±1.20 MDA 0.460	3.511±2.211 MDA 1.709	2.321±0.480 MDA 0.203	13.300±1.45 MDA 0.100	1.775±0.399 MDA 0.152	—	—
NOSH 93.5322 Duplicate	0.013±0.085 MDA 0.231	0.019±0.083 MDA 0.224	12.023±1.27 MDA 0.207	0.486±0.212 MDA 0.171	11.836±1.25 MDA 0.147	1.603±1.558 MDA 1.783	1.907±0.440 MDA 0.205	15.000±1.61 MDA 0.137	2.422±0.486 MDA 0.169	—	—
JMW 93.7733 Performance Spike	pCi/sample± 2σ 0.006±0.019 MDA 0.047 NA	pCi/sample± 2σ 1.740±0.188 K=1.6±0.2	—	—	—	pCi/sample± 2σ 0.047±0.093 MDA 0.140 NA	pCi/sample± 2σ ND MDA 0.036 NA	pCi/sample± 2σ 2.850±0.285 K= 3.1±0.3	pCi/sample± 2σ 0.014±0.013 MDA 0.008 NA	—	—
RBLK 93.7741 Reagent Blank	0.013±0.012 MDA 0.022	0.001±0.004 MDA 0.013	—	—	—	0.160±0.144 MDA 0.096	0.059±0.023 MDA 0.015	0.028±0.015 MDA 0.010	0.054±0.021 MDA 0.010	—	—
JMW 94.97 Performance Spike	—	—	pCi/sample± 2σ 2.990±0.247 K=2.8±0.3	pCi/sample± 2σ 0.106±0.033 K=0.12±0.1	pCi/sample± 2σ 3.050±0.250 K=2.8±0.3	—	—	—	—	—	—
RBLK 94.96 Reagent Blank	—	—	pCi/sample± 2σ 0.029±0.026 MDA 0.043	pCi/sample± 2σ 0.013±0.014 MDA 0.016	pCi/sample± 2σ 0.006±0.015 MDA 0.041	—	—	—	—	—	—
JMW 93.7899 Performance Spike	—	—	—	—	—	—	—	—	—	5.7±0.1 K=5.8±0.6	7.9±0.8 K=10.6±1.2
RBLK 93.8041 Reagent Blank	—	—	—	—	—	—	—	—	—	0.07±0.01	0.30±0.50

NA = No Activity Added **ND = Not Detected**
MDA = Minimum Detectable Activity **K = Known Activity**

NAREL Radiochemical Results For NIOSH Coal Slag Samples

NAREL ID	Sample ID & Date Collected	238 Pu pCi/gdry±2σ	239 Pu pCi/gdry±2σ	234 U pCi/gdry±2σ	235 U pCi/gdry±2σ	238 U pCi/gdry±2σ	227 Th pCi/gdry±2σ	228 Th pCi/gdry±2σ	230 Th pCi/gdry±2σ	232 Th pCi/gdry±2σ
NOSH 93.5321	Coal Slag +100 micron 5/29/93	ND MDA 0.304	0.107±0.117 MDA 0.225	12.500±1.183 MDA 0.180	0.231±0.136 MDA 0.128	11.500±1.122 MDA 0.180	3.107±2.179 MDA 1.861	2.200±0.514 MDA 0.376	13.740±1.565 MDA 0.216	2.205±0.472 MDA 0.176
NOSH 93.5322	Coal Slag -100/+10 micron 5/29/93	0.113±0.153 MDA 0.320	0.007±0.076 MDA 0.223	10.438±1.143 MDA 0.299	0.351±0.212 MDA 0.328	11.184±1.205 MDA 0.460	3.511±2.211 MDA 1.709	2.321±0.480 MDA 0.203	13.300±1.456 MDA 0.100	1.775±0.399 MDA 0.152
NOSH 93.5322X	Coal Slag -100/+10 micron 5/29/93	0.013±0.085 MDA 0.231	0.019±0.083 MDA 0.224	12.023±1.271 MDA 0.207	0.486±0.212 MDA 0.171	11.836±1.256 MDA 0.147	1.603±1.558 MDA 1.783	1.907±0.440 MDA 0.205	15.000±1.616 MDA 0.137	2.422±0.486 MDA 0.169
NOSH 94.1937	Coal Slag -10 micron 5/29/93	0.103±0.036 MDA 0.0329	0.049±0.024 MDA 0.0189	5.6400±0.595 MDA 0.0776	0.235±0.080 MDA 0.0581	5.59±0.590 MDA 0.062	0.455±0.094 MDA 0.014	2.790±0.192 MDA 0.085	7.027±0.334 MDA 0.007	2.802±0.184 MDA 0.007
NOSH 93.6064	Coal Slag Composite of 4544, 4545,4546, 5//29/93	ND MDA 0.237	0.189±0.122 MDA 0.126	10.579±1.657 MDA 0.363	0.386±0.269 MDA 0.186	10.579±1.661 MDA 0.311	3.653±2.351 MDA 2.258	1.810±0.424 MDA 0.213	14.820±1.613 MDA 0.119	2.154±0.447 MDA 0.119

ND = Not Detected
MDA = Minimum Detectable Activity

Gamma Spectrometry Results for NIOSH Coal Slag

NAREL ID	SAMPLE ID AND DATE COLLECTED	GAMMA pCi/gdry±2 sigma error
NOSH 93.5321 693g dry	Coal Slag +100 micron 5/29/93	214Pb 12.4±0.1 223Ra 0.65±0.15 226Ra 15.5±0.5 228Ra 1.76±0.05 235U 0.34±0.03 227Th 0.68±0.11 212Pb 1.70±0.03 214Bi 11.8±0.07 208Tl 0.57±0.02 238U 13.3±2.7 40K 12.6±0.3
NOSH 94.1938 691g dry	Coal Slag +100 micron 5/29/93	214Pb 12.1±0.0597 226Ra 15.5±0.499 223Ra 0.515±0.139 212Pb 1.78±0.0576 234Th 5.63±0.375 228Ra 2.00±0.0622 235U 0.403±0.0291 227Th 0.735±0.123 214Bi 12.0±0.0688 208Tl 0.578±0.0192 40K 12.7±0.2586
NOSH 93.5322 144g dry	Coal Slag -100/+10 micron 5/29/93	214Pb 12.9±0.1 223Ra 0.58±0.29 226Ra 15.7±0.9 228Ra 1.68±0.13 235U 0.44±0.05 227Th 0.73±0.19 212Pb 1.91±0.07 214Bi 12.2±0.18 208Tl 0.61±0.05 238U 14.8±7.1 40K 13.1±0.8
NOSH 94.1939 17.1 g dry	Coal Slag -100/+10 micron 5/29/93	214Pb 13.4±0.291 226Ra 24.1±2.23 234Th 4.05±1.54 235U 1.4±0.131 228Ra 2.11±0.379 212Pb 2.06±0.190 208Tl 0.531±0.115 214Bi 11.8±0.326 40K 15.2±1.64

NAREL ID	SAMPLE ID AND DATE COLLECTED	GAMMA pCi/gdry±2 sigma error
NOSH 93.5323-1 2.56 g in 200 mL	Coal Slag -10 micron 5/29/93	40K 10.86±12.34
NOSH 93.5323-2 1.28 g in 100 mL	Coal Slag -10 micron 5/29/93	226Ra 75.2±64.3
NOSH 93.5323-3 1.28 g in 100 mL	Coal Slag -10 micron 5/29/93	226Ra 51.33±56.7
NOSH 93.5323-4 1.28 g in 100 mL	Coal Slag -10 micron 5/29/93	212Pb 4.35±4.25
NOSH 94.1937 1.65g dry	Coal Slag -10 micron 5/29/93	214Pb 6.39±1.25 226Ra 13.3±16.8 212Pb 2.95±1.44 208Tl 0.738±0.978 40K 13.3±11.8
NOSH 93.6064 166g dry	Coal Slag Composite of 4544, 4545, 4546 5/29/93	214Pb 13.1±0.1 223Ra 0.69±0.19 226Ra 18.6±0.6 228Ra 1.87±0.09 235U 0.27±0.03 227Th 0.73±0.14 212Pb 1.89±0.05 214Bi 12.4±0.10 208Tl 0.61±0.03 238U 15.4±4.2 40K 14.0±0.5
NOSH 93.4544 700g dry	Coal Slag Whole 5/29/93	214Pb 12.4±0.069 223Ra 0.646±0.156 226Ra 17.1±0.545 228Ra 1.69±0.060 235U 0.314±0.032 227Th 0.713±0.131 212Pb 1.790±0.041 214Bi 11.90±0.071 208Tl 0.550±0.021 238U 17.4±2.770 40K 13.2±0.294

