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Assessment of the Radiological Impact of Coal Utilization

I. Preliminary Studies on Western Coal

Clarence E. Styron, Vito R. Casella, Billy M.

Farmer, Lowell C. Hopkins, Phillip H. Jenkins,

Charles A. Phillips and B. Robinson

February 12, 1979

Monsanto

MOUND FACILITY

Miamisburg, Ohio 45342

operated by

MONSANTO RESEARCH CORPORATION

a subsidiary of Monsanto Company

for the

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Foreword

This report is based on research supported jointly by the U.S. Department of Energy and the Environmental Protection Agency. A substantial amount of the material is included from the preceding technical interim report by B. M. Farmer, C. E. Styron, C. A. Phillips, B. Robinson, and W. H. Westendorf. The final report is a revision and extension of the technical interim report. Individuals providing written material for the final report are listed as co-authors. Other individuals who participated substantially in compiling the final report include C. T. Bishop, R. Brown, D. G. Carfagno, A. Glosby, B. Hollon, V. Lacy, N. May, H. E. Meyer, F. K. Tomlinson, and W. H. Westendorf.

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Summary

Coal is expected to play an increasingly important role in meeting national energy needs, and the potential for environmental contamination by trace elements and radionuclides in coal necessitates a thorough assessment of the requirements for environmental control technology. The behavior of radionuclides in the coal fuel cycle has generally received less attention than that of nonradioactive trace elements. A project at Mound Facility (formerly Mound Laboratory) has been initiated specifically to evaluate the potential radiological impact of coal utilization. It was the purpose of this phase of the project to broadly survey pathways of radionuclides in the coal fuel cycle, identifying critical questions and providing direction for subsequent, definitive studies of radionuclides in coal and the technological enhancement of concentrations of naturally occurring radionuclides through use of this coal. The scope of this preliminary study was limited to only one coal province and Western coal was selected for its prominence in the National Energy Plan.

Specific objectives of Phase I were to 1) investigate the fate of radionuclides in the coal fuel cycle and, where possible, delineate the scope of the potential environmental and human health problem associated with radionuclides in coal; 2) compile and evaluate data for uranium-238, uranium-234, lead-210, polonium-210, and thorium-230 in coal; 3) study the release, fate, and accumulation of radionuclides from a power plant burning Western coal; and 4) assess the possible need for additional control technology or standards.

Results indicate that concentration of radionuclides in coal from 18 Western mines (19 coal seams) varies widely, both within and between mines similar to other minor and trace constituents. The concentration of radionuclides in Western coal being mined today is roughly comparable to that of Eastern coal and is slightly below the average for all U. S. coal. The radionuclides of the uranium decay chain in Western coal appear initially to be in secular equilibrium.

Specific trends were not apparent in distribution of radionuclides in the environment relative to the power plant burning Western coal. A radionuclide balance indicated that over 80% of uranium-234, uranium-238, and lead-210 present in the feed coal remained with the fly ash. Thus, collection of fly ash by electrostatic precipitators is of value in controlling radionuclide emissions. An additional 8 to 9% of the radionuclides remained with bottom ash. Environmental deposition of radionuclides from stack emissions were estimated by atmospheric dispersion modeling to be 0.1 to 1.0% of measured background. The burning of Western coal in a modern power plant with emission controls has not led to detectable environmental impact. However, since over 90% of uranium-234, uranium-238 and lead-210 in feed coal remains with bottom ash and fly ash, it is suggested that the possible migration of radionuclides -- particularly radon-222 which decays to lead-210 and polonium-210 -- from the ash pond warrants further study.

Introduction

The U.S. government's desire to reduce dependency on imported fossil fuels, as well as other factors, is moving the country toward an economy based on coal as the primary fossil fuel [1]*. Use of coal as a fuel is expected to triple between 1975 and the year 2000, from approximately 10 quads (1 quad = 10^{15} Btu or 1.05×10^{18} J) to 30 quads [2]. Governmental agencies, environmentalists, and scientists have become increasingly concerned over potential problems associated with large additions of trace elements in the environment from burning fossil fuels [3-6]. Natusch et al. [7] have reported that preferential concentration of the trace elements arsenic, antimony, cadmium, lead, nickel, selenium, thallium, and zinc occurs in the smallest particles emitted from coal-fired power plants, and these particles most easily pass through conventional particulate control devices. Billings et al. [8] indicated that about 90% of the mercury in coal burned in a pulverized coal furnace appears as vapor in the flue gas. Enrichment of soil and vegetation in lead has been reported at the Four Corners Plant in New Mexico [9], and enrichment of soil in radium-226 and thorium has been reported in industrialized areas of Poland [10]. Thus, the coal-combustion process releases trace elements to the atmosphere as vapors and particles. These particles have relatively greater concentrations of certain trace elements than the feed coal [11] or the collected fly ash. Although the environmental impact of the residual on ecosystems is not certain, control of these residuals appears to be a reasonable goal within acceptable cost limits. In addition to the previously identified trace elements, coal contains uranium and its decay

products; and some rare Western coal reserves contain uranium at 10 to 100 times greater concentrations than most Eastern coal [5, 12, 13]. In fact, the coal reserves with high uranium concentrations may be viewed as a potential uranium resource and would likely be used with dual resource recovery in mind.

The potential for environmental contamination by trace elements and radionuclides present in coal necessitates a thorough assessment of requirements for environmental control technology. The effectiveness of coal cleaning and electrostatic precipitators on emissions of specific radionuclides has not been resolved. Sondreal et al. [14] report a reduced efficiency of electrostatic precipitators (ESP) in controlling particulates with Western coal, probably as a result of low sulfur content. Further, the lower heating value of Western coal, as compared to Eastern coal, requires that a greater quantity be burned [5]. Since it appears that use of coal-fired boilers for the generation of electricity will continue to increase in the future, elucidation of the fate of trace elements and radionuclides released in coal combustion is needed. This need is especially great for radionuclides that are volatile at relatively low temperatures, such as lead-210 and polonium-210 which have not been dealt with in detail [5].

Projected increased usage of coal suggests that a realistic assessment of the magnitude of release of radionuclides is needed so that standards can be evaluated. In the past, studies of the environmental impact of coal utilization [11, 12] have been incomplete so far as the total contribution of radionuclides to the

*Numbers in brackets denote literature cited.

environment (air, water, soil, and biota) is concerned. Special attention needs to be given to lead-210 and polonium-210 since they appear to have a large potential for significant environmental impact and have not received sufficient attention in trace-element studies for power plants. Another potentially important parameter in determining radiation exposure to man centers on disposal and utilization of coal ash and refuse. Lee et al. [16] have suggested that emanation of radon-222 from ash disposal ponds will be the most serious radionuclide problem associated with increased use of coal. Guimond and Fitzgerald [17] have also suggested a potential hazard associated with the use of fly ash in cement and concrete blocks and in roadway construction. The radium-226 in these concrete blocks used for home construction may constitute an important source of radon-222 dose to the public.

The U. S. Environmental Protection Agency (EPA) and Department of Energy (DOE, formerly the Energy Research and Development Administration and the Federal Energy Administration) jointly initiated a project with Monsanto Research Corporation (MRC) at Mound Facility (formerly Mound Laboratory) to assess the fate of radionuclides in coal and their associated health and environmental effects. It was the purpose of this first, preliminary phase to broadly survey pathways of radionuclides in the coal fuel cycle, identifying critical questions and providing direction for subsequent, definitive studies of radionuclides in coal and of the technological enhancement of concentrations of naturally occurring radionuclides through use of coal. The scope of this preliminary phase of the study was limited to only one coal province, and Western coal was

selected because of its prominence in the National Energy Plan. It seems almost certain that the U.S. will turn increasingly to the vast coal deposits of the Western states, since Western coal reserves (198 billion tons or 180 billion metric tons) represent 72% of the identified U.S. coal resources and this coal has a low sulfur concentration [3]. Furthermore, 50% of the coal minable at current prices is in the West [5]. The specific objectives of Phase I were to 1) investigate the fate of radionuclides in the coal fuel cycle and, where possible, delineate the scope of the potential environmental and human health problem associated with radioactivity in coal; 2) compile and evaluate data for uranium-238, uranium-234, lead-210, polonium-210, and thorium-230 found in Western coal; 3) study the release, fate, and accumulation of radionuclides from a power plant burning Western coal; and 4) assess the possible need for additional control technology or standards.

Materials and methods

A preliminary phase was incorporated into the experimental design to identify those areas of most critical concern and to optimize research efforts for assessing potential radiological impact of increased use of coal. As previously mentioned, the scope of the preliminary study was limited to the Western coal province. Samples of coal from major Western mines, as well as samples of coal, ash, stack effluents, airborne particulates, soil, and vegetation associated with a power plant using Western coal, were analyzed by alpha pulse-height spectroscopy or beta counting, as appropriate. The data were then used in an effort to calculate the radionuclide balance for the power plant, to model radiation dose to persons in the

vicinity of the power plant, to estimate hazards to power plant workers, and to estimate quantities of radioactive effluents from small manufacturing operations that have low efficiency emission controls.

Quality control program

An integrated quality control program for sample collection and analysis was initiated prior to collection of samples. A set of operation sheets was developed for collection of samples, and a logbook with detailed entries was developed to ensure consistency and validity of results.

For the coal samples, which were by far the most numerous, four sets of quadruplicate analyses were run at levels of activity ranging from the lowest to highest expected values in order to establish an error curve for this study. Known amounts of NBS standards for uranium and lead were added to the replicate samples. Generally, errors in precision experienced were found to be <10% for uranium, <15% for polonium and thorium, and <20% for lead -- all at the 95% confidence level. Detailed quality control data are presented in Appendix 1.

Mine samples

A list of mines for sampling was carefully prepared from discussions with the U.S. Geological Survey staff in Denver, Colorado. Criteria for selection of mines for this list were 1) that a mine have a Western location and be a large producer (≥ 0.4 million metric tons per year) and 2) that mines producing both lignite and subbituminous coal were included. This list was further refined through communications with state geologists in each state that was visited. This approach ensured that there were no new large mines excluded

from the list because they were not located on federal land which was leased for coal mining. The production of the selected mines in six Western states represents 65% of the total coal mined in those states. Fewer than 35 mines account for 90% of the Western coal production [18]. Coal mines selected for study are described in Table 1, and their locations are shown in Figure 1. Samples were collected in August 1976 from 19 coal seams at 18 active mines in six states. The samples, consisting of >200 g (>0.4 lb) of coal, were generally collected by ASTM methods [19] using an automatic sampler which grabs a sample at a fixed interval of time. At some locations the ASTM mechanism was not used because it was either not operational or not available. At the Dave Johnston Mine (Glen Rock, Wyoming) the sample was pulled by hand. At the Hanna #5 and Vanguard #5 mines (Hanna, Wyoming) and the Jim Bridger mine (Rock Springs, Wyoming) core borings were taken to represent seams. Core borings should be more representative of the whole seam than are grab samples from a conveyor, even though the grab samples are collected by ASTM methods. The samples collected by ASTM methods at each mine were representative of the total coal mined in a 24-hr period -- generally several thousand tons. Samples were shipped to Mound via Air Express so that analysis could begin promptly.

Power plant samples

Criteria used for selecting a power plant for study included 1) the power plant should use large quantities (≥ 0.4 million metric tons per year) of Western coal and generate ≥ 1000 MWe; 2) port holes for stack sampling should be available; 3) ecosystems around the power plant should permit an evaluation of intake of radionuclides by ingestion, i.e., a farming area; 4) personnel at the power plant should be agreeable to the

Table 1 - COAL MINES SELECTED FOR STUDY IN PHASE I

Mine	Date ^a Sample Collected	Production (in millions of metric tons for 1974)	Location (City and State)	Metric Tons Represented by Sample
Kayenta	6/76	2.27	Kayenta, Arizona	18,160
Black Mesa #1	8/04/76	3.57	Kayenta, Arizona	2,790
Seneca	7/25/76	0.42	Hayden, Colorado	2,270
Navajo	7/31/76	6.31	Fruitland, N. Mex.	19,580
Navajo	8/02/76	6.31	Fruitland, N. Mex.	10,420
Sorenson	8/04/76	2.21	Kemmerer, Wyoming	3,360
Elkol	8/04/76	0.83	Frontier, Wyoming	3,360
Hanna #5	7/76	0.57	Hanna, Wyoming	Seam Boring
Vanguard #2	7/76	0.92	Hanna, Wyoming	Seam Boring
Jim Bridger ^e	7/31/76	0.67	Rock Springs, Wyo.	Seam Boring (Upper)
Jim Bridger ^e	7/16/76	0.67	Rock Springs, Wyo.	Seam Boring (Lower)
Dave Johnston	8/06/76	1.90	Glen Rock, Wyoming	4,090
Belle Ayr	8/07/76	3.00	Gillette, Wyoming	9,080
Big Horn	8/09/76	0.90	Sheridan, Wyoming	4,310
Decker #1	8/08/76	6.16 ^d	Decker, Montana	9,480
Absoloka	8/06/76 McKay Seam			3,440
Absoloka	8/09/76 Robinson Seam	3.63	Harden, Montana	5,220
Savage ^b	8/10/76	0.27	Savage, Montana	436
Gascoyne ^b	8/11/76	0.18 ^c	Gascoyne, N. Dak.	4,090
Beulah ^b	8/11/76	1.54	Beulah, N. Dakota	908
Total		42.33		

^aDate represents the date the sample was pulled, not the date the mine was visited.

^bLignite Mines

^cProduction now up to three million metric tons per year.

^dProduction now up to 10-12 million metric tons per year.

^eUpper and lower seams are separate seams.

1. Seneca Mine
2. Navajo Mine
3. Black Mesa #1 Mine
4. Kayenta Mine
5. Sorensen Mine
6. Elko Mine

7. Jim Bridger Mine (Upper Seam)*
8. Jim Bridger Mine (Lower Seam)*
9. Hanna #5 Seam
10. Vanguard #2 Mine
11. Dave Johnston Mine
12. Belle Ayr Mine

13. Big Horn #1 Mine
14. Decker Mine
15. Absoloka Mine (Rosebud - McKay Seam)
16. Absoloka Mine (Robinson Seam)
17. Savage Mine
18. Gascoyne Mine
19. Beulah Mine

FIGURE 1
LOCATIONS OF WESTERN COAL MINES SAMPLED

study; and 5) the power plant should use coal from a mine previously shown to produce coal of relatively high radionuclide concentration. The George Neal Steam Electric Generating Station of the Iowa Public Service Company met these criteria and was selected as the subject plant for this project.

The Neal Station (Figure 2) is located on the east bank of the Missouri River approximately 17.7 km (11 mi) south of Sioux City, Iowa, and it began generating electricity in 1964. At present there are three coal-fired units at the station (Figure 3) with generating capacities of 150, 330, and 540 MWe, respectively. A fourth coal-fired unit is under construction, and it will have a generating capacity of 640 MWe. Unit #4 should become operational by early 1979 [20]. Plant heat rate for Unit #2 was 10.8 MJ/kWhr (10,200 Btu/kWhr), efficiency being 32 to 33%. Emission rates for station operation [20] are given in Appendix 2. The Neal Station used coal (0.61% sulfur) from the Hanna #5 mine in Wyoming, and this coal had the highest concentration of uranium-234 and uranium-238 among the coals sampled. The power plant maintains an Air Quality Monitoring System consisting of four monitoring stations and one weather station. Furthermore, the power plant is located in a farming area, which greatly facilitated studies of ingestion pathways. It should be noted, however, that although agricultural activity aided studies of ingestion pathways, it may have contributed to problems in assessing natural background levels of radionuclides. Phosphate fertilizers are being investigated as potential, low-level sources of radionuclides [21-22].

Samples of airborne particulates were col-

lected in October 1976 at the four air quality monitoring stations (Sites #1, #2, #4, #5) shown in Figure 2, the weather station (Site #3), and 16 km (10 mi) NNW of the plant in South Sioux City, Nebraska (Site #6). The locations of air quality monitoring stations were determined and set by the "Ambient Air Quality Study" performed for the Iowa Public Service Company by EBASCO Services Incorporated [20]. A sampling station was established by Mound personnel at the weather station because of wind direction and weather conditions at the time of sampling. The sixth sampling station was established in South Sioux City for estimation of background levels of airborne particulates for comparison with other stations. Airborne particulates were collected on Microsorban-98 filter paper (penetration <0.01%, aerosol 0.4 μ m) at a rate of 2.55 to 2.83 m³/min (90 to 100 ft³/min). Filter papers were changed at 48-hr intervals. Samples of airborne particulates were collected inside the power plant in July 1977.

Samples of soil and vegetation were collected in October 1976 and again in July 1977 from air quality monitoring stations and from more distant sites (Table 2). The second series of samples was taken to test the validity of certain data obtained in October and to incorporate additional parameters for the study. A stainless steel corer (8.3 cm in diameter) was used to collect soil samples to a depth of 30 cm (12 in). Cores from a tilled field were pooled, whereas cores from a relatively undisturbed area were split into a surface (0 to 5 cm) and subsurface (5 to 30 cm) fraction. Samples of vegetation at each site were collected by clipping at ground level.

FIGURE 2 - Locations of power plant and air quality monitoring stations.

FIGURE 3 - Photograph of the George Neal Steam Electric Generating Station.

Table 2 - LIST OF SAMPLES COLLECTED FROM ENVIRONS OF THE NEAL STATION

Site	Airborne Particulates	Sample Type					
		Soil Strata (cm depth)			Corn	Vegetation	
		0-30	0-5	5-30		Grass Bromus sp.	Misc.
Air Monitoring Sta. 1	O ^a		J ^b	J	J	J	
Air Monitoring Sta. 2	O		J	J	J	J	
Air Monitoring Sta. 3 (Weather Station)	O	O,J			J	O,J	O,J
Air Monitoring Sta. 4	O	O	J	J	J	O,J	
Air Monitoring Sta. 5	O	O,J				J	J
South Sioux City, Municipal Garage (Sta. 6)	O						
Corn field and park 40 km (25 mi) south of Neal Plant on Interstate 29			J	J	J	J	
Corn field and park 96 km (60 mi) south of Neal Plant on Interstate 29		O	J	J	J	O,J	
Furnace room, Unit #2 of Neal Plant	J						

^aA "O" indicates samples taken in October.

^bA "J" indicates samples taken in July.

Samples were also collected in October from coal at the Neal Plant, from fly ash and bottom ash of Unit #2 of the plant, and from the inlet and outlet of electrostatic precipitators on Unit #2. Stack samples were collected by LFE, Environmental Analysis Laboratories. LFE analyzed the stack samples for radon-222 and particulate loading. Mound performed analyses for uranium-234, uranium-238, thorium-230, lead-210, and polonium-210. Detailed sampling procedures for stack effluents, and the several problems encountered, are given in Appendix 3.

Analytical procedures

Numerous analytical procedures required for this project were already in use at Mound for routine analysis of environmental samples. These were successfully modified for coal and its combustion by-products. Additional procedures were developed or modified as required. Samples were analyzed by alpha pulse-height spectroscopy for uranium-238, uranium-234, polonium-210, and thorium-230. Lead-210 was analyzed by beta counting.

Sample size was adjusted to optimize analyses. Details of analytical procedures are given in Appendix 4.

Results and discussion

It must be emphasized that the purpose of this phase of the project was to broadly survey pathways of radionuclides in the coal fuel cycle, identifying critical questions and providing direction for subsequent, definitive studies of radionuclides in coal and the technological enhancement of concentrations of naturally occurring radionuclides through use of coal. Although the conclusions reported here are preliminary and there are a number of instances in which the need for additional data is obvious, the report is considered to be of value since it does make a positive contribution to an area of environmental concern that is characterized by a general paucity of information -- pathways of radionuclides in the coal fuel cycle.

Coal mine samples

Data on radionuclide concentrations in coal samples indicated excellent precision for the analysis of uranium-234 and uranium-238. Duplicate analyses of each coal sample for uranium-234 and uranium-238 showed precisions of 5.1 and 7.0%, respectively, at the 1 s confidence level.

Measurements of uranium-234 and uranium-238 concentrations in coal samples ranged from 0.04 to 1.20 pCi/g (Table 3); polonium-210, from 0.03 to 0.58 pCi/g (Table 3). Combining values for all mines studied gives a mean (± 1 s) concentration for uranium-234 of 0.31 (± 0.32) pCi/g, for uranium-238 of 0.30 (± 0.32)

pCi/g, for polonium-210 of 0.23 (± 0.14) pCi/g. These radionuclide concentrations in Western coal from operating mines are roughly comparable to values for Eastern coal as reported by Bedrosian et al. [23], Martin et al. [24], and an EPA survey [25] and are slightly below the national average (0.6 pCi/g) reported by Swanson et al. [26]. A few Western coal reserves, however, are reported to have significantly higher concentrations, on the order of 10 to 100 times [5]. These coals with high concentrations of uranium represent a valuable source of uranium and if used in combustion at all they would likely be used with dual resource recovery in mind.

Values for polonium-210 suggest that a secular equilibrium exists for isotopes of the uranium decay chain in these samples of coal, i.e., the concentrations of uranium-238 and polonium-210 are essentially equal.

The concentrations of radionuclides found in coal from sampled Western mines imply that, based on CY-1975 usage of coal [21], 160 Ci of uranium-234, 150 Ci of uranium-238, and 120 Ci of polonium-210 would be available for release to the environment per year from burning Western coal. This availability may be expected to occur primarily by three modes -- airborne particulates, ground deposition and subsequent aqueous transport, and by-product usage. Each of these pathways is discussed later in this report.

Power plant samples

Coal used at the Neal Station was from the Hanna #5 mine and contained 0.61% sulfur, as mentioned previously. Radionuclide concentration of coal sampled at the power plant (Table 4) was less

Table 3 - CONCENTRATIONS OF U-234, U-238, and Po-210 IN COAL FROM MINES SAMPLED^a

Sample Location		Mound Sample Number	U-234 (pCi/g)	U-238 (pCi/g)	Po-210 (pCi/g)
Site Name	- Seneca	WCU-1A	0.30 ± 0.01	0.30 ± 0.01	0.13 ± 0.04
County	- Routt	WCU-1B	0.28 ± 0.01	0.27 ± 0.01	0.12 ± 0.02
State	- Colorado	WCPC-1			
Site Name	- Navajo	WCU-2A	0.62 ± 0.02	0.57 ± 0.02	0.54 ± 0.11
County	- San Juan	WCU-2B	0.59 ± 0.02	0.59 ± 0.02	0.56 ± 0.09
State	- New Mexico	WCPO-2			
Site Name	- Black Mesa Mine	WCU-3A	0.18 ± 0.01	0.17 ± 0.01	0.09 ± 0.03
County	- Navajo	WCU-3B	0.16 ± 0.01	0.15 ± 0.01	0.10 ± 0.03
State	- Arizona	WCPO-3			
Site Name	- Kayenta Mine	WCU-4A	0.19 ± 0.01	0.16 ± 0.01	0.12 ± 0.02
County	- Navajo	WCU-4B	0.18 ± 0.01	0.16 ± 0.01	0.14 ± 0.03
State	- Arizona	WCPO-4			
Site Name	- Sorensen	WCU-5A	0.08 ± 0.01	0.07 ± 0.01	0.11 ± 0.05
County	- Lincoln	WCU-5B	0.06 ± 0.01	0.05 ± 0.01	0.11 ± 0.06
State	- Wyoming	WCPO-6			
Site Name	- Elkol Mine	WCU-6A	0.04 ± 0.01	0.04 ± 0.01	0.03 ± 0.04
County	- Lincoln	WCU-6B	0.05 ± 0.01	0.05 ± 0.01	0.07 ± 0.05
State	- Wyoming	WCPO-6			
Site Name	- Jim Bridger Mine (Upper Seam)	WCU-7A	0.17 ± 0.01	0.16 ± 0.01	0.17 ± 0.08
County	- Sweetwater	WCU-7B	0.17 ± 0.01	0.16 ± 0.01	0.29 ± 0.12
State	- Wyoming	WCPO-7			
Site Name	- Jim Bridger Mine (Lower Seam)	WCU-8A	0.23 ± 0.01	0.19 ± 0.01	0.27 ± 0.09
County	- Sweetwater	WCU-8B	0.23 ± 0.01	0.22 ± 0.01	0.22 ± 0.09
State	- Wyoming	WCPO-8			
Site Name	- Hanna #5 Pit 24	WCU-9A	1.20 ± 0.02	1.12 ± 0.01	0.24 ± 0.05
County	- Carbon	WCU-9B	1.18 ± 0.01	1.21 ± 0.01	0.25 ± 0.04
State	- Wyoming	WCPO-9			
Site Name	- Vangard #2 Mine	WCU-10A	1.13 ± 0.02	1.17 ± 0.02	0.45 ± 0.08
County	- Carbon	WCU-10B	1.10 ± 0.02	1.08 ± 0.02	0.40 ± 0.10
State	- Wyoming	WCPO-10			
Site Name	- Dave Johnson	WCU-11A	0.50 ± 0.02	0.45 ± 0.02	0.58 ± 0.08
County	- Converse	WCU-11B	0.47 ± 0.02	0.44 ± 0.02	0.53 ± 0.08
State	- Wyoming	WCPO-11			

Table 3 (Continued)

Sample Location	Mound Sample Number	U-234 (pCi/g)	U-238 (pCi/g)	Po-210 (pCi/g)
Site Name - Belle Ayr Mine	WCU-12A	0.13 ± 0.01	0.12 ± 0.01	0.19 ± 0.06
County - Campbell	WCU-12B	0.12 ± 0.01	0.11 ± 0.01	0.14 ± 0.05
State - Wyoming	WCPO-12			
Site Name - Big Horn Mine	WCU-13A	0.12 ± 0.01	0.11 ± 0.01	0.14 ± 0.06
County - Sheridan	WCU-13B	0.12 ± 0.01	0.13 ± 0.01	0.14 ± 0.07
State - Wyoming	WCPO-13			
Site Name - Decker Mine	WCU-14A	0.13 ± 0.01	0.13 ± 0.01	0.10 ± 0.04
County - Big Horn	WCU-14B	0.13 ± 0.01	0.12 ± 0.01	0.11 ± 0.05
State - Montana	WCPO-14			
Site Name - Absoloka Mine	WCU-15A	0.22 ± 0.01	0.20 ± 0.01	0.22 ± 0.05
Rosebud-McKay Seam				
County - Rosebud	WCU-15B	0.24 ± 0.01	0.24 ± 0.01	0.22 ± 0.05
State - Montana	WCPO-15			
Site Name - Absoloka Mine	WCU-16A	0.19 ± 0.01	0.19 ± 0.01	0.24 ± 0.05
Robinson Seam				
County - Rosebud	WCU-16B	0.21 ± 0.01	0.21 ± 0.01	0.27 ± 0.08
State - Montana	WCPO-16			
Site Name - Savage Mine	WCU-17A	0.16 ± 0.01	0.15 ± 0.01	0.24 ± 0.05
County - Richland	WCU-17B	0.17 ± 0.01	0.17 ± 0.01	0.16 ± 0.04
State - Montana	WCPO-17			
Site Name - Gascoyne	WCU-18A	0.23 ± 0.02	0.23 ± 0.01	0.28 ± 0.06
County - Bowman	WCU-18B	0.25 ± 0.01	0.22 ± 0.01	0.27 ± 0.06
State - North Dakota	WCPO-18			
Site Name - Beulah	WCU-19A	0.11 ± 0.01	0.10 ± 0.01	0.11 ± 0.04
County - Mercer	WCU-19B	0.10 ± 0.01	0.10 ± 0.01	0.13 ± 0.04
State - North Dakota	WCPO-19			

^aFor U-234, 1 pCi/g = 0.16 ppb; for U-238, 1 pCi/g = 3.0 ppm; for Po-210, 1 pCi/g = 0.22 × 10⁻⁶ ppb.

Table 4 - RADIONUCLIDE CONCENTRATIONS IN COAL BURNED AT NEAL STATION

<u>Sample Description</u>	<u>Mound Sample Number</u>	<u>U-234 (pCi/g)</u>	<u>U-238 (pCi/g)</u>	<u>Po-210^a (pCi/g)</u>	<u>Pb-210 (pCi/g)</u>	<u>Th-230 (pCi/g)</u>
Represents coal burned October 15, 1976	WCPU-2A	0.40 ± 0.02	0.36 ± 0.02		0.71 ± 0.10	
	WCPU-2B	0.41 ± 0.03	0.37 ± 0.03			
	WCPPO-2A			1.98 ± 0.85		
	WCPPO-2B			1.37 ± 0.77		
Represents coal burned October 20, 1976	WCPU-6A	0.44 ± 0.02	0.40 ± 0.02		N.A. ^b	
	WCPU-6B	0.41 ± 0.03	0.38 ± 0.02			
	WCPPO-6A			0.69 ± 0.11		
	WCPPO-6B			1.03 ± 0.25		
Represents coal burned October 23, 1976	WCPU-9A	0.54 ± 0.03	0.49 ± 0.03		1.17 ± 0.16 ^a	0.52 ± 0.03 ^c
	WCPU-9B	0.50 ± 0.03	0.49 ± 0.03		0.54 ± 0.18 ^c	0.56 ± 0.03 ^c
	WCPPO-9A			0.88 ± 0.07	0.43 ± 0.16 ^c	
	WCPPO-9B			0.80 ± 0.07		
Represents coal burned October 24, 1976	WCPU-10A	0.47 ± 0.02	0.47 ± 0.02		0.50 ± 0.07	
	WCPU-10B	0.51 ± 0.02	0.45 ± 0.02			
	WCPPO-10A			1.13 ± 0.10		
	WCPPO-10B			1.59 ± 0.25		

^aThese data are suspect due to possible errors in the analytical procedures used initially in this phase of the project. Caution should be used in interpreting calculations in which these data are used.