NAREL ID	SAMPLE ID AND DATE COLLECTED	GAMMA pCi/gdry±2 sigma error
NOSH 93.4545 685g dry	Coal Slag Whole 5/29/93	214Pb 12.8±0.083 226Ra 15.4±0.671 223Ra 0.487±0.163 228Ra 1.800±0.078 235U 0.493±0.039 227Th 0.654±0.143 212Pb 1.840±0.052 214Bi 12.4±0.092 208Tl 0.529±0.025 238U 12.60±3.330 40K 13.30±0.372
NOSH 93.4546 666g dry	Coal Slag Whole 5/29/93	214Pb 13.5±0.076 226Ra 15.9±0.622 223Ra 0.698±0.175 228Ra 1.830±0.062 235U 0.466±0.036 227Th 0.802±0.163 212Pb 1.920±0.047 214Bi 12.9±0.079 208Tl 0.612±0.024 238U 17.0±2.89 40K 14.2±0.317

APPENDIX B

Commercial and Residential Risk Analysis

CONCENTRATIONS OF RADIONUCLIDES USED FOR RISK ASSESSMENT

The concentrations used for this assessment were obtained using two methods. The first method is direct measurement using gamma spectrometry and/or alpha spectrometry after radiochemical separation, or radon deemanation for radium-226. The maximum concentration obtained from five analyses of the "whole" slag was used, in most cases, to establish the maximum (and most conservative) risk to workers and the public. Since the concentrations were similar for most radionuclides, it is believed that this assumption will introduce little error into the final results.

There were several radionuclides whose concentrations did not correlate well with other data for that nuclide or for parents and/or daughters. Uranium-238 and uranium-234 analyses by alpha spectrometry yielded results which were significantly lower than the daughter concentrations determined by gamma spectrometry. Therefore, the gamma spectrometry concentrations for protactinium-234m was used for the concentrations for uranium-238 and uranium-234. Also, the gamma spectrometry concentration for thorium-227 was used rather than the alpha spectrometry concentration since the alpha spectrometry concentration was approximately five times larger than gamma spectrometry concentrations, which were in close agreement with the concentrations of the daughters and parents. Finally, the radium-228 concentration by co-precipitation was not used since it was significantly lower than the gamma spectrometry concentrations of the parents and daughters, which were consistent and in equilibrium with other radionuclides in the thorium chain.

Lead-214 and bismuth-214 appear to be present in much lower concentrations than their parent radionuclides in the chain. This is caused by leakage of radon gas from the container in which the sample is held. The leakage causes less radon to decay inside the container, thus, less lead and bismuth are formed and present at time of analysis of the sample. For the purposes of this assessment, no correction to the lead-214 and bismuth-214 concentrations will be made since a portion of the radon-222 gas is removed from a potential site by the wind, which would reduce the concentrations of the lead-214 and bismuth-214 found at a potential site. The airborne concentration of lead-214 and bismuth-214 may not be significantly different than the radium-226 concentration for airborne assessments (inhalation and immersion). If further study is conducted, this would be one area where additional sampling should be conducted (i.e., particulate air sampling and surface sampling around the blasting locations).

The second method for obtaining a concentration was to assume that the radionuclide was in equilibrium with its parents (or sometimes with its daughters). This was done to estimate the concentration of the radionuclides which could not be measured by the methods listed in the above paragraphs. All concentrations obtained in this manner were based on the concentration of the parent radionuclide, with the exception of uranium-238, thorium-234, and radium-228.

Since there was no reliable concentration measurement for uranium-238 or thorium-234, the only reasonable option was to assume equilibrium with protactinium-234m. Therefore, the concentrations of uranium-238 and thorium-234 are assumed to be equal to that of protactinium-234m. In the case of radium-228, the actinium-228 daughter has been shown to follow the radium-228 concentration well, mainly due to the relatively short half-life (6.15 hours) of actinium-228. Therefore, the radium-228 concentration is assumed to be the same as the actinium-228 concentration. Finally, radionuclides in the naturally occurring series which have very low branching ratios (e.g., protactinium-234 and francium-223) were omitted from these calculations since their concentrations would be significantly lower than their parents. These assumptions should not cause significant error in the risk analysis.

Table B-1 presents the concentrations obtained from the analysis of each sample by method, the concentration used for that radionuclide in the assessment, and the basis for selection of concentration for those which could not be detected by the above methods or had results which were inconsistent with other data.

RISK FACTORS USED FOR RISK ASSESSMENT

The risk factors used for this risk assessment were obtained from a data file of risk factors from the RISKCALC computer program, written by Steve Dean of the Environmental Protection Agency (EPA). The data file which contains the risk factors was written by Michael Boyd, also of EPA. The risk factors in this table were based on those from the Health Effects Assessment and Summary Tables for Fiscal Year 1992 (HEAST92). The units for these risk factors are risk/pCi for the ingestion and inhalation pathways and risk/year per pCi/g for the external pathway. Other published risk factors may be substituted for these risk factors, but consistency of units must be maintained. The risk factors are based upon the lifetime additional risk that the subject recipient will develop cancer from exposure to the radionuclide, but will not necessarily die from that cancer.

No risk factors were available in HEAST92 for immersion. The risk factors used for immersion were computer generated from RADRISK93/EPA1993.

ASSUMPTIONS FOR RISK ASSESSMENT

Numerous assumptions must be made in order to complete the risk assessment. These assumptions are dependent upon the pathway and the target population (industrial worker versus local resident). The assumptions must be reasonable, but should also be somewhat conservative, to ensure protection of workers and local residents. Many of the assumptions are based upon those used by EPA which are documented in the HEAST92.

Inhalation Pathway

The assumptions made for the inhalation of radionuclides due to blasting operations using coal slag are discussed below for both workers and local residents. Resuspension of slag material from the ground is not considered for the inhalation pathway since significant resuspension would be needed to have an effect on the airborne slag concentration. Also, measurements of airborne concentrations, which would include blasting, resuspension, and other sources, have been made and are being used for this assessment.

Inhalation rate

The standard inhalation rate as given in HEAST92 is 20 m^3 per day. This inhalation rate shall be used for the assessment of risk to the local residents. However, workers in the area of the blasting operations may breath at higher rates while working. Therefore, a value of 25 m^3 per day will be used for these workers while on-site.

Exposure time per year

It is assumed that workers may work as much as 6 days per week for 12 hours per day. Assuming that they will take 2 weeks vacation away from the site, the effective exposure time to the airborne radionuclides is 150.5 effective days per year.

$$\left(\frac{365.25\ days}{year}\right)\left(\frac{6\ days\ worked}{7\ days\ per\ week}\right)\left(\frac{50\ weeks\ worked}{52\ weeks\ per\ year}\right)\left(\frac{12\ hours\ worked\ per\ day}{24\ hours\ per\ day}\right) = 150.5\ days\ per\ year$$

For residents in the vicinity of the blasting area, it is assumed that the exposure period averages approximately 18 hours per day, 365 days per year. The assumptions made are that 8 hours per weekday will be spent away from home while at work or school and that the entire weekend will be spent at home.

$$\frac{(16\ hours \cdot 5\ days) + (24\ hours \cdot 2\ days)}{7\ days} = \left(\frac{18.3\ hours}{day}\right)\left(\frac{day}{24\ hours}\right)\left(\frac{365.25\ days}{year}\right) = 280\ days\ per\ year$$

Years of exposure

It is assumed that a worker will be in the vicinity of blasting for a 30 year period. It is assumed that residents of the area will reside for a full lifetime of approximately 70 years.

Airborne concentrations

Airborne concentrations of up to 70 mg/m^3 have been measured in the area of blasting operations. However, the average concentration has been measured to be 13.7 mg/m^3. Since workers performing blasting operations wear respiratory protection, the effective concentration to which workers are exposed is less. The respiratory protection factor has been assumed to be 10. Therefore, the concentration of airborne material which is inhaled is $13.7/10 = 1.37$ mg/m^3.

Residents of the area will not be exposed to similar concentrations of material in air. A mixing factor of 15 is assumed for local residents. Therefore, the airborne concentration of material in air is assumed to be $13.7/15 = 0.91$ mg/m^3 for residential exposure.