^bN.A. = not analyzed.

^cAnalyzed in September, 1977.

Error values listed are counting statistics at the 2s confidence level.

than half that sampled at the Hanna #5 mine. Measurements of uranium-234 and uranium-238 concentrations ranged from 0.36 to 0.54 pCi/g in coal samples from the power plant and from 1.12 to 1.21 pCi/g in coal samples from the mine. Possible explanations for this variation in values for coal from the same mine are the ranges of values for radionuclide concentrations vertically and horizontally within a coal seam, the different sampling techniques used at the mine and at the power plant, and coal preparation and leaching by rain. A core boring taken at the mine was representative of the entire seam, whereas the sample taken from the power plant was from coal being used so there was no indication of the level within the seam from which this coal originated. In addition, the ASTM mechanism was not operational at the power plant, and these coal samples were obtained manually.

One sample of coal at the power plant was also analyzed for thorium-230. Concentration measurements for this sample were 0.49 pCi/g for uranium-238, and 0.54 pCi/g for thorium-230. This suggests that a secular equilibrium exists for these two radionuclides.

Measurements of radionuclide concentrations in bottom ash and fly ash were higher than in the feed coal, probably due to a loss of mass during combustion. Measurements of radionuclide concentrations in bottom ash (Table 5) ranged from 2.33 to 2.74 pCi/g for uranium-234 and uranium-238, from 4.98 to 5.11 pCi/g for polonium-210, from 2.52 to 5.63 pCi/g for lead-210, and from 2.65 to 3.95 pCi/g for thorium-230. Measurements of concentrations in fly ash ranged from 4.00 to 4.68 pCi/g for uranium-234 and uranium-238, from 5.25 to 5.37 pCi/g for

polonium-210, from 4.82 to 5.76 pCi/g for lead-210, and from 3.66 to 4.24 pCi/g for thorium-230. With an ash content of 11.91%, one would expect an increase in concentration of nonvolatile elements in ash over feed coal by a factor of 8.4. The measured ratios of radionuclide concentrations in bottom ash to feed coal were 5.9 for uranium-234, 5.9 for uranium-238, 4.3 for polonium-210, 6.6 for lead-210, and 6.1 for thorium-230. Similar ratios for the fly ash were 9.5 for uranium-234, 9.9 for uranium-238, 4.5 for polonium-210, 7.7 for lead-210, and 7.3 for thorium-230. Ratios less than 8.4 for bottom ash suggest an enriched fraction of the radionuclides is incorporated into stack effluents.

Radionuclide concentrations in stack effluents from Unit #2 of the Neal Station are presented in Tables 6-8. Measurements of the radionuclide concentrations in effluents at the input to the electrostatic precipitator averaged 9.99 pCi/m³ for uranium-234, 9.15 pCi/m³ for uranium-238, 9.95 pCi/m³ for polonium-210, 13.2 pCi/m³ for lead-210, and 560 pCi/m³ for radon-222. Measurements at the output of the electrostatic precipitator averaged 7.48 pCi/m³ for uranium-234, 7.54 pCi/m³ for uranium-238, 9.17 pCi/m³ for polonium-210, 14.6 pCi/m³ for lead-210, and 290 pCi/m³ for radon-222. These limited data indicate that concentrations of uranium-234 and uranium-238 are reduced by the electrostatic precipitator, whereas polonium-210 and lead-210 are not affected significantly. The data also indicate a reduction in the concentration of radon-222, although the precipitator should have no effect on the radon-222. The fact that the power plant had just returned on line and other problems in gathering representative samples, as explained in Appendix 2 by LFE, argue strongly against accepting these conclusions until

Table 5 - RADIONUCLIDE CONCENTRATIONS IN ASH FROM THE NEAL STATION

<u>Sample Identification</u>	<u>Mound Sample Number</u>	<u>U-234 (pCi/g)</u>	<u>U-238 (pCi/g)</u>	<u>Po-210 (pCi/g)</u>	<u>Pb-210 (pCi/g)</u>	<u>Th-230^a (pCi/g)</u>
Bottom Ash	BAU-1	2.73 ± 0.07	2.33 ± 0.06		5.63 ± 0.38 ^b	2.65 ± 0.85
	BAU-2	2.72 ± 0.09	2.74 ± 0.09		2.82 ± 0.16 ^c	3.95 ± 0.41
	BAPO-1			4.98 ± 0.28	2.52 ± 0.16 ^c	
	BAPO-2			5.11 ± 0.23		
Fly Ash	FAU-1	4.68 ± 0.09	4.45 ± 0.09		5.76 ± 0.41 ^b	4.24 ± 0.23
	FAU-2	4.04 ± 0.11	4.00 ± 0.11		4.82 ± 0.14 ^c	3.66 ± 0.13
	FAPO-1			5.37 ± 0.25	4.98 ± 0.09 ^c	
	FAPO-2			5.25 ± 0.27		

^aTh-230 samples analyzed in September, 1977.

^bThese data are suspect due to possible errors in the analytical procedures used initially in this phase of the project. Caution should be used in interpreting calculations in which these data are used.

^cPb-210 samples analyzed in September, 1977.

Table 6 - RADIONUCLIDE CONCENTRATIONS IN STACK (UNIT #2) EMISSIONS FROM THE NEAL STATION

<u>Sample Identification</u>	<u>Mound Sample Number</u>	<u>U-234 (pCi/m³)</u>	<u>U-238 (pCi/m³)</u>	<u>Po-210 (pCi/m³)</u>	<u>Pb-210 (pCi/m³)</u>
Inlet 1, 2, and 3 Boiler #2 (Composite of Samples 1, 2, and 3) October 23-24, 1976 70.74 ft ³	WIU-1 WIPO-1	9.99 ± 1.77	9.15 ± 1.70	9.95 ± 0.96	13.19 ± 1.72
Outlet #4 Boiler #2 (Stack Effluent) Oct. 25, 1976 - 53.32 ft ³	WOU-4 WOPO-4	5.27 ± 0.93	5.83 ± 0.98	9.51 ± 1.19	12.96 ± 1.96
Outlet #5 Boiler #2 (Stack Effluent) Oct. 25, 1976 - 56.56 ft ³	WOU-5 WOPO-5	7.34 ± 1.56	7.03 ± 1.52	8.26 ± 1.08	12.01 ± 1.76
Outlet #6 Boiler #2 (Stack Effluent) Oct. 26, 1976 - 47.75 ft ³	WOU-6	9.83 ± 1.54	9.77 ± 1.54	9.75 ± 1.00	18.83 ± 3.64

Table 7 - RADON CONCENTRATIONS IN EMISSIONS FROM
THE GEORGE NEAL POWER PLANT, UNIT #2^a

A. Precipitator Inlet

<u>Date of Sampling</u>	<u>Time of Sampling</u>	<u>Radon Concentration (pCi/m³)</u>	<u>Radon Emission (mCi/hr)</u>
10/23/76	17:15	1500 + 200	2.7 + 0.4
10/24/76	11:36	300 + 100	0.5 + 0.2
10/24/76	13:15	<200	<0.4
10/25/76	9:30	<200	<0.4
10/26/76	8:58	600 + 160	1.07 + 0.28

B. Precipitator Outlet

<u>Date of Sampling</u>	<u>Time of Sampling</u>	<u>Radon Concentration (pCi/m³)</u>	<u>Radon Emission (mCi/hr)</u>
10/25/76	11:24	460 + 140	0.70 + 0.21
10/25/76	16:54	<200	<0.3
10/26/76	12:06	<200	<0.3

^aThese analyses from LFE, Environmental Analysis Laboratories.

Table 8 - PARTICULATE EMISSIONS FROM THE
GEORGE NEAL POWER PLANT, UNIT #2^a

A. Precipitator Inlet

<u>Sampling Date & Time</u>	<u>Sampled Gas Volume^b</u>	<u>Mass Collected (mg)</u>	<u>Particulate Loading^c (mg/m³)</u>	<u>g/std.ft³</u>
10/23/76 10:25-12:00	0.689 m ³ (24.33 ft ³)	1429.5	2100	0.91
10/23/76 16:30-18:00	0.638 m ³ (22.52 ft ³)	986.0	1525	0.66
10/24/76 11:15-12:45	0.676 m ³ (23.89 ft ³)	1959.6	2900	1.21

B. Precipitator Outlet

<u>Sampling Date & Time</u>	<u>Sampled Gas Volume^b</u>	<u>Mass Collected (mg)</u>	<u>Particulate Loading^c (mg/m³)</u>	<u>g/std.ft³</u>
10/25/76 14:35-15:50	1.51 m ³ (53.32 ft ³)	1868.6	1250	0.54
10/25/76 16:25-17:50	1.60 m ³ (56.57 ft ³)	2028.2	1225	0.55
10/26/76 11:10-12:25	1.35 m ³ (47.75 ft ³)	1985.0	1425	0.61

^aThese analyses from LFE, Environmental Analysis Laboratories.

^bMeter conditions

^cStandard dry conditions of 20°C (68°F) and 1 atmosphere (760 mm mercury or 29.92 in mercury).

the data can be verified in subsequent sampling. Data on efficiency of electrostatic precipitators in reducing particulate emissions (Table 8) further suggest the need for additional stack sampling.

Radionuclide balance for the power plant

A calculation of the radionuclide balance for Unit #2 of the Neal Station was made to check the consistency of the measured data and to gain an insight into the pathways of radionuclides within the plant. A schematic of the input and output coal streams is shown in Figure 4. Samples of coal, bottom ash, fly ash, and stack particulates were collected and analyzed for the radionuclides uranium-234, uranium-238, polonium-210 and lead-210. Stack particulates were sampled by LFE both at the inlet and outlet of the electrostatic precipitator. Other samples were collected by Mound personnel.

The applicable data for the balance exercise are shown in Table 9. Since the stack samples were collected between October 23 and 26, 1976, the coal data used were the average of the sample results for that period. A sample calculation of a radionuclide balance for uranium-234 is given in Appendix 5.

Results for all radionuclides are shown in Table 10. Since a relative imbalance of $\pm 25\%$ is generally considered satisfactory [27], all balances obtained are reasonably acceptable except that of polonium-210. The variability from day to day of the polonium-210 measurements in coal is quite large relative to the variability of uranium-238 measurements, possibly due to errors associated with analytical procedures for polonium-210 (See Table 4 footnote a). The concentration of polonium-210 measured in the coal sampled

on October 23 was 0.84 pCi/g, while for the coal sampled on October 24, the measured concentration averaged 1.36 pCi/g. By using the October 23 value, the relative imbalance of polonium-210 was reduced to $+14\%$ as shown in the last column of Table 10. The possible daily variability of feed coal points out the importance of taking all measurements, i.e., the coal, bottom ash, fly ash, and stack, on as nearly the same coal sample as is practicable.

As stated in the previous section, inaccuracies in the stack measurements at the precipitator outlet are suspected. However, the stack output has a relatively small effect on the balance, since it represents a relatively small percentage of the total output. Thus, large inaccuracies in the stack output measurements will have a relatively small effect on the radionuclide balance.

The results indicate that the radionuclides studied are in reasonable balance, but the large variability in polonium-210 and lead-210 in the coal can produce an imbalance unless care is taken to collect all samples on the same coal. By far, the largest percentage of the radioisotopes in coal stay with the fly ash, i.e., over 80% for uranium-234, uranium-238, and lead-210. Approximately 8-9% of the radioisotopes in the feed coal stays with bottom ash. Inaccuracies in the precipitator outlet stack measurements can produce errors in subsequent atmospheric dispersion calculations, since these values serve as a source term for these calculations.

Environmental samples

The radionuclide concentration of airborne particulates collected at the five air-sampling stations around the power plant averaged at each station from 28.6 to 48.8 aCi/m³ for uranium-234, 36.8 to 54.2 aCi/m³ for uranium-238, 983 to 1300 aCi/m³ for polonium-210, and 5410 to 24220 aCi/m³ for

FIGURE 4 - Schematic of coal input and output streams.

Table 9 - DATA USED IN RADIONUCLIDE BALANCE EXERCISE

Component	Radionuclide			
	U-234	U-238	Po-210	Pb-210
Coal (pCi/g)	0.51	0.48	1.10	0.66
Bottom Ash (pCi/g)	2.72	2.54	5.05	3.66
Fly Ash (pCi/g)	4.36	4.23	5.31	5.19
Precipitator Inlet (pCi/m ³)	9.99	9.15	9.95	13.19
Precipitator Outlet (pCi/m ³)	7.48	7.54	9.17	14.60

Table 10 - RADIONUCLIDE BALANCE FOR UNIT #2 OF THE NEAL STATION^a

Radionuclide Throughput (pCi/sec)					
Component	U-234	U-238	Po-210	Pb-210	Po-210 ^b
Input Coal	17843	16793	38484	23090	29388
Bottom Ash	1446	1350	2685	1946	2685
Fly Ash	15849	15376	19302	18866	19302
Stack	2644	2665	3241	5160	3241
Total Output	19939	19391	25228	25972	25228
% Relative Imbalance	-12	-15	+34	-12	+14

^aOut of the arithmetic context of the above table, these values should not be used with more than three significant figures.

^bOctober 23 coal measurement only.

Table 11 - RADIONUCLIDE CONCENTRATION IN AIRBORNE PARTICULATES AROUND THE NEAL STATION^a

Sample Location County and State	Mound Sample #	U-234 (aCi/m ³)	U-238 (aCi/m ³)	Po-210 (aCi/m ³)	Pb-210 (aCi/m ³)
Monitoring Site #1 Woodbury, Iowa	WAU(1) WAPO(1)	41 ± 11	39 ± 11	983 ± 216	5410 ± 516 ^b
Monitoring Site #2 Woodbury, Iowa	WAU(2) WAPO(2)	49 ± 12	54 ± 13	1210 ± 240	24200 ± 1170 ^b
Monitoring Site #3 Woodbury, Iowa	WAU(3) WAPO(3)	29 ± 9	37 ± 10	1300 ± 180	N.S. ^c
Monitoring Site #4 Dakota, Nebraska	WAU(4) WAPO(4)	38 ± 20	43 ± 22	1270 ± 327	13000 ± 770 ^b
Monitoring Site #5 Woodbury, Iowa	WAU(5) WAPO(5)	48 ± 12	48 ± 12	1300 ± 204	N.S. ^c
Monitoring Site #6 South Sioux City, Nebraska	WAU(6) WAPO(6)	54 ± 14	62 ± 16	1570 ± 371	22300 ± 1160

^aThese are average values for the total sampling period and average values of the duplicates for each sampling location. The error values are averages of individual errors from counting statistics only at the 2s confidence level.

^bOnly one sample of partial sampling period, however, assumed as an average for this study.

^cN.S. = No Sample.

lead-210. The average value for airborne particulates (Table 11) is not significantly different from station #6 in South Sioux City, Nebraska (background).

The daily average wind direction was obtained for each of the sampling periods. Because the wind was from the northwest 50% of the sampling time, it would be expected that if the stack emissions were significant the maximum radionuclide concentration would be observed at the southeast sampler. This expectation, however, was not met in the case of uranium-234 and uranium-238. No trend could be detected from the levels of uranium-234 and uranium-238 found at the five air-sampling locations. Furthermore, values for polonium-210 concentrations in airborne particulates at air-sampling stations #1-5 are not significantly different from values reported by NCRP Report No. 45, Natural Background Radiation in the U.S. [28].

Concentration of radionuclides in airborne particulates collected at the sixth station, the municipal garage in South Sioux City 16 km (10 mi) north of the power plant, was at essentially the same level as samples collected nearer the power plant (Table 11). Data from this site were to be used as estimates of background levels; therefore, sources of airborne radionuclides which might invalidate such use of the data were sought. Two adjacent concrete processing plants were investigated, because they had been reported to occasionally use fly ash from the Neal Station in formulating concrete products. Closer checking with management and personnel of both concrete plants and of the firm that hauls ash from the Neal Station revealed that the concrete plants rarely used the ash, perhaps as little as one truck load per year, and that they were not using the ash during the

time of the October sampling. The concentrations of lead-210 and polonium-210 in samples of raw materials from the concrete plants were measured to be (mean $\pm$ 2 s) 0.22 ± 0.04 pCi/g for polonium-210 and 0.31 ± 0.06 pCi/g for lead-210 in cement, 0.24 ± 0.01 pCi/g for polonium-210 and 0.36 ± 0.22 pCi/g for lead-210 in limestone aggregate, 0.32 ± 0.01 pCi/g for polonium-210 and 0.34 ± 0.04 pCi/g for lead-210 in sand, and 0.38 ± 0.07 pCi/g for polonium-210 and 0.32 ± 0.03 pCi/g for lead-210 in a mixture of sand and gravel. These concentrations are approximately a factor of ten lower than those measured in samples of soil reported below. Although no measurements were made of airborne effluents from the concrete plants, it is believed that the plants did not cause the data from air sampling at station #6 to be significantly different from background.

Radionuclide concentrations in soil samples (Table 12) evinced no pattern of distribution relative to the power plant and were not significantly above background levels reported by NCRP Report No. 45, Natural Background Radiation in the U.S. [28]. Concentrations of uranium-234 and uranium-238 ranged from 0.50 pCi/g at monitoring site #4 to 1.05 pCi/g at a cornfield 96 km south of the power plant; polonium-210 ranged from 1.09 pCi/g for the lower strata of soil at monitoring site #2 to 2.93 pCi/g for the upper strata of soil at the same site. Concentrations of lead-210 ranged from 0.70 pCi/g at monitoring site #3 to 3.17 pCi/g in the upper strata of soil at monitoring site #2. Concentrations of thorium-230 ranged from 0.44 pCi/g at site #2 to 1.94 pCi/g in the lower strata of soil at monitoring site #4.

Evidence of possible increased concentrations of radionuclides in soil due to deposition of airborne effluents from

Table 12 - RADIONUCLIDE CONCENTRATION IN SOIL AROUND THE NEAL STATION

Sample Location and Description	Mound Sample #	U-234 (pCi/g)	U-238 (pCi/g)	Po-210 (pCi/g)	Pb-210 (pCi/g)	Th-230 (pCi/g)
Monitoring Site #1 tilled soil, 0-30 cm July 1977	8029	0.82 + 0.03 0.85 ± 0.02	0.91 + 0.03 0.99 ± 0.01	1.33 + 0.14 1.63 ± 0.17	1.29 + 0.27 1.33 ± 0.08	1.36 + 0.08 1.28 ± 0.07
Monitoring Site #2 soil 0-5 cm July 1977	8044	0.82 + 0.03 0.83 ± 0.04	0.76 + 0.03 0.77 ± 0.03	2.93 + 0.09 2.82 ± 0.10	3.17 + 0.10 3.06 ± 0.10	0.89 + 0.07 0.44 ± 0.08
Monitoring Site #2 soil 5-30 cm July 1977	8034	0.74 + 0.03 0.75 ± 0.03	0.80 + 0.03 0.82 ± 0.03	1.09 + 0.12 1.10 ± 0.09	1.45 + 0.12 1.20 ± 0.12	0.91 + 0.07 0.99 ± 0.08
Monitoring Site #3 tilled soil, 0-30 cm October 1976	WSU-2 WSPO-2	0.67 + 0.03	0.86 + 0.04	1.81 + 0.17 1.88 ± 0.28	0.70 + 0.10	
Monitoring Site #3 tilled soil, 0-30 cm July 1977	8035	0.84 + 0.03 0.84 ± 0.03	0.94 + 0.03 0.94 ± 0.03	1.69 + 0.07 1.51 ± 0.06		1.14 + 0.06 1.05 ± 0.09
Monitoring Site #4 tilled soil, 0-30 cm October 1976	WSU-1 WSPO-1	0.50 + 0.03 0.50 ± 0.03	0.53 + 0.03 0.50 ± 0.03	2.73 + 0.24 2.52 ± 0.27		
Monitoring Site #4 soil 0-5 cm July 1977	8037	0.69 + 0.02 0.69 ± 0.01	0.75 + 0.02 0.78 ± 0.01	2.32 + 0.15 2.93 ± 0.16		0.95 + 0.03 0.95 ± 0.02
Monitoring Site #4 soil 5-30 cm July 1977	8031	0.76 + 0.01 0.73 ± 0.01	0.67 + 0.01 0.65 ± 0.01	1.06 + 0.06 1.14 ± 0.06		1.89 + 0.12 1.94 ± 0.10
Monitoring Site #5 tilled soil, 0-30 cm October 1976	WSU-3 WSPO-3	0.71 + 0.05 0.68 ± 0.03	0.73 + 0.05 0.76 ± 0.03	1.82 + 0.13 1.63 ± 0.12		
Monitoring Site #5 tilled soil, 0-30 cm July 1977	8054	0.78 + 0.03 0.79 ± 0.03	0.75 + 0.03 0.72 ± 0.03	1.21 + 0.09 1.33 ± 0.10		0.93 + 0.08 0.97 ± 0.09
Cornfield and Park 40 km south of Neal Plant, soil 0-5 cm July 1977	8106	0.83 + 0.03 0.94 ± 0.03	0.80 + 0.03 0.87 ± 0.03	2.49 + 0.15 2.59 ± 0.16	2.73 + 0.12 2.34 ± 0.10	1.12 + 0.05 1.10 ± 0.03
Cornfield and Park 40 km south of Neal Plant, soil 5-30 cm July 1977	8105	0.87 + 0.03 0.88 ± 0.03	0.93 + 0.03 0.89 ± 0.03	1.41 + 0.11 1.54 ± 0.12	1.40 + 0.08 2.03 ± 0.07	1.09 + 0.08 1.14 ± 0.08
Cornfield and Park 96 km south of Neal Plant, soil 0-30 cm October 1976	WSU-4 WSPO-4	0.80 + 0.06 0.91 ± 0.08	0.77 + 0.06 0.85 ± 0.08	2.01 + 0.16 1.88 ± 0.14	2.04 + 0.19	
Cornfield and Park 96 km south of Neal Plant, soil 0-5 cm July 1977	8101	0.92 + 0.03 1.04 ± 0.03	0.91 + 0.03 1.05 ± 0.03	2.06 + 0.30 2.15 ± 0.30		1.00 + 0.04 0.95 ± 0.04
Cornfield and Park 96 km south of Neal Plant, soil 5-30 cm July 1977	8100	0.91 + 0.03 0.91 ± 0.03	0.93 + 0.03 0.88 ± 0.03	1.39 + 0.13 1.44 ± 0.12	1.34 + 0.28	1.21 + 0.08 1.28 ± 0.08

the power plant may be derived by comparing concentrations of radionuclides in upper (0 to 5 cm) vs lower (5 to 30 cm) soil strata. Presumably, the upper stratum of undisturbed soil would have a higher concentration of radionuclides than the lower stratum if deposition were the predominating mechanism. Tilled soils would not show a significant difference in radionuclide concentrations of radionuclides in upper vs lower soil strata. Ratios of measured concentrations of radionuclides in upper vs lower soil strata (Table 13) indicate no significant difference (ratio ≈ 1) for uranium-234, uranium-238, and thorium-230. Ratios for lead-210 and polonium-210 are significantly different ($P \leq 0.05$) from unity, as would be expected from characteristics of the radon-222 decay scheme [29]. The radon-222 diffuses upward through soil to the atmosphere and decays to lead-210 which deposits on soil. Subsequently, lead-210 decays to polonium-210 (via bismuth-210), and the lead-210:polonium-210 ratio depends on the length of time lead-210 and its matrix coexist and whether the polonium-210 is selectively removed by geochemical mechanisms. Ratios of measured concentrations of lead-210 and polonium-210 in soil are not significantly different from unity except at site #3. It is suggested that agricultural activities at this site could have sufficiently modified the natural state of this site to account for the radionuclide imbalance. Phosphate fertilizers are being investigated as possible, low-level sources of radionuclides [21-22], and application of these fertilizers to the extensively farmed areas around the power plant may have obscured patterns of natural background radioactivity. The remaining sampling sites have apparently remained undisturbed long enough for establishment of a lead-210:polonium-210 equilibrium in soil.

Difficulties in defining "background" for this area dictate use of an analytical technique that is not dependent upon the parameter. One such approach involves the use of ratios of radionuclide concentrations in upper vs lower soil strata. Presumably, if the power plant were a source of radionuclides, the ratio of specific radionuclides in upper vs lower soil strata would decline with distance from the power plant. Ratios for specific radionuclide concentrations in upper vs lower soil strata are given in Table 13 for the various sampling stations. There is no discernable trend in distribution of the radionuclides.

Measurements of radionuclide concentrations in samples of vegetation (Table 14) ranged from <0.001 to 0.022 pCi/g for uranium-234, from <0.001 to 0.021 pCi/g for uranium-238, from 0.025 to 0.64 pCi/g for polonium-210, and from 0.023 to 5.70 pCi/g for lead-210. Concentrations of uranium-234, uranium-238, and polonium-210 in vegetation are considerably lower than in the soil, suggesting that these isotopes are either geochemically unavailable to the vegetation or that the plants discriminate against them. On the other hand, lead-210 was present in or on vegetation at concentrations frequently exceeding concentrations in soil. The elevated concentrations of lead-210 on vegetation is most likely to have occurred as a result of the characteristics of radon-222 and its decay products previously described for radionuclides in soil. Upon the decay of atmospheric radon-222 to lead-210, the lead-210 tends to deposit on the earth's surface where broadleafed plants which present convenient surfaces for deposition are enriched in lead-210 [29].

Table 13 - RATIOS OF RADIONUCLIDE CONCENTRATIONS
IN 0 to 5-cm AND 5 to 30-cm SOIL STRATA

Sample Location	Radionuclides				
	U-234	U-238	Po-210	Pb-210	Th-230
Site #1 ^a , 3.1 km NNE					
Site #2, 1.4 km N	1.11	0.94	2.63	2.41	b
Site #3 ^a , 2.3 km E					
Site #4, 5.3 km SW	0.92	1.15	1.88	b	0.49
Site #5 ^a , 3.7 km SE					
Park, 40 km S of Neal Station	1.02	0.92	1.72	1.44	1.09
Park, 96 km S of Neal Station	1.08	1.08	1.49	b	0.87

^aRatio not appropriate, since site is a tilled field.

^bNo data.

Furthermore, the lead-210:polonium-210 ratio will vary with the length of time lead-210 has been deposited. The ratios of concentrations of lead-210 and polonium-210 measured in grass are significantly greater ($P \leq 0.05$) than unity. Measurements of concentrations of lead-210 and polonium-210 in corn kernels and cobs, although limited, indicate that the concentration of these nuclides in kernels and cobs were approximately an order of magnitude lower than in grass and that the nuclides in kernels and cobs were more nearly in secular equilibrium than in grass. These data indicate, therefore, that the concentrations of lead-210 and polonium-210 observed in broadleafed grass (*Bromus* sp.) were due more to deposition rather than to uptake from soil.

A central, or point, source for the lead-210 or its parent radionuclides is not suggested by the distribution of elevated concentrations in vegetation. The highest concentrations of lead-210 and its daughter polonium-210 were found at the park 96 km from the power plant. The second highest concentration of lead-210 occurred 3.6 km from the plant at site #5; the second highest concentration of polonium-210 occurred at site #2, closest to the power plant. The absence of a clear trend of declining concentrations of lead-210 and polonium-210 in vegetation with increasing distance from the power plant indicates that the Neal Station is not a discernable source of these radionuclides.