Although particle size is an important factor in determining airborne concentrations of material, the effect of particle size for the samples analyzed for radionuclide content are not being used. The basis for this is that many larger particles will become much smaller from abrasive actions during the blasting process, the concentrations of radionuclides in different particle-size fractions were similar, and the extremely small quantities of fine particles separated from the conglomerate slag were in such small quantities that precise quantification of radionuclide content was not possible. It is believed that little error will result from this assumption.

Example calculations of inhalation pathway risk

Worker inhalation of actinium-227. The risk for the other radionuclides is determined similarly. The total risk for this pathway is determined by adding the risk calculated for each radionuclide.

$$0.86\left(\frac{pCi}{g}\right) * 8\times10^{-8}\left(\frac{1}{pCi}\right) * 25\left(\frac{m^3}{d}\right) * 150.5\left(\frac{d}{yr}\right) * 30\ (yr) * 0.00137\left(\frac{g}{m^3}\right) = 1.1\times10^{-5}$$

Inhalation of actinium-227 by local residents.

$$0.86\left(\frac{pCi}{g}\right) * 8\times10^{-8}\left(\frac{1}{pCi}\right) * 20\left(\frac{m^3}{d}\right) * 280\left(\frac{d}{yr}\right) * 70\ (yr) * 0.00091\left(\frac{g}{m^3}\right) = 2.5\times10^{-5}$$

Ingestion Pathway

The assumptions made for the ingestion of radionuclides due to blasting operations using coal slag are discussed below for both workers and local residents. Resuspension of slag material from the ground is not considered for the ingestion pathway since significant resuspension would be needed to have an effect on the airborne slag concentration. Also, measurements of airborne concentrations, which would include blasting, resuspension, and other sources, have been made and are being used for this assessment.

Ingestion rate

The standard ingestion rate as given in HEAST92 is 0.2 grams of material ingested daily for children aged 6 and below, and 0.1 grams of material ingested daily after the age of 6. This ingestion rate (0.1086 grams per day) shall be used for the assessment of risk to the local residents. However, workers in the area of the blasting operations may have additional material ingested due to higher airborne concentrations, and may also be wiping their faces with material which is covered with fines from the blasting material. Therefore, an ingestion rate of 0.2 grams per day will be used for these workers while on-site.

Exposure time per year

It is assumed that workers may work as much as 6 days per week for 12 hours per day. Assuming that they will take 2 weeks vacation away from the site, the effective exposure time to the airborne radionuclides is given to be 150.5 effective days per year.

$$\left(\frac{365.25\ days}{year}\right)\left(\frac{6\ days\ worked}{7\ days\ per\ week}\right)\left(\frac{50\ weeks\ worked}{52\ weeks\ per\ year}\right)\left(\frac{12\ hours\ worked\ per\ day}{24\ hours\ per\ day}\right) = 150.5\ days\ per\ year$$

For residents in the vicinity of the blasting area, it is assumed that the exposure period averages approximately 18 hours per day, 365 days per year. The assumptions made are that 8 hours per weekday will be spent away from home while at work or school and that the entire weekend will be spent at home.

$$\frac{(16\ hours \cdot 5\ days) + (24\ hours \cdot 2\ days)}{7\ days} = \left(\frac{18.3\ hours}{day}\right)\left(\frac{day}{24\ hours}\right)\left(\frac{365.25\ days}{year}\right) = 280\ days\ per\ year$$

Years of exposure

It is assumed that a worker will be in the vicinity of blasting for a 30 year period. It is assumed that residents of the area will reside for a full lifetime of approximately 70 years.

Example calculations of ingestion pathway risk

Worker ingestion of actinium-227. The risk for the other radionuclides is determined similarly. The total risk for this pathway is determined by adding the risk calculated for each radionuclide.

$$0.86\left(\frac{pCi}{g}\right) \cdot 2.8\times10^{-10}\left(\frac{1}{pCi}\right) \cdot 0.2\left(\frac{g}{d}\right) \cdot 150.5\left(\frac{d}{yr}\right) \cdot 30\ (yr) = 2.2\times10^{-7}$$

Ingestion of actinium-227 by local residents. Note that a mixing factor of 0.25 has been added to account for the fact that not all material ingested has come from the site. It is assumed that only one-fourth of the ingested material comes from the site.

$$0.86\left(\frac{pCi}{g}\right) \cdot 2.8\times10^{-10}\left(\frac{1}{pCi}\right) \cdot 0.1086\left(\frac{g}{d}\right) \cdot 0.25 \cdot 280\left(\frac{d}{yr}\right) \cdot 70\ (yr) = 1.3\times10^{-7}$$

External Exposure Pathway

The assumptions made for the external exposure to radionuclides due to abrasive blasting operations using coal slag are discussed below for both workers and local residents.

Material density

The density of the coal slag blasting material has be measured to be approximately 1.5 grams per cubic centimeter. This value will be used for the density of the material. A correction to the risk factor must be made since the density of material will affect the amount of radiation which may be released for material on the ground. As the density of material increases, a larger mass of material is available for a given thickness of material on the ground. Therefore, a unitless ratio between the actual density, 1.5 g/cc, and the reference density for which the risk factor is based, 1.43 g/cc, is entered into the equation to correct for this density difference.

Dilution factor

Not all of the material on the ground will be blasting residue. Therefore, a dilution factor must be assumed. In this case, it is assumed that the dilution factor is 0.25 for the slag in the work area and one-tenth of that value for the slag in residential areas.

Effective exposure time

It is assumed that workers may work as much as 6 days per week for 12 hours per day. Assuming that they will take 2 weeks vacation away from the site, the effective exposure time to the airborne radionuclides is given to be 150.5 effective days per year, which is 41.2% of their time on-site.

$$\left(\frac{365.25\ days}{year}\right)\left(\frac{6\ days\ worked}{7\ days\ per\ week}\right)\left(\frac{50\ weeks\ worked}{52\ weeks\ per\ year}\right)\left(\frac{12\ hours\ worked\ per\ day}{24\ hours\ per\ day}\right) = \frac{150.5\ days\ per\ year}{365.25\ days\ per\ year} = 0.412$$

For residents in the vicinity of the blasting area, it is assumed that the exposure period averages approximately 18 hours per day, 365 days per year. The assumptions made are that 8 hours per weekday will be spent away from home while at work or school and that the entire weekend will be spent at home. This equates to 76.7% of their time exposed to the radionuclides.

$$\frac{(16\ hours * 5\ days) + (24\ hours * 2\ days)}{7\ days} = \left(\frac{18.3\ hours}{day}\right)\left(\frac{day}{24\ hours}\right)\left(\frac{365.25\ days}{year}\right) = \frac{280\ days\ per\ year}{365.25\ days\ per\ year} = 0.767$$

Years of exposure

It is assumed that a worker will be in the vicinity of blasting for a 30 year period. It is assumed that residents of the area will reside for a full lifetime of approximately 70 years.

Example calculations of the external exposure pathway risk

Worker exposure to actinium-227. The risk for the other radionuclides is determined similarly. The total risk for this pathway is determined by adding the risk calculated for each radionuclide.

$$0.86\left(\frac{pCi}{g}\right) * 2.6\times10^{-11}\left(\frac{g}{pCi-yr}\right) * \frac{1.5}{1.43} * 0.412 * 30\ (yr) * 0.25 = 7.3\times10^{-11}$$

Exposure to actinium-227 for local residents.

$$0.86\left(\frac{pCi}{g}\right) * 2.6\times10^{-11}\left(\frac{g}{pCi-yr}\right) * \frac{1.5}{1.43} * 0.767 * 70\ (yr) * 0.025 = 3.2\times10^{-11}$$

Immersion Pathway

The assumptions made for the immersion of people surrounded by radioactively contaminated air from blasting operations using coal slag are discussed below for both workers and local residents. Resuspension of slag material from the ground is not considered for the immersion pathway since significant resuspension would be needed to have an effect on the airborne slag concentration. Also, measurements of airborne concentrations, which would include blasting, resuspension, and other sources, have been made and are being used for this assessment.