Table 14 - RADIONUCLIDE CONCENTRATIONS IN VEGETATION
AROUND THE NEAL STATION

Sample Location and Description	Mound Sample #	U-234 (pCi/g)	U-238 (pCi/g)	Po-210 (pCi/g)	Pb-210 (pCi/g)
Monitoring Site #1 <u>Bromus sp. grass</u> July 1977	9787	0.009 + 0.001 0.012 + 0.001	0.009 + 0.001 0.012 + 0.001	0.32 + 0.01 0.31 + 0.02	1.03 + 0.04 1.04 + 0.04
Monitoring Site #2 <u>Bromus sp. grass</u> July 1977	9786	0.016 + 0.001 0.022 + 0.002	0.016 + 0.001 0.021 + 0.002	0.49 + 0.03 0.48 + 0.03	1.14 + 0.03 1.12 + 0.03
Monitoring Site #3 <u>Bromus sp. grass</u> October 1976	WGU-2 WGPO-2	0.02 + 0.005 0.02 + 0.007	0.02 + 0.005 0.02 + 0.006	0.11 + 0.04 0.13 + 0.05	
Monitoring Site #3 Corn Kernels & Cob July 1977	9782	0.002 + 0.001 0.001 + 0.001	<0.001 <0.001	<0.01 <0.01	
Monitoring Site #3 Corn Stalks July 1977	9776	0.009 + 0.001 0.014 + 0.001	0.008 + 0.001 0.009 + 0.001	0.39 + 0.03 0.37 + 0.02	
Monitoring Site #3 Alfalfa July 1977	9771			0.27 + 0.02 0.28 + 0.02	
Monitoring Site #4 <u>Bromus sp. grass</u> October 1976	WGU-1 WGPO-1	0.007 + 0.003 0.009 + 0.003	0.012 + 0.004 0.012 + 0.004	0.13 + 0.06 0.20 + 0.07	
Monitoring Site #5 <u>Bromus sp. grass</u> October 1976	WGU-3 WGPO-3	0.009 + 0.003 0.008 + 0.003	0.010 + 0.003 0.009 + 0.003	0.13 + 0.05 0.03 + 0.04	2.23 + 0.19
Cornfield and Park 40 km south of Neal Plant, <u>Bromus sp.</u> July 1977	9770	0.004 + 0.001 0.005 + 0.001	0.005 + 0.001 0.005 + 0.001	0.36 + 0.03 0.40 + 0.03	0.73 + 0.10 0.40 + 0.03
Cornfield and Park 40 km south of Neal Plant, Corn Kernels and Cob, July 1977	9785	0.005 + 0.001 0.005 + 0.001	0.005 + 0.001 0.005 + 0.001	0.025 + 0.003 0.026 + 0.003	0.035 + 0.006 0.032 + 0.005
Cornfield and Park 96 km south of Neal Plant, <u>Bromus sp.</u> October 1976	WGU-4 WGPO-4	0.020 + 0.005 0.004 + 0.002	0.010 + 0.005 0.007 + 0.003	0.27 + 0.06 0.21 + 0.06	5.70 + 0.32
Cornfield and Park 96 km south of Neal Plant, <u>Bromus sp.</u> July 1977	9777	0.012 + 0.002 0.014 + 0.002	0.014 + 0.002 0.012 + 0.002	0.54 + 0.03 0.64 + 0.03	1.12 + 0.04 1.19 + 0.04
Cornfield and Park 96 km south of Neal Plant, Corn Kernels and Cob, July 1977	9781	<0.001 <0.001	<0.001 <0.001		0.028 + 0.007 0.023 + 0.005

Dose evaluations

Calculation of doses and concentrations by dispersion modeling

Atmospheric dispersion calculations were performed to estimate concentrations of radionuclides in air and soil, as well as doses from inhalation and ingestion pathways, resulting from radioactive materials in the airborne effluents from the Neal Station. Although inaccuracies are suspected in the measurement of radionuclide concentration of stack effluents (discussed elsewhere in this report) these data are judged to represent a reasonable approximation of emissions from the plant for this preliminary study.

The computer code AIREM [30] was used to calculate ground-level air concentrations of radionuclides. This computer code uses a Gaussian dispersion plume model. It divides the area around the source into 16 sectors and allows up to 12 radial distances. The relative ground-level air concentration, χ/Q (sec/m^3), is calculated for each sector element by summing the contributions to that sector for six stability classes. The air concentration, χ (Ci/m^3), for each nuclide is calculated by multiplying the χ/Q by the source term, Q (Ci/scc).

The AIREM code allows the calculation of the ingrowth of one radioactive decay product per parent nuclide during plume transit. The ground-level air concentration of polonium-218 due to the emission of radon-222 was calculated using this option. Subsequently, the ratio of the

concentrations of radon-222 and polonium-218 was used to calculate an effective transit time. This effective transit time was then used to calculate the ground-level air concentrations of the remaining short-lived decay products of radon-222; specifically, lead-214, bismuth-214, and polonium-214.

The meteorological data used in the dispersion calculations were obtained from the National Climatic Center in Asheville, North Carolina. These data were based on observations covering the 5-year period, January, 1970, through December, 1974, at the Sioux City, Iowa, weather station. The meteorological data are presented in Appendix 6.

The three operating units at the Neal Station were considered individually because of the differences in the heights and operating characteristics of the three stacks. The effective stack height was calculated for each stack. Plume rise was calculated using the Holland [31] equation:

$$\Delta H = \frac{v d}{u} \left(1.5 + 2.60 \times 10^{-3} p \frac{T_s - T_a}{T_s} d \right)$$

where ΔH = plume rise (m)
 v = efflux velocity (m/sec)
 d = inside stack diameter (m)
 u = wind speed (m/sec)
 p = atmospheric pressure (mb)
 T_s = stack gas temperature ($^{\circ}\text{K}$)
 T_a = ambient air temperature ($^{\circ}\text{K}$)

The following parameter values were used:

$u = 4.92$ m/sec
 $p = 920$ mb
 $T_a = 293$ $^{\circ}\text{K}$

Unit 1	Unit 2	Unit 3
$v = 32.6$ m/sec	$v = 27.4$ m/sec	$v = 22.0$ m/sec
$d = 2.87$ m	$d = 4.65$ m	$d = 6.09$ m
$T_s = 421$ $^{\circ}\text{K}$	$T_s = 406$ $^{\circ}\text{K}$	$T_s = 397$ $^{\circ}\text{K}$

Values of plume rise were calculated to be 69.4 m, 121.5 m, and 148.0 m for Units 1, 2, and 3, respectively. The physical heights of the stacks are 76.2 m (250 ft), 91.4 m (300 ft), and 121.9 m (400 ft) [20]; therefore, the calculated values of effective height are 146 m, 213 m, and 270 m.

The maximum dispersion coefficient was based on an estimate of the annual average height of the mixing layer for the specific location of the Neal Station. This information was extracted from Martin, et al. [30], yielding a maximum dispersion coefficient of 490 m.

The source terms for uranium-234, uranium-238, polonium-210, and lead-210 were based on stack measurements of Unit 2 (Table 6). The measurements of concentration at the precipitator outlet were averaged and multiplied by the nominal gas flow rate to obtain the source terms for Unit 2. The source terms for the other two units were estimated by multiplying those for Unit 2 by the ratios of the power ratings of the other units to that of Unit 2, i.e., multiplying by 150/330 for Unit 1 and by 540/330 for Unit 3. It is realized that the source term is dependent upon other factors besides power level; however, in light of the uncertainties in the stack measurements, this simple approximation should be adequate for the purposes of these calculations.

A different approach was used for estimating the radon-222 source terms. The radon-222 source term was based on two assumptions: (1) radon-222 is in secular equilibrium with uranium-234 in coal, and (2) all the radon-222 in the coal is sent up the stack as the coal is crushed and burned. Therefore, the radon-222 source term value used for Unit 2 is the same

as the uranium-234 input rate value from the radionuclide balance for Unit 2 (Table 10). This approach is believed to be superior to using the stack measurement values, because an unknown, but probably significant, fraction of the measured values is from background radon-222. The radon-222 source terms for the other two units were estimated by applying the power level ratios as described above. The source terms for the short-lived decay products of radon-222 were assumed to be zero. The source terms used in the dispersion calculations are presented in Table 15.

Summaries of the calculated ground-level air concentrations are presented in Appendix 6 for each of the three units and for the total of the three units. In Table 16, calculated and measured air concentration values are presented for a few locations. It should be pointed out that the measured values are based on a short sampling duration, whereas the calculated values are estimates of annual averages; therefore, comparisons between the two may not be very meaningful.

Background concentrations of uranium in air have been reported [28] ranging from 120 aCi/m³ at Argonne, Illinois, to 400 aCi/m³ in New York state. Both the calculated and measured uranium concentrations in the vicinity of the Neal Station are on the order of background. The calculated concentrations of polonium-210 and lead-210 in air are significantly lower than the measured values. Reported [28] background concentrations for polonium-210 are on the order of 1000 aCi/m³, and those for lead-210 vary between 8000 and 26000 aCi/m³. The measured values for both polonium-210 and lead-210 are on the order of the reported background values. The calculated values are approximately 5% of background for polonium-210 and approximately

Table 15 - SOURCE TERMS USED IN THE DISPERSION CALCULATIONS

Nuclide	Source Term (pCi/sec)		
	Unit 1	Unit 2	Unit 3
U-234	1202	2644	4327
U-238	1211	2665	4361
Po-210	1473	3241	5303
Pb-210	2345	5160	8444
Rn-222	8110	17843	29198

0.1 to 1.0% of background for lead-210 in air. Reported [28] background concentrations of radon-222 vary between 50 and 1040 pCi/m³, with an average of about 150 pCi/m³ (1.5×10^8 aCi/m³). The calculated radon-222 concentrations are small in comparison to typical background levels (approximately 0.0002% of background).

Calculated and measured concentrations of radionuclides in soil for several locations are presented in Table 17. The deposition rate of each radionuclide was calculated by multiplying the calculated ground-level air concentration by a deposition velocity, which was assumed to be 0.01 m/sec [32]. Ground concentrations were calculated assuming deposition of the radionuclides at the given deposition rates over a period of 20 yr including the ingrowth of decay products after deposition of the parent nuclides. The only mechanism assumed for removal of the radionuclides from the soil was radioactive decay. The ground concentrations were divided by the "effective surface density" of a 15-cm layer of soil, 240 kg/m² [33], to obtain the calculated soil concentrations. The calculated soil concentrations are smaller than the measured soil concentrations by a factor of approximately 500 for uranium-234 and uranium-238 and approximately 1000

for polonium-210 and lead-210.

Inhalation doses were calculated using the maximum calculated ground-level air concentration values presented in Table 16. In this report the term "dose" is used for convenience to mean a 50-year dose commitment equivalent to an adult individual. Dose conversion factors (DCF's), which are normalized to a unit air concentration, were calculated and are presented in Table 18. The DCF's for bone, liver, total body, kidney, G. I. tract, and lung were calculated by multiplying dose commitment factors derived by Hoenes and Soldat [34] by an assumed breathing rate of 8000 m³/yr [33] and converting to the desired units. For example, the DCF for dose to bone from the inhalation of uranium-234 was calculated as follows:

$$\begin{aligned}
 & 1.04 \times 10^{-2} \text{ mrem/pCi} \\
 & \times 8000 \text{ m}^3/\text{yr} \\
 & \times 10^{-6} \text{ pCi/aCi} \\
 & = 8.32 \times 10^{-5} \frac{\text{mrem/yr}}{\text{aCi/m}^3}
 \end{aligned}$$

Also, DCF's for the dose from the short-lived decay products of radon-222 to the bronchial epithelium are presented in

Table 16 - CALCULATED AND MEASURED GROUND-LEVEL AIR CONCENTRATIONS (aCi/m³)

Sampling Station	Location from Power Plant	U-234		U-238		Po-210		Pb-210		Rn-222	Po-218	Pb-214	Bi-214
		Calc	Meas	Calc	Meas	Calc	Meas	Calc	Meas	Calc	Calc	Calc	Calc
1	3.1 km, NNW	45	41	46	39	56	983	89	5410	307	287	56	9
2	1.4 km, N	59	48	59	54	72	1207	114	24220	395	315	34	3
3	2.3 km, E	32	29	33	37	40	1298	63	-	219	202	37	5
4	5.3 km, SW	18	38	18	43	22	1270	35	12964	122	121	39	10
5	3.7 km, SE	45	47	45	48	55	1299	88	-	306	278	49	7
Park	96 km, S	-	54	-	62	-	1572	-	22274	-	-	-	-
Max. Calc.	2.5 km, N	65	-	65	-	79	-	127	-	438	387	58	7

Table 17 - CALCULATED AND MEASURED SOIL CONCENTRATIONS

A. Calculated deposition rate ($\mu\text{Ci}/\text{m}^2 \cdot \text{sec}$)

Site	Location	U-234	U-238	Po-210	Pb-210	Po-218	Pb-214	Bi-214
1	3.1 km, NNW	4.54(-1) ^a	4.57(-1)	5.56(-1)	8.86(-1)	2.87	5.64(-1)	8.9(-2)
2	1.4 km, N	5.85(-1)	5.90(-1)	7.17(-1)	1.14	3.15	3.45(-1)	3.1(-2)
3	2.3 km, E	3.23(-1)	3.26(-1)	3.96(-1)	6.31(-1)	2.02	3.69(-1)	5.4(-2)
4	5.3 km, SW	1.80(-1)	1.81(-1)	2.20(-1)	3.50(-1)	1.21	3.93(-1)	1.00(-1)
5	3.7 km, SE	4.51(-1)	4.55(-1)	5.53(-1)	8.81(-1)	2.78	4.93(-1)	7.2(-2)
Max. Calc.	2.5 km, N	6.48(-1)	6.53(-1)	7.95(-1)	1.27	3.87	5.82(-1)	7.2(-2)

B. Calculated soil concentration after 20 yr of deposition ($\mu\text{Ci}/\text{g}$)

Site	Location	U-234	U-238	Po-210	Pb-210	Po-218	Pb-214	Bi-214
1	3.1 km, NNW	1.20(-3)	1.20(-3)	1.74(-3)	1.74(-3)	3.47(-9)	8.92(-9)	9.56(-9)
2	1.4 km, N	1.54(-3)	1.55(-3)	2.24(-3)	2.23(-3)	3.87(-9)	7.21(-9)	7.43(-9)
3	2.3 km, E	8.49(-4)	8.57(-4)	1.24(-3)	1.24(-3)	2.44(-9)	6.01(-9)	6.40(-9)
4	5.3 km, SW	4.73(-4)	4.76(-4)	6.88(-4)	6.86(-4)	1.45(-9)	5.25(-9)	5.97(-9)
5	3.7 km, SE	1.19(-3)	1.20(-3)	1.73(-3)	1.73(-3)	3.37(-9)	8.14(-9)	8.65(-9)
Max. Calc.	2.5 km, N	1.70(-3)	1.72(-3)	2.46(-3)	2.49(-3)	4.70(-9)	1.03(-8)	1.08(-8)

C. Measured soil concentrations ($\mu\text{Ci}/\text{g}$)

Site	Location	U-234	U-238	Po-210	Pb-210
1	3.1 km, NNW	8.4(-1)	9.5(-1)	1.48	1.31
2	1.4 km, N	8.3(-1)	7.7(-1)	2.88	3.12
3	2.3 km, E	7.6(-1)	9.0(-1)	1.72	7.0(-1)
4	5.3 km, SW	5.0(-1)	5.2(-1)	2.63	-
5	3.7 km, SE	7.4(-1)	7.4(-1)	1.50	-
Park	96 km, S	8.6(-1)	8.1(-1)	1.95	2.04

$$^a 4.54(-1) = 4.54 \times 10^{-1}$$

Table 18 - INHALATION DOSE CONVERSION FACTORS (mrem/yr per aCi/m³)

Nuclide	Organ						Bronchial Epithelium
	Bone	Liver	Total Body	Kidney	G.I.	Lung	
U-234	8.32(-5) ^a	-	5.17(-6)	1.99(-5)	3.05(-7)	4.18(-4)	-
U-238	7.66(-5)	-	4.54(-6)	1.74(-5)	2.73(-7)	3.66(-4)	-
Po-210	3.18(-6)	6.88(-6)	7.66(-7)	2.36(-5)	3.35(-7)	2.51(-4)	-
Pb-210	2.11(-4)	5.38(-5)	6.70(-6)	1.70(-4)	2.92(-7)	2.10(-4)	-
Rn-222	-	-	-	-	-	1.64(-8)	-
Po-218	-	-	-	-	-	-	1.53(-7)
Pb-214	-	-	-	-	-	-	1.64(-7)
Bi-214	-	-	-	-	-	-	7.5(-8)

^a8.32(-5) = 8.32 x 10⁻⁵

Table 18 as an alternative method of calculating the dose from radon-222 and its decay products. The DCF's were derived by Nicoll et al. [35] in units of rem/yr per pCi/liter and were converted for use here to the units shown in Table 18.