Effective exposure time per year

It is assumed that workers may work as much as 6 days per week for 12 hours per day. Assuming that they will take 2 weeks vacation away from the site, the effective exposure time to the airborne radionuclides is given to be 150.5 effective days per year.

$$\left(\frac{365.25\ days}{year}\right)\left(\frac{6\ days\ worked}{7\ days\ per\ week}\right)\left(\frac{50\ weeks\ worked}{52\ weeks\ per\ year}\right)\left(\frac{12\ hours\ worked\ per\ day}{24\ hours\ per\ day}\right) = \frac{150.5\ days\ per\ year}{365.25\ days\ per\ year} = 0.412$$

For residents in the vicinity of the blasting area, it is assumed that the exposure period averages approximately 18 hours per day, 365 days per year. The assumptions made are that 8 hours per weekday will be spent away from home while at work or school and that the entire weekend will be spent at home.

$$\frac{(16\ hours \cdot 5\ days) + (24\ hours \cdot 2\ days)}{7\ days} = \left(\frac{18.3\ hours}{day}\right)\left(\frac{day}{24\ hours}\right)\left(\frac{365.25\ days}{year}\right) = \frac{280\ days\ per\ year}{365.25\ days\ per\ year} = 0.767$$

Years of exposure
It is assumed that a worker will be in the vicinity of blasting for a 30 year period. It is assumed that residents of the area will reside for a full lifetime of approximately 70 years.

Airborne concentrations
Airborne concentrations of up to 70 mg/m^3 have been measured in the area of blasting operations. However, the average concentration has been measured to be 13.7 mg/m^3. Therefore, this is assumed to be the concentration that workers will be exposed to in the vicinity of blasting operations.

Residents of the area will not be exposed to similar concentrations of material in air. A mixing factor of 15 is assumed for local residents. Therefore, the airborne concentration of material in air is assumed to be 0.91 mg/m^3 for residential exposure.

Although particle size is an important factor in determining airborne concentrations of material, the effect of particle size for the samples analyzed for radionuclide content are not being used. The basis for this is that many larger particles will become much smaller from abrasive actions during the blasting process, the concentrations of radionuclides in different particle size fractions were similar, and the extremely small quantities of fine particles separated from the conglomerate slag were in such small quantities that precise quantification of radionuclide content was not possible. It is believed that little error will result from this assumption.

Example calculations of immersion pathway risk
Worker immersion of actinium-227. The risk for the other radionuclides is determined similarly. The total risk for this pathway is determined by adding the risk calculated for each radionuclide.

$$0.86\left(\frac{pCi}{g}\right) \cdot 1.01 \times 10^{-11}\left(\frac{m^3}{Bq\text{-}yr}\right) \cdot \left(\frac{Bq}{27\ pCi}\right) \cdot 0.0137\left(\frac{g}{m^3}\right) \cdot 0.412 \cdot 30\ (yr) = 5.5 \times 10^{-14}$$

Immersion in actinium-227 for local residents.

$$0.86\left(\frac{pCi}{g}\right) \cdot 1.01 \times 10^{-11}\left(\frac{m^3}{Bq\text{-}yr}\right) \cdot \left(\frac{Bq}{27\ pCi}\right) \cdot 0.00091\left(\frac{g}{m^3}\right) \cdot 0.767 \cdot 70\ (yr) = 1.6 \times 10^{-14}$$

Effect of Changing Assumptions on Risk Assessment Inhalation Pathways

<u>Commercial Inhalation Pathway</u>
The assumptions which were made are as follows:

Workers work **6** days per week, **12** hours per day, **50** weeks per year.
Worker inhalation rate is **25** m^3/day.
Workers are exposed for a **30** year career.
Average airborne concentration is **1.37** mg/m^3.

$$New\,Risk = Total\,Worker\,Inhalation\,Risk \times \left(\frac{New\,Breathing\,Rate}{25\,m^3/day}\right) \times \left(\frac{New\,days\,worked\,per\,week}{6\,days\,per\,week}\right) \times \left(\frac{New\,weeks\,worked\,per\,year}{50\,weeks\,worked\,per\,year}\right) \times \left(\frac{New\,hours\,worked\,per\,day}{12\,hours\,worked\,per\,day}\right) \times \left(\frac{New\,years\,exposed}{30\,years\,exposed}\right) \times \left(\frac{New\,airborne\,concentration}{1.37\,mg/m^3}\right)$$

<u>Residential Inhalation Pathway</u>
The assumptions which were made are as follows:

Residents at home **365.25** days per year, **18.3** hours per day.
Residents inhalation rate is **20** m^3/day.
Residents are exposed for a **70** year lifetime.
Average airborne concentration is **0.91** mg/m^3.

$$New\,Risk = Total\,Residents\,Inhalation\,Risk \times \left(\frac{New\,Breathing\,Rate}{20\,m^3/day}\right) \times \left(\frac{New\,days\,home\,per\,year}{365.25\,days\,per\,year}\right) \times \left(\frac{New\,hours\,home\,per\,day}{18.3\,hours\,home\,per\,day}\right) \times \left(\frac{New\,years\,exposed}{70\,years\,exposed}\right) \times \left(\frac{New\,airborne\,concentration}{0.91\,mg/m^3}\right)$$

<u>Example</u>
It is determined that a worker will only work **5** days per week, **8** hours per day, **48** weeks per year. This worker will breath at a rate of **22** m^3/day at an average airborne concentration of **1** mg/m^3 for a **20** year career. His new risk will be:

$$New\,Risk = 2.7 \times 10^{-4} \times \left(\frac{22\,m^3/day}{25\,m^3/day}\right) \times \left(\frac{5\,days\,worked\,per\,week}{6\,days\,per\,week}\right) \times \left(\frac{48\,weeks\,worked\,per\,year}{50\,weeks\,worked\,per\,year}\right) \times \left(\frac{8\,hours\,worked\,per\,day}{12\,hours\,worked\,per\,day}\right) \times \left(\frac{20\,years\,exposed}{30\,years\,exposed}\right) \times \left(\frac{1\,mg/m^3}{1.37\,mg/m^3}\right) = 6.2 \times 10^{-5}$$

Effect of Changing Assumptions on Risk Assessment Ingestion Pathways

Commercial Ingestion Pathway

The assumptions which were made are as follows:

Workers work **6** days per week, **12** hours per day, **50** weeks per year.

Worker ingestion rate is **0.2** mg/day.

Workers are exposed for a **30** year career.

$$\text{New Risk} = \text{Total Worker Ingestion Risk} \cdot \left(\frac{\text{New Ingestion Rate}}{0.2\ \text{mg/day}}\right) \cdot \left(\frac{\text{New days worked per week}}{6\ \text{days per week}}\right) \cdot \left(\frac{\text{New weeks worked per year}}{50\ \text{weeks worked per year}}\right) \cdot \left(\frac{\text{New hours worked per day}}{12\ \text{hours worked per day}}\right) \cdot \left(\frac{\text{New years exposed}}{30\ \text{years exposed}}\right)$$

Residential Ingestion Pathway

The assumptions which were made are as follows:

Residents at home **365.25** days per year, **18.3** hours per day.

Residents ingestion rate is **0.1086** mg/day.

Residents are exposed for a **70** year lifetime.

Mixing factor is 0.25

$$\text{New Risk} = \text{Total Residents Ingestion Risk} \cdot \left(\frac{\text{New Ingestion Rate}}{0.1086\ \text{mg/day}}\right) \cdot \left(\frac{\text{New days home per year}}{365.25\ \text{days per year}}\right) \cdot \left(\frac{\text{New hours home per day}}{18.3\ \text{hours home per day}}\right) \cdot \left(\frac{\text{New years exposed}}{70\ \text{years exposed}}\right) \cdot \left(\frac{\text{New mixing factor}}{0.25}\right)$$

Example

It is determined that a worker will only work **5** days per week, **8** hours per day, **48** weeks per year. This worker will ingest material at a rate of **0.1** mg/day for a **20** year career. His new risk will be:

$$\text{New Risk} = 1.1 \times 10^{-5} \cdot \left(\frac{0.1\ \text{mg/day}}{0.2\ \text{mg/day}}\right) \cdot \left(\frac{5\ \text{days worked per week}}{6\ \text{days per week}}\right) \cdot \left(\frac{48\ \text{weeks worked per year}}{50\ \text{weeks worked per year}}\right) \cdot \left(\frac{8\ \text{hours worked per day}}{12\ \text{hours worked per day}}\right) \cdot \left(\frac{20\ \text{years exposed}}{30\ \text{years exposed}}\right) = 2.0 \times 10^{-6}$$

Effect of Changing Assumptions on Risk Assessment External Exposure Pathways

Commercial External Exposure Pathway
The assumptions which were made are as follows:

The density of the slag material is **1.5** g/cc.
Dilution factor is **0.25**.
Workers work **6** days per week, **12** hours per day, **50** weeks per year.
Workers are exposed for a **30** year career.

$$\text{New Risk} = \text{Total Worker External Exposure Risk} \cdot \left(\frac{\text{New Slag Density}}{1.5\ g/cc}\right) \cdot \left(\frac{\text{New dilution factor}}{0.25}\right) \cdot \left(\frac{\text{New days worked per week}}{6\ \text{days per week}}\right) \cdot \left(\frac{\text{New weeks worked per year}}{50\ \text{weeks worked per year}}\right) \cdot \left(\frac{\text{New hours worked per day}}{12\ \text{hours worked per day}}\right) \cdot \left(\frac{\text{New years exposed}}{30\ \text{years exposed}}\right)$$

Residential External Exposure Pathway
The assumptions which were made are as follows:

The density of the slag material is **1.5** g/cc.
Dilution factor is **0.025**.
Residents are exposed for a **70** year lifetime.
Residents at home **365.25** days per year, **18.3** hours per day.

$$\text{New Risk} = \text{Total Residents External Exposure Risk} \cdot \left(\frac{\text{New Slag Density}}{1.5\ g/cc}\right) \cdot \left(\frac{\text{New dilution factor}}{0.025}\right) \cdot \left(\frac{\text{New days home per year}}{365.25\ \text{days per year}}\right) \cdot \left(\frac{\text{New hours home per day}}{18.3\ \text{hours home per day}}\right) \cdot \left(\frac{\text{New years exposed}}{70\ \text{years exposed}}\right)$$

Example
It is determined that a worker will only work **5** days per week, **8** hours per day, **48** weeks per year. This worker will be exposed to slag with a density of **2.2** g/cc, diluted such that **10%** of the material causing the exposure is slag. His exposure will cover a **20** year career. His new risk will be:

$$\text{New Risk} = 3.3 \times 10^{-4} \cdot \left(\frac{2.2\ g/cc}{1.5\ g/cc}\right) \cdot \left(\frac{0.1\ \text{dilution factor}}{0.25}\right) \cdot \left(\frac{5\ \text{days worked per week}}{6\ \text{days per week}}\right) \cdot \left(\frac{48\ \text{weeks worked per year}}{50\ \text{weeks worked per year}}\right) \cdot \left(\frac{8\ \text{hours worked per day}}{12\ \text{hours worked per day}}\right) \cdot \left(\frac{20\ \text{years exposed}}{30\ \text{years exposed}}\right) = 6.9 \times 10^{-5}$$

Effect of Changing Assumptions on Risk Assessment Immersion Pathways

Commercial Immersion Pathway

The assumptions which were made are as follows:

- Workers work **6** days per week, **12** hours per day, **50** weeks per year.
- Workers are exposed for a **30** year career.
- Average airborne concentration is **13.7** mg/m^3.

$$\mathit{New\,Risk} = \mathit{Total\,Worker\,Immersion\,Risk} \cdot \left(\frac{\text{New days worked per week}}{\text{6 days per week}}\right) \cdot \left(\frac{\text{New weeks worked per year}}{\text{50 weeks worked per year}}\right) \cdot \left(\frac{\text{New hours worked per day}}{\text{12 hours worked per day}}\right) \cdot \left(\frac{\text{New years exposed}}{\text{30 years exposed}}\right) \cdot \left(\frac{\text{New airborne concentration}}{13.7\ mg/m^3}\right)$$

Residential Immersion Pathway

The assumptions which were made are as follows:

- Residents at home **365.25** days per year, **18.3** hours per day.
- Residents are exposed for a **70** year lifetime.
- Average airborne concentration is **0.91** mg/m^3.

$$\mathit{New\,Risk} = \mathit{Total\,Residents\,Immersion\,Risk} \cdot \left(\frac{\text{New days home per year}}{\text{365.25 days per year}}\right) \cdot \left(\frac{\text{New hours home per day}}{\text{18.3 hours home per day}}\right) \cdot \left(\frac{\text{New years exposed}}{\text{70 years exposed}}\right) \cdot \left(\frac{\text{New airborne concentration}}{0.91\ mg/m^3}\right)$$

Example

It is determined that a worker will only work **5** days per week, **8** hours per day, **48** weeks per year. The average airborne concentration is **1** mg/m^3. His career will last **20** year career. His new risk will be:

$$\mathit{New\,Risk} = 1.8 \times 10^{-8} \cdot \left(\frac{\text{5 days worked per week}}{\text{6 days per week}}\right) \cdot \left(\frac{\text{48 weeks worked per year}}{\text{50 weeks worked per year}}\right) \cdot \left(\frac{\text{8 hours worked per day}}{\text{12 hours worked per day}}\right) \cdot \left(\frac{\text{20 years exposed}}{\text{30 years exposed}}\right) \cdot \left(\frac{1\ mg/m^3}{13.7\ mg/m^3}\right) = 4.7 \times 10^{-10}$$

SUMMARY OF RISK ANALYSIS RESULTS AND QUALIFIERS

Tables of the results of the risk assessments for each pathway and target group are given in Tables B-2 through B-9. A summary table of the results is given below in Table B-10.

Table B-10. Summary Risk Assessment Results for Coal Slag

Risk Type	Inhalation	Ingestion	External	Immersion	Total
Commercial	2.7×10^{-4}	1.1×10^{-5}	3.3×10^{-4}	1.8×10^{-8}	6.1×10^{-4}
Residential	6.2×10^{-4}	6.7×10^{-6}	1.4×10^{-4}	5.2×10^{-9}	7.7×10^{-4}

Based on the total risk from this assessment, it is apparent that the risk to both workers and local residents is high. However, this assessment is based on numerous assumptions, most of which are essentially best guesses. Some of these assumptions will not make much of a difference in the final results. However, some of these parameters may vary greatly from the assumed value, which would change the results and possibly the conclusions. The assumptions were, in general, directed toward the conservative (greater risk) to ensure protection of workers and residents. However, there is the possibility that some of the assumptions used were not conservative, which may result in greater risk than estimated.

Table B-1. Concentrations of Radionuclides Found in Coal Slag

Nuclide	Method	Sample 94.4544	Sample 94.4545	Sample 94.4546	Sample 94.6064	Sample 95.1934	Concentration used for Assessment	Basis for Concentration used for Risk Assessment
Uranium Series								
U-238	A				10.6		17.4	Pa-234m
Th-234							17.4	Pa-234m
Pa-234m	G	17.4	12.6	17.0	15.4	13.6	17.4	Pa-234m
U-234	A				10.6		17.4	U-234
Th-230	A				14.8		14.8	Th-230
Ra-226	G	17.1	15.4	15.9	18.6	10.0	18.6	Ra-226 (Gamma)
	D				13.0			
Rn-222							18.6	Ra-226
Po-218							18.6	Ra-226
Pb-214	G	12.4	12.8	13.5	13.1	8.35	13.5	Pb-214
Bi-214	G	11.9	12.4	12.9	12.4	10.0	12.9	Bi-214
Po-214							12.9	Bi-214
Pb-210							12.9	Bi-214
Bi-210							12.9	Bi-214
Po-210							12.9	Bi-214
Actinium Series								
U-235	G	0.31	0.49	0.47	0.27	0.36	0.49	U-235
	A				0.39			
Th-231							0.49	U-235
Pa-231	G					0.86	0.86	Pa-231
Ac-227							0.86	Pa-231
Th-227	G	0.71	0.65	0.80	0.73	0.49	0.80	Th-227 (Gamma)
	A				3.65			
Ra-223	G	0.65	0.49	0.70	0.69	0.46	0.70	Ra-223
Rn-219							0.70	Ra-223
Po-215							0.70	Ra-223
Pb-211							0.70	Ra-223
Bi-211							0.70	Ra-223
Tl-207							0.70	Ra-223
Thorium Series								
Th-232	A				2.15		2.15	Th-232
Ra-228	C				0.54		1.87	Ac-228
Ac-228	G	1.69	1.80	1.83	1.87	1.67	1.87	Ac-228
Th-228	A				1.81		1.81	Th-228
Ra-224							1.81	Th-228
Rn-220							1.81	Th-228
Po-216							1.81	Th-228
Pb-212	G	1.79	1.84	1.92	1.89	1.29	1.92	Pb-212
Bi-212							1.92	Pb-212
Po-212							1.23	Pb-212 * 0.64 (branching)
Tl-208	G	0.55	0.53	0.61	0.61	0.46	0.61	Tl-208
Other Nuclides								
K-40	G	13.2	13.3	14.2	14.0	12.6	14.2	K-40
Pu-239	A				0.19		0.19	Pu-239

A Alpha Spectrometry
C Coprecipitation
D Deemanation
G Gamma Spectrometry

Blanks indicate the nuclide was not analyzed for or was not detected.