The maximum calculated annual inhalation doses are presented in Table 19. These doses were calculated by multiplying the maximum calculated ground-level air concentration for each radionuclide by the DCF's for that radionuclide. The total dose for each organ from all the nuclides considered is also presented in Table 19. The organs receiving the largest annual doses are lung, bone, and kidney; however, these doses are relatively small, 0.098, 0.037, and 0.026 mrem respectively.

McBride et al. [36] have suggested that,

for the radionuclides in the uranium decay series, the ingestion pathway may be more important for population doses than the inhalation pathway. Ingestion doses were calculated using the maximum calculated ground deposition rates presented in Table 17. Jenkins et al. [37] derived a set of dose conversion factors (DCF's) for several ingestion pathways for the radionuclides in the uranium decay series, which are normalized to a unit deposition rate. In the derivation of these DCF's, methods were used which are consistent with those recommended in U.S. Nuclear Regulatory Commission Regulatory Guide 1.109 [33]. Included in the derivation was the consideration of 1) deposition directly onto crops during the growing season, 2) deposition onto soil for various lengths of plant operation, 3) uptake of radionuclides from the soil, 4) decay and ingrowth of radionuclides

Table 19 - MAXIMUM CALCULATED ANNUAL INHALATION DOSE COMMITMENTS (mrem)

<u>Nuclide</u>	<u>Organ</u>						<u>Bronchial Epithelium</u>
	<u>Bone</u>	<u>Liver</u>	<u>Total Body</u>	<u>Kidney</u>	<u>G.I.</u>	<u>Lung</u>	
U-234	5.41(-3) ^a	-	3.36(-4)	1.29(-3)	1.98(-5)	2.72(-2)	-
U-238	4.98(-3)	-	2.95(-4)	1.13(-3)	1.77(-5)	2.38(-2)	-
Po-210	2.51(-4)	5.44(-4)	6.05(-5)	1.86(-3)	2.65(-5)	1.98(-2)	-
Pb-210	2.68(-2)	6.83(-3)	8.51(-4)	2.16(-2)	3.71(-5)	2.67(-2)	-
Pn-222	-	-	-	-	-	7.18(-6)	-
Po-218	-	-	-	-	-	-	5.92(-5)
Pb-214	-	-	-	-	-	-	9.51(-6)
Bi-214	-	-	-	-	-	-	5.3(-7)
Total	3.7(-2)	7.4(-3)	1.5(-3)	2.6(-2)	1.0(-4)	9.8(-2)	6.9(-5)

^a5.41(-3) = 5.41×10^{-3}

during periods of deposition and of storage of food, 5) usage factors recommended in Regulation Guide 1.109 [33] for the maximum individual in lieu of site-specific data, and 6) ingestion dose commitment factors for the adult derived by Hoenes and Soldat [34]. The largest DCF's were calculated for the consumption of fresh and stored vegetables. The DCF's presented in Table 20 were calculated by adding the DCF's for the fresh- and stored-vegetable pathways derived by Jenkins, et al. [37] assuming a 20-yr period of deposition onto soil and converting from the given units (mrem/yr per $\mu\text{Ci}/\text{m}^2 \cdot \text{sec}$) to the units in Table 20. Use of these DCF's implies that the individual consumes annually 520 kg of stored vegetables (including fruits and grains) and 64 kg of fresh vegetables that were grown at the site of radionuclide deposition.

The maximum calculated annual doses from the ingestion of vegetables are presented in Table 21. These doses were calculated by multiplying the maximum calculated ground deposition rates for each radionuclide by the DCF's for that nuclide. The total dose for each organ from all the radionuclides considered is also presented in Table 21. The largest annual doses calculated are 3.7 mrem to bone, 3.6 mrem to kidney, and 1.2 mrem to liver, most of which were due to the deposition of lead-210. These doses are small compared to background doses and are below regulatory guidelines.

A rigorous discussion of dose pathway analyses is beyond the scope of this report; however, it is felt that a few comments are appropriate. The calculations discussed above indicate that an individual may receive higher doses from ingestion than from inhalation. However, it is believed that, because of the numerous assumptions

Table 20 - INGESTION DOSE CONVERSION FACTORS (mrem/y per aCi/m²·sec)
(Vegetable Pathway)

<u>Nuclide</u>	<u>Organ</u>				
	<u>Bone</u>	<u>Liver</u>	<u>Total Body</u>	<u>Kidney</u>	<u>G.I.</u>
U-234	8.74(-2) ^a	2.02(-7)	5.40(-3)	2.08(-2)	6.42(-3)
U-238	8.02(-2)	4.32(-7)	4.75(-3)	1.83(-2)	1.61(-2)
Po-210	2.07(-2)	4.39(-2)	4.99(-3)	1.46(-1)	3.69(-3)
Pb-210	2.78	9.27(-2)	1.14(-1)	2.69	2.43(-2)
Po-218	7.36(-7)	2.45(-7)	3.01(-8)	7.13(-7)	6.41(-9)
Pb-214	6.41(-6)	2.14(-6)	2.62(-7)	6.23(-6)	5.60(-8)
Bi-214	4.75(-6)	1.59(-6)	1.95(-7)	4.61(-6)	4.15(-8)

$$^a 8.74(-2) = 8.74 \times 10^{-2}$$

Table 21 - MAXIMUM CALCULATED ANNUAL INGESTION DOSE COMMITMENTS (mrem)
(Vegetable Pathway)

<u>Nuclide</u>	<u>Bone</u>	<u>Liver</u>	<u>Total Body</u>	<u>Kidney</u>	<u>G.I.</u>
U-234	5.66(-2) ^a	1.31(-7)	3.50(-3)	1.35(-2)	4.16(-3)
U-238	5.24(-2)	2.82(-7)	3.10(-3)	1.19(-2)	1.05(-2)
Po-210	1.65(-2)	3.49(-2)	3.97(-3)	1.16(-1)	2.93(-3)
Pb-210	3.53	1.18	1.45(-1)	3.42	3.09(-2)
Po-218	2.85(-6)	9.48(-7)	1.16(-7)	2.76(-6)	2.48(-8)
Pb-214	3.73(-6)	1.25(-6)	1.52(-7)	3.63(-6)	3.26(-8)
Bi-214	3.42(-7)	1.14(-7)	1.40(-8)	3.32(-7)	2.99(-9)
Total	3.7	1.2	1.6(-1)	3.6	4.8(-2)

$$^a 5.66(-2) = 5.66 \times 10^{-2}$$

that are required for the ingestion pathway analysis, there may be more conservatism inherent in the analysis of the ingestion pathway than of the inhalation pathway. Therefore, direct comparisons of doses from the two pathways may be misleading. For the purposes of this study, what is important is the fact that no significant environmental impact is indicated from either pathway.

Evaluation of occupational doses to power plant workers

Potential inhalation doses to power plant workers were evaluated by collecting samples of airborne particulates inside the Neal Station and estimating doses from quantities of airborne particulates. In 30.5 hr a total of 1.220 g of fly ash was deposited on a Microsorban filter from 4974 m³ of air, indicating a particulate concentration in air of 2.45×10^{-4} g/m³. Previously reported values for radionuclide concentrations in fly ash were used to estimate concentrations of radionuclides in air as indicated in Table 22. A breathing rate of 10⁷ cm³ per 8-hr workday [38] was assumed; therefore, the breathing rate expressed on an annual basis is assumed to be 10⁷ cm³/day X 5 days/week X 50 weeks/yr = 2.5×10^9 cm³/yr or 2500 m³/yr. The DCF's in Table 18 are based on a breathing rate of 8000 m³/yr; therefore, multiplying those values by 2500/8000 or 0.3125 would produce DCF's appropriate for occupational dose calculations. The occupational doses in Table 22 were calculated by multiplying the radionuclide concentrations by 0.3125 times the DCF's from Table 18. The total annual dose to each organ from the radionuclides considered is presented in Table 22. The largest of these are 0.45 mrem to lung and 0.15 mrem to bone. These doses are not

considered significant in relation to natural background levels and in relation to current standards of radiation dose for the general public.

Dose estimates assuming conditions of reduced emission controls

The release, fate, and accumulation of radionuclides from burning Western coal has thus far been evaluated for a modern power plant using effective emission control equipment. It is anticipated, however, that numerous small manufacturers will be turning to Western coal, since its low sulfur concentration may eliminate the need for expensive emission control equipment to control SO_x emissions. An evaluation of the release of radionuclides from Western coal is facilitated by characteristics of the foregoing radionuclide balance exercise and atmospheric dispersion modeling. A linear relationship exists for the input (source term) and output (predicted deposition, etc.). That is, a doubling of radionuclide concentration of feed coal or a doubling of the amount of coal burned will double the output of radionuclides. Problems will arise, however, extrapolating beyond Unit #2 of the Neal Station. The stack is taller than that of most small manufacturers, and shorter stacks may lead to greater concentrations of radionuclides close in to the plant. The unit is a pulverized coal furnace, and there is no assurance that the radionuclide balance can be extrapolated to other types of furnace, e.g., fluidized bed. Radically different furnace designs will require individual evaluation of radionuclide balance. Furthermore, Unit #2 uses an electrostatic precipitator for emission control. The efficiency of bag houses, scrubbers, etc. in removing radionuclides from stack effluents has not been evaluated

Table 22 - ANNUAL OCCUPATIONAL INHALATION DOSES (mrem)

Nuclide	Conc. in Air (aCi/m ³)	Organ					
		Bone	Liver	Tot. Body	Kidney	G.I.	Lung
U-234	1070	2.78(-2) ^a	-	1.73(-3)	6.65(-3)	1.02(-4)	1.40(-1)
U-238	1040	2.49(-2)	-	1.48(-3)	5.66(-3)	8.87(-5)	1.19(-1)
Po-210	1300	1.29(-3)	2.80(-3)	3.11(-4)	9.59(-3)	1.36(-4)	1.02(-1)
Pb-210	1410	9.30(-2)	2.37(-2)	2.95(-3)	7.49(-2)	1.29(-4)	9.25(-2)
Total		1.5(-1)	2.7(-2)	6.5(-3)	9.7(-2)	4.6(-4)	4.5(-1)

$$^a 2.78(-2) = 2.78 \times 10^{-2}$$

The stack source term is critical to estimates of dose and deposition with the dispersion model, but it was measured only once.

With these caveats established, the effect on the maximum calculated doses in the vicinity of the Neal Station from increased releases of radionuclides due to decreased emission controls and/or increased radionuclide input to the plant is estimated below.

The annual dose resulting from operation of the Neal Station with altered conditions may be estimated by the following equation:

$$D_a = IF \times [1 + (ECR \times FA)] \times D$$

where D_a = annual dose with altered conditions (mrem)

IF = Input Factor

ECR = Emission Control Reduction fraction

FA = Fly Ash throughput (pCi/sec) / stack throughput (pCi/sec)

D = annual dose under present Neal Station operating conditions (mrem)

$$IF (U-234) = \frac{U-234 (pCi/g)}{0.51 \text{ pCi/g}} \times \frac{\text{Coal usage (kg/sec)}}{108 \text{ kg/sec}}$$

$$IF (U-238) = \frac{U-238 (pCi/g)}{0.48 \text{ pCi/g}} \times \frac{\text{Coal usage (kg/sec)}}{108 \text{ kg/sec}}$$

$$IF (Po-210) = \frac{Po-210 (pCi/g)}{1.10 \text{ pCi/g}} \times \frac{\text{Coal usage (kg/sec)}}{108 \text{ kg/sec}}$$

$$IF (Pb-210) = \frac{Pb-210 (pCi/g)}{0.66 \text{ pCi/g}} \times \frac{\text{Coal usage (kg/sec)}}{108 \text{ kg/sec}}$$

$$FA (U-234) = 6.00$$

$$FA (U-238) = 5.77$$

$$FA (Po-210) = 5.96$$

$$FA (Pb-210) = 3.66$$

The FA factor above implies that under normal operating conditions at the Neal Station, for each radionuclide in the fly ash and stack gases, a fraction equal to $FA/1+FA$ is removed by the precipitator. For uranium-234, for example, 6/7 or 0.857 of the uranium-234 in the fly ash and stack gases is removed by the precipitator, and the remainder goes up the stack. A 10% reduction in emission controls ($ECR = 0.1$) means that 0.9×0.857 , or 0.771 of the uranium-1

234 would be removed by the precipitator. A 100% reduction in emission controls (ECR = 1) means that none of the uranium-234 would be removed by the precipitator.

Results of calculations of doses assuming 10% and 100% reductions in emission controls are presented in Table 23. Doses resulting from using coal with an increased radionuclide content can be calculated by multiplying the values in Table 23 by the factor by which the radionuclide concentration is increased. Assuming the worst credible case in which coal with 100 times [5,12,13] the radionuclide concentration of that presently used at the Neal Station is used with a 100% reduction in emission control, the largest annual inhalation doses predicted by the dispersion model are 61 mrem to lung, 22 mrem to bone, and 14 mrem to kidney. The doses are within current standards for the uranium fuel cycle (nuclear power), but the dose to lung exceeds proposed standards (25 mrem). The largest predicted annual doses due to ingestion (vegetable pathway) are about 1.6 rem to bone, 1.6 rem to kidney, and 0.5 rem to liver due to deposition of lead-210. These dose values are most likely unrealistically high, because they are based on conservative assumptions for a situation which does not reflect conditions at the Neal Station or any power plant except under the most extreme conditions. Nonetheless, the magnitude of these doses indicates that a realistic, site-specific assessment of the radiological environmental impact of burning coal with a very large radionuclide content should be performed when and if such coal is to be used in the future.

Accumulation of radionuclides in ash ponds

The accumulation of radionuclides in the ash pond is related to radionuclide concentration in feed coal; quantity of coal burned; partitioning of radionuclides to bottom ash, fly ash, and stack gases; and efficiency of emission controls. The radionuclide balance presented in Table 10 indicates that, in the pulverized coal/electrostatic precipitator system of the Neal Station, over 90% of the uranium-234, uranium-238, and lead-210 and approximately 50-75% of the polonium-210 remain with ash (bottom ash and fly ash). The rates at which these radionuclides accumulate in the ash pond under normal operating conditions at the Neal Station are shown in Table 24. The accumulation of radionuclides in the ash pond is directly proportional to the radionuclide concentration in the feed coal.

One potential problem associated with the accumulation of radionuclides in ash ponds is the emanation of radon-222 from the radium-226 accumulated in the ash. The emanation of radon-222 is related to several factors including the concentration of radium-226 in the ash, the "emanation power" or the fraction of the radon-222 which is free to diffuse out of the ash pond, quantity and configuration of ash in the pond, and several parameters such as moisture content and compaction of the ash which affect the ability of the radon-222 to diffuse out of the ash pond. If it is assumed that radium-226 is in secular equilibrium with uranium-238 in feed coal and that radium-226 follows uranium-238 during combustion, then the concentrations

Table 23 - ESTIMATION OF MAXIMUM ANNUAL DOSES IN VICINITY OF
THE NEAL STATION UNDER CONDITIONS OF REDUCED
EMISSION CONTROL

<u>Nuclide</u>	<u>Organ</u>	<u>Dose under normal operating conditions (mrem)</u>	<u>Dose with 10% emission control reduction (mrem)</u>	<u>Dose with no emission control (mrem)</u>
Inhalation				
U-234	Lung	0.0272	0.0435	0.190
	Bone	0.00541	0.00866	0.0379
	Kidney	0.00129	0.00206	0.00903
U-238	Lung	0.0238	0.0375	0.161
	Bone	0.00498	0.00785	0.0531
	Kidney	0.00113	0.00178	0.0121
Po-210	Lung	0.0198	0.0316	0.138
	Bone	0.000251	0.000401	0.00175
	Kidney	0.00186	0.00297	0.0129
Pb-210	Lung	0.0267	0.0365	0.124
	Bone	0.0268	0.0366	0.125
	Kidney	0.0216	0.0295	0.101
Total	Lung	0.098	0.15	0.61
	Bone	0.037	0.054	0.22
	Kidney	0.026	0.036	0.14
Ingestion				
Pb-210	Bone	3.53	4.82	16.4
	Kidney	3.42	4.67	15.9
	Liver	1.18	1.61	5.50

Table 24 - RATE OF ACCUMULATION OF RADIONUCLIDES IN ASH PONDS
AT THE NEAL STATION

<u>Nuclide</u>	<u>Rate of Accumulation</u>	
	<u>(pCi/sec)</u>	<u>(Ci/yr)</u>
U-234	17300	0.55
U-238	16700	0.53
Po-210	22000	0.69
Pb-210	20800	0.66

of radium-226 in fly ash and bottom ash at the Neal Station would be approximately 2.5 pCi/g and 4.2 pCi/g, respectively. These concentrations are above average "background" concentrations for soil in the United States. The concentration of radionuclides in bottom ash and fly ash is related to ash content of the feed coal. The coal burned at the Neal Station contained 11.9% ash, but some coals have ash contents on the order of 3%. Burning such coal at the Neal Station could result in an increase in the radium-226 concentration in the ash by a factor of approximately four.

Still assuming that radium-226 is in equilibrium with and follows uranium-238 during combustion, radium-226 could accumulate in the ash ponds at the Neal Station at a rate of 0.53 Ci/yr. At this rate, approximately 15.8 Ci of radium-226 would accumulate in the ash pond over a period of 30 yr. This quantity of radium-226 would result in the production of radon-222 at a rate of about 2.7 Ci/day. Only a fraction of the radon-222 produced would be released to the atmosphere. The literature contains several widely varying estimates of this fraction. At the present time, it is not clear what the magnitude of radon-222 release would be. The potential environmental impact of radon-222 emanation from ash ponds warrants further attention.

Conclusions

1. Western coal from 18 mines (19 coal seams) varied widely in concentration of radionuclides: 0.04 to 1.20 pCi/g for uranium-234, 0.04 to 1.21 pCi/g for uranium-238, and 0.03 to 0.58 for polonium-210.

2. The greatest fraction of uranium-234, uranium-238, polonium-210, and lead-210

in feed coal remained with bottom and fly ash after combustion. The distribution of radium-226 between coal, bottom ash, fly ash, and stack effluents could not be estimated from existing data, but may be an important parameter for future efforts.

3. Specific trends in distribution of radionuclides in the environment (airborne particulates, vegetation, and soil) relative to the power plant were not apparent.

4. Atmospheric dispersion modeling of stack effluents for uranium-234, uranium-238, lead-210, polonium-210, and radon-222 indicated there would be no significant impact from either the inhalation or ingestion pathways.

5. Environmental concentrations of radionuclides predicted by atmospheric dispersion modeling to accumulate in soil are two to three orders of magnitude lower than measured concentrations in soil. This difference in values predicted from data on stack effluents and values actually measured is evidence that the power plant stack is not a significant source of environmental radionuclides. Concentrations of radionuclides measured in the environment adjacent to the power plant are not significantly different from background concentrations measured 40 and 96 km away.

6. Occupational radiation doses to workers inside the Neal Station were not found to be significant (<0.5 mrem/yr).

7. Burning coal at the Neal Station with reduced emission controls could increase the release of radionuclides by a factor as high as five to seven.

8. Accumulation of radionuclides in ash

ponds may present an environmental problem, primarily due to the emanation of radon-222. Use of coal with high concentrations of radionuclides could increase the magnitude of this problem.

9. Use of Western coal being mined today in a modern power plant with effective emission controls (ESP) has led to no significant environmental impact due to radionuclides.

Recommendations

A complete assessment of the potential radiological impact of the fossil fuel cycle will involve analyses of coal sources and of mobilization of radionuclides from use of coal. Sources of Western coal are broadly viewed as long-term (coal mines to be used by the year 2000), short-term (operating mines), and immediate-term (coal at power plants and other industries). The scope of mobilization of radionuclides is both regional and local. Regional mobilization involves transportation and distribution of coal from the mines to sites of use. Local mobilization of the radionuclides occurs when coal is mined, cleaned, and burned (primary mechanism); when collected fly ash and bottom ash with their attendant complement of radionuclides are either released to the environment or used in fabrication of concrete and other products (secondary mechanism); and when effluents from primary and secondary mechanisms reach surrounding ecosystems and circulate within biogeochemical cycles (tertiary or environmental mechanisms).

Results of the Phase I study do not suggest that a major national effort is required at this time. However, several potentially problematic areas related to the radiological impact of expanded coal utiliza-

tion do warrant further attention. The following list contains a number of areas in which information is needed.

1. Evaluate pathways and partitioning coefficients for uranium-238 and radium-226 during coal cleaning, coal combustion, and coal conversion: Radionuclide balance for the processes, including waste products.
2. Evaluate potential population doses from radium-226 and radon-222 in coal refuse and flue gas desulfurization sludge disposal sites, as well as use of this waste material in manufacturing various products, e.g., concrete blocks and gypsum-based wallboard.
3. Conduct interlaboratory calibration for analysis of radionuclides in coal and coal refuse.
4. Determine whether uranium-238 and radium-226 are in secular equilibrium in coal.
5. Conduct extensive surveys of mines for uranium-238 and radium-226 in coal of all U.S. coal provinces.

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Appendix 1. Quality Control Data

Table 1.1 - COMPARISON OF NBS STANDARD AND MOUND
VALUES FOR RADIONUCLIDES IN COAL FLY ASH

<u>Sample No.</u>	<u>Radionuclide</u>	<u>NBS Standard^a (ppm)</u>	<u>Mound Result (ppm)</u>
SRM-1632	Uranium	1.4 ± 0.1	1.2 ± 0.1 1.4 ± 0.1
SRM-1632	Lead	30 ± 9	33.3^b 29.3
SRM-1633	Uranium	11.6 ± 0.2	10.6 ± 0.4 10.9 ± 0.4
SRM-1633	Lead	70 ± 4	70.4^b c

^aThese are values certified by NBS.

^bThere is no error given here due to the laboratory procedure.

^cSecond determination not made.

Table 1.2 - QUALITY CONTROL DATA COMPARISON:
 REPLICATE ANALYSES OF PREPARED COAL SAMPLES

<u>Sample</u>	Uranium-236 (pCi/g)	<u>Sample</u>	Polonium-210 (pCi/g)
1	1.03 $\pm$ 0.03 1.07 $\pm$ 0.02 1.06 $\pm$ 0.01 1.08 $\pm$ 0.02	5	3.05 $\pm$ 0.13 3.26 $\pm$ 0.13 3.14 $\pm$ 0.14 3.14 $\pm$ 0.14
2	0.49 $\pm$ 0.01 0.52 $\pm$ 0.01 0.52 $\pm$ 0.01 0.47 $\pm$ 0.01	6	1.44 $\pm$ 0.12 1.64 $\pm$ 0.14 1.67 $\pm$ 0.13 1.65 $\pm$ 0.13
3	0.18 $\pm$ 0.01 0.22 $\pm$ 0.01 0.22 $\pm$ 0.01 0.23 $\pm$ 0.01	7	0.66 $\pm$ 0.10 0.76 $\pm$ 0.09 0.76 $\pm$ 0.10 0.73 $\pm$ 0.10
4	0.13 $\pm$ 0.01 0.13 $\pm$ 0.01 0.14 $\pm$ 0.01 0.11 $\pm$ 0.01	8	0.30 $\pm$ 0.06 0.20 $\pm$ 0.06 0.29 $\pm$ 0.05 0.33 $\pm$ 0.05

Table 1.3 - QUALITY CONTROL DATA COMPARISON: REPLICATE ANALYSES OF PREPARED AIRBORNE PARTICULATE SAMPLES

Sample	Uranium-236 (pCi/g)	Sample	Polonium-210 (pCi/g)
1	1.16 $\pm$ 0.11 1.37 $\pm$ 0.10 1.23 $\pm$ 0.10 1.31 $\pm$ 0.10	5	0.79 $\pm$ 0.11 0.66 $\pm$ 0.11 0.72 $\pm$ 0.11 N.S. ^a
2	3.39 $\pm$ 0.17 3.35 $\pm$ 0.15 2.90 $\pm$ 0.15 3.21 $\pm$ 0.16	6	1.79 $\pm$ 0.18 1.88 $\pm$ 0.18 1.64 $\pm$ 0.17 1.59 $\pm$ 0.17
3	5.89 $\pm$ 0.25 6.21 $\pm$ 0.22 5.77 $\pm$ 0.24 6.49 $\pm$ 0.24	7	3.42 $\pm$ 0.24 3.05 $\pm$ 0.22 3.25 $\pm$ 0.24 3.47 $\pm$ 0.25
4	11.95 $\pm$ 0.36 12.90 $\pm$ 0.41 12.29 $\pm$ 0.37 12.0 $\pm$ 0.38	8	6.55 $\pm$ 0.37 6.05 $\pm$ 0.38 6.99 $\pm$ 0.36 N.S. ^a

^a N.S. = no sample

Table 1.4 - QUALITY CONTROL DATA COMPARISON:
 REPLICATE ANALYSES OF PREPARED SOIL SAMPLES

<u>Sample</u>	<u>Uranium-236</u> <u>(pCi/g)</u>	<u>Sample</u>	<u>Polonium-210</u> <u>(pCi/g)</u>
1	0.13 + 0.02	3	2.67 + 0.21
	0.11 + 0.01		2.42 + 0.19
	0.10 + 0.01		2.84 + 0.20
	0.11 + 0.01		2.50 + 0.19
2	0.28 + 0.02	4	4.05 + 0.26
	0.29 + 0.02		3.98 + 0.24
	0.35 + 0.02		3.81 + 0.24
	0.29 + 0.02		3.61 + 0.23
		5	5.62 + 0.29
			5.33 + 0.23
			5.52 + 0.26
			5.49 + 0.32
		6	8.99 + 0.37
			8.86 + 0.42
			9.42 + 0.39
			N.S. ^a

^a N.S. = no sample

Table 1.5 - MINIMUM DETECTION LEVELS (MDL)
FOR SPECIFIED RADIONUCLIDES

<u>Isotope</u>	<u>MDL (pCi) *</u>
U-238	0.02
U-234	0.02
Po-210	0.06
Th-230	0.2
Pb-210	0.1

*These are absolute activities; minimum detectable concentrations in pCi/g will be lower depending on the size of the sample taken for analysis.

Appendix 2. Emission rates for station operation

**Appendix 2 - EMISSION RATES FOR STATION OPERATION AT 100 PERCENT CAPACITY
FACTOR AND OTHER INPUT PARAMETERS FOR DIFFUSION CALCULATIONS**

		<u>Unit 1</u>	<u>Unit 2</u>	<u>Unit 3</u>	<u>Unit 4</u>
Heat Input	(MBtu/hr)	1,482	3,091	5,011	5,920
Fuel Rate	(klb/hr)	165	343	557	729
Excess Air	(%)	20	20	20	20
Air Heat Leakage	(%)	8.7	8.7	8.7	10
Stack Exit Temperature	(F)	300	263	274	274
Heat Release Rate	(cal/sec)	6.7×10^6	12.0×10^6	20.5×10^6	24.2×10^5
SO ₂ Release Rate <u>a/</u>	(lb/MBtu)	1.36	1.35	1.33	1.2
	(lb/MBtu)	2,010	4,185	6,795	7,104
NO ₂ Release Rate <u>b/</u>	(lb/MBtu)	1.4	0.8	0.8	0.7
	(lb/MBtu)	2,080	2,470	4,010	4,144
Particulate Release	(lb/MBtu)	0.067	0.13	0.53	0.1
Rate <u>c/</u>	(lb/MBtu)	100	410	267	592

a/ Units 1,2,3 - For 0.61 % sulfur Hanna coal with all fuel sulfur as SO₂.
Unit 4 - For 0.487 % sulfur coal with all fuel sulfur as SO₂

b/ Units 1,2,3 - NO₂ emission rate estimated
Unit 4 - NO₂ emission rate based on Federal Standards of Performance for new stationary sources.

c/ Unit 1 - 60 % coal ash as furnace bottom ash, 99.0% efficient electrostatic precipitator.
Unit 2 - 20% of coal ash as furnace bottom ash, 99.0% efficient electrostatic precipitator.
Unit 3 - 20% of coal ash as furnace bottom ash, 99.7% efficient electrostatic precipitator.
Unit 4 - Particulate emission rate based on Federal Standards of Performance for new stationary source.