TABLE B-2 ASSESSMENT OF COMMERCIAL INHALATION

Assumptions:
25 cubic meters air inhaled per day
150.5 days worked per year
30 years exposed
1.37 mg suspended material per cubic meter

Radionuclide	Concentration (pCi/g)	Slope Factor (risk/pCi)	Risk
Uranium Series			
U-238	17.4	2.4E-08	6.5E-05
Th-234	17.4	3.2E-11	8.6E-08
Pa-234m	17.4	1.6E-15	4.3E-12
U-234	17.4	2.6E-08	7.0E-05
Th-230	14.8	2.9E-08	6.6E-05
Ra-226	18.6	3.0E-09	8.6E-06
Rn-222	18.6	7.3E-13	2.1E-09
Po-218	18.6	5.8E-13	1.7E-09
Pb-214	13.5	2.9E-12	6.1E-09
Bi-214	12.9	2.1E-12	4.2E-09
Po-214	12.9	2.8E-19	5.6E-16
Pb-210	12.9	1.3E-09	2.6E-06
Bi-210	12.9	8.0E-11	1.6E-07
Po-210	12.9	2.6E-09	5.2E-06
Actinium Series			
U-235	0.49	2.5E-08	1.9E-06
Th-231	0.49	4.9E-13	3.7E-11
Pa-231	0.86	3.6E-08	4.8E-06
Ac-227	0.86	8.0E-08	1.1E-05
Th-227	0.80	4.9E-09	6.1E-07
Ra-223	0.70	3.1E-09	3.3E-07
Rn-219	0.70	4.6E-14	5.0E-12
Po-215	0.70	5.7E-18	6.2E-16
Pb-211	0.70	2.8E-12	3.0E-10
Bi-211	0.70	1.9E-13	2.1E-11
Tl-207	0.70	4.5E-15	4.9E-13
Thorium Series			
Th-232	2.15	2.8E-08	9.3E-06
Ra-228	1.87	6.6E-10	1.9E-07
Ac-228	1.87	2.6E-11	7.5E-09
Th-228	1.81	7.7E-08	2.2E-05
Ra-224	1.81	1.2E-09	3.4E-07
Rn-220	1.81	1.2E-13	3.4E-11
Po-216	1.81	4.8E-16	1.3E-13
Pb-212	1.92	4.3E-11	1.3E-08
Bi-212	1.92	6.6E-12	2.0E-09
Po-212	1.23	6.1E-22	1.2E-19
Tl-208	0.61	5.0E-15	4.7E-13
Others			
K-40	14.20	7.6E-12	1.7E-08
Pu-239	0.19	3.8E-08	1.1E-06
TOTAL RISK			2.7E-04

TABLE B-3 ASSESSMENT OF RESIDENTIAL INHALATION

Assumptions:
20 cubic meters air inhaled per day
280 days exposed per year
70 years exposed
0.91 mg suspended material per cubic meter

Radionuclide	Concentration (pCi/g)	Slope Factor (risk/pCi)	Risk
Uranium Series			
U-238,	17.4	2.4E-08	1.5E-04
Th-234	17.4	3.2E-11	2.0E-07
Pa-234m	17.4	1.6E-15	9.9E-12
U-234	17.4	2.6E-08	1.6E-04
Th-230	14.8	2.9E-08	1.5E-04
Ra-226	18.6	3.0E-09	2.0E-05
Rn-222	18.6	7.3E-13	4.8E-09
Po-218	18.6	5.8E-13	3.8E-09
Pb-214	13.5	2.9E-12	1.4E-08
Bi-214	12.9	2.1E-12	9.7E-09
Po-214	12.9	2.8E-19	1.3E-15
Pb-210	12.9	1.3E-09	6.0E-06
Bi-210	12.9	8.0E-11	3.7E-07
Po-210	12.9	2.6E-09	1.2E-05
Actinium Series			
U-235	0.49	2.5E-08	4.4E-06
Th-231	0.49	4.9E-13	8.6E-11
Pa-231	0.86	3.6E-08	1.1E-05
Ac-227	0.86	8.0E-08	2.5E-05
Th-227	0.80	4.9E-09	1.4E-06
Ra-223	0.70	3.1E-09	7.7E-07
Rn-219	0.70	4.6E-14	1.1E-11
Po-215	0.70	5.7E-18	1.4E-15
Pb-211	0.70	2.8E-12	7.0E-10
Bi-211	0.70	1.9E-13	4.7E-11
Tl-207	0.70	4.5E-15	1.1E-12
Thorium Series			
Th-232	2.15	2.8E-08	2.2E-05
Ra-228	1.87	6.6E-10	4.4E-07
Ac-228	1.87	2.6E-11	1.7E-08
Th-228	1.81	7.7E-08	5.0E-05
Ra-224	1.81	1.2E-09	7.7E-07
Rn-220	1.81	1.2E-13	7.7E-11
Po-216	1.81	4.8E-16	3.1E-13
Pb-212	1.92	4.3E-11	2.9E-08
Bi-212	1.92	6.6E-12	4.5E-09
Po-212	1.23	6.1E-22	2.7E-19
Tl-208	0.61	5.0E-15	1.1E-12
Others			
K-40	14.20	7.6E-12	3.8E-08
Pu-239	0.19	3.8E-08	2.6E-06
TOTAL RISK			6.2E-04

TABLE B-4 ASSESSMENT OF COMMERCIAL INGESTION

Assumptions: 0.2 grams ingested daily
150.5 days worked per year
30 years exposed

Radionuclide	Concentration (pCi/g)	Slope Factor (risk/pCi)	Risk
Uranium Series			
U-238	17.4	1.6E-11	2.5E-07
Th-234	17.4	4.0E-12	6.3E-08
Pa-234m	17.4	5.8E-15	9.1E-11
U-234	17.4	1.6E-11	2.5E-07
Th-230	14.8	1.3E-11	1.7E-07
Ra-226	18.6	1.2E-10	2.0E-06
Rn-222	18.6	1.4E-12	2.4E-08
Po-218	18.6	2.8E-14	4.7E-10
Pb-214	13.5	1.7E-13	2.1E-09
Bi-214	12.9	1.3E-13	1.5E-09
Po-214	12.9	1.0E-20	1.2E-16
Pb-210	12.9	5.1E-10	5.9E-06
Bi-210	12.9	1.6E-12	1.9E-08
Po-210	12.9	1.5E-10	1.7E-06
Actinium Series			
U-235	0.49	1.6E-11	7.1E-09
Th-231	0.49	4.0E-13	1.8E-10
Pa-231	0.86	9.2E-11	7.2E-08
Ac-227	0.86	2.8E-10	2.2E-07
Th-227	0.80	4.5E-12	3.3E-09
Ra-223	0.70	6.4E-11	4.0E-08
Rn-219	0.70	0.0E+00	0.0E+00
Po-215	0.70	2.8E-19	1.8E-16
Pb-211	0.70	1.8E-13	1.1E-10
Bi-211	0.70	1.2E-14	7.6E-12
Tl-207	0.70	1.3E-14	8.2E-12
Thorium Series			
Th-232	2.15	1.2E-11	2.3E-08
Ra-228	1.87	1.0E-10	1.7E-07
Ac-228	1.87	5.0E-13	8.4E-10
Th-228	1.81	1.1E-11	1.8E-08
Ra-224	1.81	3.8E-11	6.2E-08
Rn-220	1.81	0.0E+00	0.0E+00
Po-216	1.81	3.0E-17	4.9E-14
Pb-212	1.92	5.5E-12	9.5E-09
Bi-212	1.92	3.1E-13	5.4E-10
Po-212	1.23	2.2E-23	2.4E-20
Tl-208	0.61	1.8E-14	9.9E-12
Others			
K-40	14.20	1.1E-11	1.4E-07
Pu-239	0.19	2.3E-10	3.9E-08
TOTAL RISK			1.1E-05

TABLE B-5 ASSESSMENT OF RESIDENTIAL INGESTION

Assumptions:
- 0.11 grams ingested daily
- 280 days exposed per year
- 70 years exposed
- 0.25 mixing factor (Not all ingested material comes from site).

Radionuclide	Concentration (pCi/g)	Slope Factor (risk/pCi)	Risk
Uranium Series			
U-238	17.4	1.6E-11	1.5E-07
Th-234	17.4	4.0E-12	3.7E-08
Pa-234m	17.4	5.8E-15	5.4E-11
U-234	17.4	1.6E-11	1.5E-07
Th-230	14.8	1.3E-11	1.0E-07
Ra-226	18.6	1.2E-10	1.2E-06
Rn-222	18.6	1.4E-12	1.4E-08
Po-218	18.6	2.8E-14	2.8E-10
Pb-214	13.5	1.7E-13	1.2E-09
Bi-214	12.9	1.3E-13	8.9E-10
Po-214	12.9	1.0E-20	6.9E-17
Pb-210	12.9	5.1E-10	3.5E-06
Bi-210	12.9	1.6E-12	1.1E-08
Po-210	12.9	1.5E-10	1.0E-06
Actinium Series			
U-235	0.49	1.6E-11	4.2E-09
Th-231	0.49	4.0E-13	1.0E-10
Pa-231	0.86	9.2E-11	4.2E-08
Ac-227	0.86	2.8E-10	1.3E-07
Th-227	0.80	4.5E-12	1.9E-09
Ra-223	0.70	6.4E-11	2.4E-08
Rn-219	0.70	0.0E+00	0.0E+00
Po-215	0.70	2.8E-19	1.0E-16
Pb-211	0.70	1.8E-13	6.7E-11
Bi-211	0.70	1.2E-14	4.5E-12
Tl-207	0.70	1.3E-14	4.8E-12
Thorium Series			
Th-232	2.15	1.2E-11	1.4E-08
Ra-228	1.87	1.0E-10	1.0E-07
Ac-228	1.87	5.0E-13	5.0E-10
Th-228	1.81	1.1E-11	1.1E-08
Ra-224	1.81	3.8E-11	3.7E-08
Rn-220	1.81	0.0E+00	0.0E+00
Po-216	1.81	3.0E-17	2.9E-14
Pb-212	1.92	5.5E-12	5.6E-09
Bi-212	1.92	3.1E-13	3.2E-10
Po-212	1.23	2.2E-23	1.4E-20
Tl-208	0.61	1.8E-14	5.9E-12
Others			
K-40	14.20	1.1E-11	8.3E-08
Pu-239	0.19	2.3E-10	2.3E-08
TOTAL RISK			6.7E-06

TABLE B-6 ASSESSMENT OF COMMERCIAL EXTERNAL EXPOSURE

Assumptions:
150.5 days worked per year
30 years exposed
0.25 dilution factor
1.5 density of material (g/cc)

Radionuclide	Concentration (pCi/g)	Slope Factor (risk/yr per pCi/g)	Risk
Uranium Series			
U-238	17.4	2.1E-11	1.2E-09
Th-234	17.4	3.5E-09	2.0E-07
Pa-234m	17.4	3.6E-08	2.0E-06
U-234	17.4	3.0E-11	1.7E-09
Th-230	14.8	5.4E-11	2.6E-09
Ra-226	18.6	1.2E-08	7.2E-07
Rn-222	18.6	1.2E-09	7.2E-08
Po-218	18.6	0.0E+00	0.0E+00
Pb-214	13.5	6.4E-07	2.8E-05
Bi-214	12.9	5.3E-06	2.2E-04
Po-214	12.9	2.8E-10	1.2E-08
Pb-210	12.9	1.3E-10	5.4E-09
Bi-210	12.9	0.0E+00	0.0E+00
Po-210	12.9	2.9E-11	1.2E-09
Actinium Series			
U-235	0.49	2.4E-07	3.8E-07
Th-231	0.49	2.3E-09	3.7E-09
Pa-231	0.86	2.6E-08	7.3E-08
Ac-227	0.86	2.6E-11	7.3E-11
Th-227	0.80	1.6E-07	4.2E-07
Ra-223	0.70	2.3E-07	5.2E-07
Rn-219	0.70	1.6E-07	3.6E-07
Po-215	0.70	4.6E-10	1.0E-09
Pb-211	0.70	1.6E-07	3.6E-07
Bi-211	0.70	1.3E-07	2.9E-07
Tl-207	0.70	7.5E-09	1.7E-08
Thorium Series			
Th-232	2.15	2.6E-11	1.8E-10
Ra-228	1.87	0.0E+00	0.0E+00
Ac-228	1.87	2.9E-06	1.8E-05
Th-228	1.81	5.5E-10	3.2E-09
Ra-224	1.81	2.3E-08	1.3E-07
Rn-220	1.81	1.7E-09	1.0E-08
Po-216	1.81	5.0E-11	2.9E-10
Pb-212	1.92	2.8E-07	1.7E-06
Bi-212	1.92	5.9E-07	3.7E-06
Po-212	1.23	0.0E+00	0.0E+00
Tl-208	0.61	1.3E-05	2.6E-05
Others			
K-40	14.20	5.4E-07	2.5E-05
Pu-239	0.19	1.7E-11	1.0E-11
TOTAL RISK			3.3E-04

TABLE B-7 ASSESSMENT OF RESIDENTIAL EXTERNAL EXPOSURE

Assumptions:
280 days exposed per year
70 years exposed
0.025 dilution factor
1.5 density of material (g/cc)

Radionuclide	Concentration (pCi/g)	Slope Factor (risk/yr per pCi/g)	Risk
Uranium Series			
U-238	17.4	2.1E-11	5.1E-10
Th-234	17.4	3.5E-09	8.6E-08
Pa-234m	17.4	3.6E-08	8.8E-07
U-234	17.4	3.0E-11	7.3E-10
Th-230	14.8	5.4E-11	1.1E-09
Ra-226	18.6	1.2E-08	3.1E-07
Rn-222	18.6	1.2E-09	3.1E-08
Po-218	18.6	0.0E+00	0.0E+00
Pb-214	13.5	6.4E-07	1.2E-05
Bi-214	12.9	5.3E-06	9.6E-05
Po-214	12.9	2.8E-10	5.1E-09
Pb-210	12.9	1.3E-10	2.4E-09
Bi-210	12.9	0.0E+00	0.0E+00
Po-210	12.9	2.9E-11	5.3E-10
Actinium Series			
U-235	0.49	2.4E-07	1.7E-07
Th-231	0.49	2.3E-09	1.6E-09
Pa-231	0.86	2.6E-08	3.2E-08
Ac-227	0.86	2.6E-11	3.2E-11
Th-227	0.80	1.6E-07	1.8E-07
Ra-223	0.70	2.3E-07	2.3E-07
Rn-219	0.70	1.6E-07	1.6E-07
Po-215	0.70	4.6E-10	4.5E-10
Pb-211	0.70	1.6E-07	1.6E-07
Bi-211	0.70	1.3E-07	1.3E-07
Tl-207	0.70	7.5E-09	7.4E-09
Thorium Series			
Th-232	2.15	2.6E-11	7.9E-11
Ra-228	1.87	0.0E+00	0.0E+00
Ac-228	1.87	2.9E-06	7.6E-06
Th-228	1.81	5.5E-10	1.4E-09
Ra-224	1.81	2.3E-08	5.9E-08
Rn-220	1.81	1.7E-09	4.3E-09
Po-216	1.81	5.0E-11	1.3E-10
Pb-212	1.92	2.8E-07	7.6E-07
Bi-212	1.92	5.9E-07	1.6E-06
Po-212	1.23	0.0E+00	0.0E+00
Tl-208	0.61	1.3E-05	1.1E-05
Others			
K-40	14.20	5.4E-07	1.1E-05
Pu-239	0.19	1.7E-11	4.5E-12
TOTAL RISK			1.4E-04

TABLE B-8 ASSESSMENT OF COMMERCIAL IMMERSION

Assumptions: 13.7 mg suspended material per cubic meter
150.5 days worked per year
30 years exposed

Radionuclide	Concentration (pCi/g)	Slope Factor (risk per Bq-yr/m^3)	Risk
Uranium Series			
U-238	17.4	7.46E-12	8.1E-13
Th-234	17.4	5.98E-10	6.5E-11
Pa-234m	17.4	1.05E-09	1.1E-10
U-234	17.4	1.13E-11	1.2E-12
Th-230	14.8	3.00E-11	2.8E-12
Ra-226	18.6	5.72E-10	6.7E-11
Rn-222	18.6	3.38E-11	3.9E-12
Po-218	18.6	0.00E+00	0.0E+00
Pb-214	13.5	2.12E-08	1.8E-09
Bi-214	12.9	1.44E-07	1.2E-08
Po-214	12.9	7.63E-12	6.2E-13
Pb-210	12.9	9.09E-11	7.4E-12
Bi-210	12.9	0.00E+00	0.0E+00
Po-210	12.9	7.79E-13	6.3E-14
Actinium Series			
U-235	0.49	1.28E-08	4.0E-11
Th-231	0.49	8.91E-10	2.8E-12
Pa-231	0.86	2.54E-09	1.4E-11
Ac-227	0.86	1.01E-11	5.5E-14
Th-227	0.80	8.78E-09	4.4E-11
Ra-223	0.70	1.11E-08	4.9E-11
Rn-219	0.70	4.91E-09	2.2E-11
Po-215	0.70	1.29E-11	5.7E-14
Pb-211	0.70	4.56E-09	2.0E-11
Bi-211	0.70	4.05E-09	1.8E-11
Tl-207	0.70	2.01E-10	8.8E-13
Thorium Series			
Th-232	2.15	1.39E-11	1.9E-13
Ra-228	1.87	4.77E-18	5.6E-20
Ac-228	1.87	8.49E-08	1.0E-09
Th-228	1.81	1.58E-10	1.8E-12
Ra-224	1.81	8.54E-10	9.7E-12
Rn-220	1.81	4.58E-11	5.2E-13
Po-216	1.81	1.33E-12	1.5E-14
Pb-212	1.92	1.23E-08	1.5E-10
Bi-212	1.92	1.69E-08	2.0E-10
Po-212	1.23	0.00E+00	0.0E+00
Tl-208	0.61	3.54E-07	1.4E-09
Others			
K-40	14.20	1.44E-08	1.3E-09
Pu-239	0.19	3.83E-12	4.5E-15
TOTAL RISK			1.8E-08

TABLE B-9 ASSESSMENT OF RESIDENTIAL IMMERSION

Assumptions: 0.91 mg suspended material per cubic meter
280 days exposed per year
70 years exposed

Radionuclide	Concentration (pCi/g)	Slope Factor (risk per Bq-yr/m^3)	Risk
Uranium Series			
U-238	17.4	7.46E-12	2.3E-13
Th-234	17.4	5.98E-10	1.9E-11
Pa-234m	17.4	1.05E-09	3.3E-11
U-234	17.4	1.13E-11	3.6E-13
Th-230	14.8	3.00E-11	8.0E-13
Ra-226	18.6	5.72E-10	1.9E-11
Rn-222	18.6	3.38E-11	1.1E-12
Po-218	18.6	0.00E+00	0.0E+00
Pb-214	13.5	2.12E-08	5.2E-10
Bi-214	12.9	1.44E-07	3.4E-09
Po-214	12.9	7.63E-12	1.8E-13
Pb-210	12.9	9.09E-11	2.1E-12
Bi-210	12.9	0.00E+00	0.0E+00
Po-210	12.9	7.79E-13	1.8E-14
Actinium Series			
U-235	0.49	1.28E-08	1.1E-11
Th-231	0.49	8.91E-10	7.9E-13
Pa-231	0.86	2.54E-09	4.0E-12
Ac-227	0.86	1.01E-11	1.6E-14
Th-227	0.80	8.78E-09	1.3E-11
Ra-223	0.70	1.11E-08	1.4E-11
Rn-219	0.70	4.91E-09	6.2E-12
Po-215	0.70	1.29E-11	1.6E-14
Pb-211	0.70	4.56E-09	5.8E-12
Bi-211	0.70	4.05E-09	5.1E-12
Tl-207	0.70	2.01E-10	2.5E-13
Thorium Series			
Th-232	2.15	1.39E-11	5.4E-14
Ra-228	1.87	4.77E-18	1.6E-20
Ac-228	1.87	8.49E-08	2.9E-10
Th-228	1.81	1.58E-10	5.2E-13
Ra-224	1.81	8.54E-10	2.8E-12
Rn-220	1.81	4.58E-11	1.5E-13
Po-216	1.81	1.33E-12	4.4E-15
Pb-212	1.92	1.23E-08	4.3E-11
Bi-212	1.92	1.69E-08	5.9E-11
Po-212	1.23	0.00E+00	0.0E+00
Tl-208	0.61	3.54E-07	3.9E-10
Others			
K-40	14.20	1.44E-08	3.7E-10
Pu-239	0.19	3.83E-12	1.3E-15
TOTAL RISK			5.2E-09

APPENDIX C

OSHA Airborne Radioactivity Limit Calculations

TABLE C-1 COMPARISON OF CONCENTRATIONS WITH NRC AIRBORNE LIMITS
(Assume natural background = 0 for all radionuclides)

Radionuclide	Concentration (pCi/g)	Air Limit (Soluble) (uCi/ml)	Air Limit (Insoluble) (uCi/ml)	Soluble Ratio (@ 1 mg/m^3)	Insoluble Ratio (@ 1 mg/m^3)	Soluble Ratio	Insoluble Ratio
Uranium Series							
U-238	17.4	7E-11	1E-10	0.00025	0.00017	0.00349	0.00273
Th-234	17.4	6E-08	3E-08	0.00000	0.00000	0.00000	0.00001
Pa-234m	17.4	1E-06	1E-06	0.00000	0.00000	0.00000	0.00000
U-234	17.4	6E-10	1E-10	0.00003	0.00017	0.00041	0.00273
Th-230	14.8	2E-12	1E-11	0.00741	0.00148	0.10408	0.02323
Ra-226	18.6	3E-11	5E-11	0.00062	0.00037	0.00871	0.00583
Rn-222	18.6	3E-08		0.00000		0.00001	
Po-218	18.6	6E-13	6E-13	0.03100	0.03100	0.43540	0.48590
Pb-214	13.5	1E-06	1E-06	0.00000	0.00000	0.00000	0.00000
Bi-214	12.9	1E-06	1E-06	0.00000	0.00000	0.00000	0.00000
Po-214	12.9	6E-13	6E-13	0.02150	0.02150	0.30197	0.33700
Pb-210	12.9	1E-10	2E-10	0.00013	0.00006	0.00181	0.00101
Bi-210	12.9	6E-09	6E-09	0.00000	0.00000	0.00003	0.00003
Po-210	12.9	5E-10	2E-10	0.00003	0.00006	0.00036	0.00101
Actinium Series							
U-235	0.49	5E-10	1E-10	0.00000	0.00000	0.00001	0.00008
Th-231	0.49	1E-06	1E-06	0.00000	0.00000	0.00000	0.00000
Pa-231	0.86	1E-12	1E-10	0.00086	0.00001	0.01209	0.00013
Ac-227	0.86	2E-12	3E-11	0.00043	0.00003	0.00605	0.00045
Th-227	0.80	3E-10	2E-10	0.00000	0.00000	0.00004	0.00006
Ra-223	0.70	2E-09	2E-10	0.00000	0.00000	0.00000	0.00005
Rn-219	0.70	6E-13	6E-13	0.00116	0.00116	0.01634	0.01823
Po-215	0.70	6E-13	6E-13	0.00116	0.00116	0.01634	0.01823
Pb-211	0.70	1E-06	1E-06	0.00000	0.00000	0.00000	0.00000
Bi-211	0.70	6E-13	6E-13	0.00116	0.00116	0.01634	0.01823
Tl-207	0.70	1E-06	1E-06	0.00000	0.00000	0.00000	0.00000
Thorium Series							
Th-232	2.15	3E-11	3E-11	0.00007	0.00007	0.00101	0.00113
Ra-228	1.87	7E-11	4E-11	0.00003	0.00005	0.00038	0.00073
Ac-228	1.87	8E-08	2E-08	0.00000	0.00000	0.00000	0.00000
Th-228	1.81	9E-12	6E-12	0.00020	0.00030	0.00282	0.00473
Ra-224	1.81	5E-09	7E-10	0.00000	0.00000	0.00001	0.00004
Rn-220	1.81	3E-07		0.00000		0.00000	
Po-216	1.81	6E-13	6E-13	0.00302	0.00302	0.04237	0.04728
Pb-212	1.92	2E-08	2E-08	0.00000	0.00000	0.00000	0.00000
Bi-212	1.92	1E-07	2E-07	0.00000	0.00000	0.00000	0.00000
Po-212	1.23	6E-13	6E-13	0.00205	0.00205	0.02877	0.03211
Tl-208	0.61	1E-06	1E-06	0.00000	0.00000	0.00000	0.00000
Others							
K-40	14.20	3E-09	3E-09	0.00000	0.00000	0.00007	0.00007
Pu-239	0.19	2E-12	4E-11	0.00009	0.00000	0.00133	0.00007
TOTAL				0.07122	0.06387	1.00024	1.00113
Air Concentration where ratio = 1						14.05	15.67