Coal at 9,000 BTU/lb

Coal at 8,125 BTU/lb

Appendix 3. Stack sampling for radon-222 and particulates at a coal-fired power plant, LFE report

STACK SAMPLING FOR ^{222}Rn AND PARTICULATES AT A COAL-FIRED POWER PLANT

Submitted to

MONSANTO RESEARCH CORPORATION
Mound Laboratory
Miamisburg, Ohio

Prepared by

Arthur J. Soinski
James Gendron

November 19, 1976

W.O. No. 13178
P.O. No. 54359

LFE CORPORATION
ENVIRONMENTAL ANALYSIS LABORATORIES
2030 Wright Avenue
Richmond, California 94804

INTRODUCTION

Particulate and gaseous emissions from Unit 2 of the George Neal Power Plant, Sioux City, Iowa, were sampled during late October, 1976. Particulate matter, which was collected on tared glass fiber filters, will be analyzed for naturally-occurring radionuclides by Mound Laboratory. The ^{222}Rn content of the gaseous emissions was determined in the field by LFE Environmental personnel. The sampling and analysis is a step in a program conducted by Mound Laboratory to quantify radionuclide releases from electrical generating plants burning western coal.

The sample collection and radon counting techniques are described briefly in the next section, and the results and discussions are presented in the subsequent section. That section is then followed by the conclusions and recommendations.

SAMPLE COLLECTION AND RADON ANALYSIS TECHNIQUES

The objectives of the stack sampling program at an electricity generating plant burning western coal were two-fold; first, to collect particulate matter for subsequent radiochemical analyses by Mound Laboratory; and, second, to measure ^{222}Rn (radon) emissions. Samples were collected both before (the inlet) and after (the outlet) of the electrostatic precipitator of Unit 2 of the George Neal Power Plant in Sioux City, Iowa. The inlet duct is rectangular in cross section measuring 12.2 m (39.9 ft.) by 4.78 m (15.7 ft.); the cross sectional area is 58.3 m^2 (625 ft^2). The outlet is circular in cross section with a diameter of 5.2 m (17 ft.); the cross sectional area is 21.1 m^2 (227 ft^2).

Because a compliance test was not the goal of LFE Environmental's program, data from a previous compliance test were used to select sampling points. The average flow velocity during the compliance test was 8.5 m/sec (28 ft./sec.) and 20.7 m/sec (67.9 ft./sec.) at the inlet and outlet, respectively. The gas had a specific gravity of 1.01 referred to air at 68°F and standard atmospheric pressure. The gas composition was 82.6% N_2 , 14% CO_2 , and 3.4% O_2 . The moisture content of the outlet gas stream was 9.2%.

It was not practical to collect samples from the large number of sampling points used in a compliance test. Therefore, we selected eight sampling points on the inlet and six sampling points at the outlet that were characterized by flow velocities close to the average stack flow velocity. The actual stack temperatures and velocities were measured according to standard stack sampling procedures.

An RAC Staksampler (manufactured by Research Appliance Company, Gibsonia, Pennsylvania) with a modified 3 m (10 ft.) effective length stainless steel pitobe was used for particulate collection. The precipitator inlet sampling ports are vertical rather than horizontal. It was not possible to collect samples with the pitobe attached directly to the sample case; therefore, a 3 m (10 ft.) length of 1.2 cm (0.5 inch) internal diameter tygon tubing was connected between the pitobe outlet and sample case inlet. Collection velocities approximating isokinetic conditions were used. The outlet ports are located approximately 52 m (175 ft.) downstream from the electrostatic precipitators. Isokinetic sampling was performed at the North and West ports.

A different procedure was used to collect the samples for radon analysis. Isokinetic sampling is not required for gas collection; therefore a gas sample was drawn through a 1.2 m (4 ft.) long probe and into a tedlar gas sampling bag by means of a hand pump over a one minute period. Radon was determined by counting in a Lucas cell. Appropriate corrections were made for radon decay both before and during counting, lack of equilibration between ^{222}Rn and its daughter products, and Lucas cell background and efficiency. Prior to sample introduction, the Lucas cell was flushed several times with N_2 , evacuated to 50-200 $\mu\text{m Hg}$, and the cell background was measured. The Lucas cell was attached to a gas handling manifold, the sample was filtered through a PVC filter to remove radon daughters, moisture was removed by an anhydrous drying tube, and the cell was filled to atmospheric pressure. Counting electronics consisted of a photomultiplier tube, a DC bias supply, an integrated preamplifier/amplifier, and a timer/scaler operated in a pre-set time mode. A few 100 minute counts were taken to assure that the sample decayed with the appropriate half-life. Instrument stability was checked daily with an alpha standard.

RESULTS AND DISCUSSION

The particulate sampling results are summarized in Table I. The grain loadings at the precipitator inlet are a factor of 5 lower than loadings obtained during previous compliance testing ($\sim 10 \text{ g/m}^3$). The reduced grain loads are probably the result of losses in the sampling line and the failure to obtain true isokinetic flow at the pitot inlet. Furthermore, the first two tests were conducted shortly after Unit 2 returned on line, and plant equipment may not have stabilized. Therefore, we regard the third inlet test as being the most representative.

The outlet particulate loadings are slightly higher than loadings obtained during previous compliance testing ($0.4\text{--}0.5 \text{ g/m}^3$). There are two reasons for this. First, Unit 2 was operating at peak overload power output of 310 MWe/hr rather than the normal 295 MWe/hr. Second, the test on October 26th was conducted at a time when the plant operators were cleaning out an accumulation of fly ash that had collected at the boiler bottom during the previous shutdown.

It is perhaps somewhat unfortunate that weather and plant operational conditions prevented sampling during typical plant operations. However, for the purposes of the sampling program, representative particulate samples were obtained. Mound Laboratory personnel will have the opportunity to test their analysis techniques on the samples and to modify subsequent collection and analysis procedures as indicated.

The total particulate emissions can be calculated as follows: The outlet stack diameter is 5.2 m (17 ft.), and the cross sectional area is 21.1 m^2 (227 ft.^2). The average flow velocity at the outlet is 20.7 m/sec. (67.94 ft./sec.). Therefore, the total gas flow is $437 \text{ m}^3/\text{sec.}$ ($15420 \text{ ft.}^3/\text{sec.}$). The total gas flow times the particulate load yields the total particulate emission per second.

The radon data are given in Table 2. The counting errors are 1σ values assuming a Poisson distribution. The less than values represent three times the background counting rate. The stack radon concentrations are within the range of ambient air radon concentrations ($0.03 - 3.0 \text{ pCi/l}$); however, levels are above the average ambient air concentration of 0.1 pCi/l . The stack radon concentration variability may be the result either of variable ^{226}Ra concentration in the coal or of a variation in the time between coal pulverization and combustion.

The radon concentration should be the same at the inlet and outlet because there is no mechanism within the electrostatic precipitator for radon removal. The variability in the radon concentration prohibits a confirmation of this hypothesis.

¹ W. Jacobi and K. Andre, "The Vertical Distribution of ^{222}Rn and Their Decay Products in the Atmosphere", J. Geophys. Res. 68, 3799 (1963).

TABLE 1. Particulate Emissions from the George Neal Power Plant, Unit 2,
Operated by Iowa Public Service. Fuel Feed: Western Coal.
Nominal Power Output: 305 MWe/hr.

A. Precipitator Inlet

Sampling Date and Time	Sampled Gas Volume *	Mass Collected (mg)	Particulate Loading **	
			(mg/m ³)	(gr/SCF)
10-23-76; 10:25 - 12:00	0.689 m ³ (24.33 ft ³)	1429.5	2100	0.91
10-23-76; 16:30 - 18:00	0.638 m ³ (22.52 ft ³)	986.0	1625	0.66
10-24-76; 11:15 - 12:45	0.676 m ³ (23.89 ft ³)	1959.6	2900	1.21

B. Precipitator Outlet

Sampling Date and Time	Sampled Gas Volume *	Mass Collected (mg)	Particulate Loading	
			(mg/m ³)	(gr/SCF)
10-25-76; 14:35 - 15:50	1.51 m ³ (53.32 ft ³)	1868.6	1250	0.54
10-25-76; 16:25 - 17:50	1.60 m ³ (56.57 ft ³)	2028.2	1225	0.55
10-26-76; 11:10 - 12:25	1.35 m ³ (47.75 ft ³)	1985.0	1425	0.61

* Meter Conditions.

** Standard dry conditions of 20°C (68°F) and 1 atmosphere (760 mmHg or 29.92 in Hg.)

TABLE 2. Radon-222 Emissions from the George Neal Power Plant, Unit 2.

A. Precipitator Inlet

Date of Sampling	Time of Sampling	Radon Concentration (pCi/l)	Radon Emission (mCi/hr)
10-23-76	17:15	1.5 ± 0.2	2.7 ± 0.4
10-24-76	11:36	0.3 ± 0.1	0.5 ± 0.2
10-24-76	13:15	<0.2	<0.4
10-25-76	9:30	<0.2	<0.4
10-26-76	8:58	0.60 ± 0.16	1.07 ± 0.28

B. Precipitator Outlet

Date of Sampling	Time of Sampling	Radon Concentration (pCi/l)	Radon Emission (mCi/hr)
10-25-76	11:24	0.46 ± 0.14	0.70 ± 0.21
10-25-76	16:54	<0.2	<0.3
10-26-76	12:06	<0.2	<0.3

CONCLUSIONS AND RECOMMENDATION

The objectives of LFE Environmental's sampling and analysis program were achieved. However, weather and plant operational conditions prevented the collection of truly representative samples. The variability in the stack radon concentrations is not surprising because of the number of factors that affect radon emanation rates. An objective of future studies should be to define both the short and the long term variability of radon emission rates and the reasons for the variability. Ambient air radon measurements should be made in order to separate the coal-derived radon from the combustion air-derived radon. Radon measurements at the coal pulverizer outlet might be instructive in explaining stack radon variability.

Particulate samples are collected during standard compliance tests. Considerable cost savings can result by obtaining particulate collections from these tests rather than by performing particulate collections solely for radiochemical analyses.

4. Analytical Procedures

URANIUM

The determination of uranium-234 and uranium-238 in samples involved a nitric acid-hydrofluoric acid dissolution, coprecipitation of uranium with iron hydroxide, an ether extraction, separation of uranium by anion exchange, and electrodeposition of the uranium followed by alpha pulse height analysis.

After uranium-232 tracer was added, organic matter was removed from the sample by heating at 600°C for 4 hr. Subsequently the sample was decomposed by a nitric acid-hydrofluoric acid digestion, and an iron hydroxide precipitation was performed to coprecipitate the uranium. The hydroxide precipitate was dissolved in 8 M hydrochloric acid, which was extracted with isopropyl ether to remove the bulk of the iron present. The 8 M hydrochloric acid solution was passed through an anion exchange resin column. Uranium, polonium, and bismuth were adsorbed onto the resin, while thorium and radium passed through the column. Plutonium and any unextracted iron were also retained by the resin, but were eluted with 6 M HCl containing hydrogen iodide. The iodide ion reduced plutonium(IV) to plutonium(III) and reduced the iron(III) to iron(II), and neither of these ions were retained by the ion exchange resin in 6 M HCl. The uranium was eluted from the column with 1.0 M HCl, while any zinc adsorbed on the column remained. The uranium was electrodeposited onto a stainless steel slide, and the slide was counted by alpha pulse height analysis using a silicon surface barrier detector for at least 1000 min.

THORIUM

The analytical procedure for thorium-230 in coal, soil, and vegetation involved a nitric acid-hydrofluoric acid dissolution, coprecipitation of thorium with iron hydroxide, separation of the thorium by anion exchange, electrodeposition of the thorium on stainless steel slide, and an alpha pulse height analysis with a minimum counting time of 1000 min.

A tracer, thorium-229, was used in evaluating chemical recovery of thorium. After the thorium-229 tracer was added to a sample, it was ashed to remove organic matter. The sample was decomposed by a nitric acid-hydrofluoric acid digestion with the addition of heat and stirring. Boric acid was added to complex the fluoride ion. Iron hydroxide was used to remove the thorium by coprecipitation. The hydroxide precipitate was dissolved in 8 M nitric acid and passed through an anion exchange resin column, onto which thorium was adsorbed. After 8 M nitric acid rinsing, the thorium was eluted from the column with 9 M hydrochloric acid. Electrodeposition of the thorium onto a highly polished, 0.75-in. diameter stainless steel disc was performed in an ammonium sulfate solution. The disc, or slide, was counted for a minimum of 1000 min in an alpha pulse height analyzer using a silicon surface-barrier detector.

POLONIUM

The analytical procedure for polonium-210 in coal involved a hydrochloric acid leach of a raw coal sample, spontaneous deposition of the polonium

onto a stainless steel slide, followed by an alpha pulse height analysis with a minimum counting time of 1000 min.

A tracer of polonium-208/209 was used to evaluate the chemical recovery of polonium-210. After polonium-208/209 tracer was added to the coal sample, the sample was dried at 30 to 40°C. The dried sample was then leached with 2 M HCl and filtered. The filtrate was transferred to a prepared electrodeposition cell. Polonium was isolated by deposition at 1.5 A current on a 0.75-in. stainless steel disc in the presence of ascorbic acid to complex the iron present in the sample. The disc was air dried and counted for a minimum of 1000 min in an alpha pulse height analyzer using a silicon surface-barrier detector.

Polonium was extracted from samples other than coal with a combination of nitric, hydrofluoric, and hydrochloric acids in the presence of polonium-208 tracer. For samples of soil, cement, and limestone, iron hydroxide precipitation removed the nitric acid and soluble fluorides. The iron was extracted with isopropyl ether from a solution adjusted to 8 M with hydrochloric acid. Instead of the iron hydroxide precipitation, vegetation samples were treated with 30% hydrogen peroxide and wet ashed as necessary to completely rid the sample of organic matter. Nitric and hydrofluoric acids were removed by heating. The precipitate was then dissolved and the solution was adjusted to 1 M with hydrochloric acid from which the polonium was isolated by spontaneous deposition on a 1.88-in. diameter stainless steel disc. The polonium was then dissolved from the disc with nitric acid, and the iron was extracted with isopropyl ether, followed by electrodeposition onto a 0.75-in. diameter stainless steel disc for determination by alpha pulse height spectroscopy.

LEAD

The determination of lead-210 in samples involved dissolution with nitric and hydrofluoric acids, coprecipitation with iron hydroxide, lead nitrate precipitation, separation of lead by anion exchange, and mounting the lead on a 2-in. diameter stainless steel slide for counting.

After stable lead tracer was added, organic matter was removed from the sample by heating in a muffle furnace. The sample was further decomposed by a nitric acid-hydrofluoric acid digestion. Lead was coprecipitated with iron hydroxide, and this precipitate was dissolved in dilute nitric acid. The nitric acid concentration of this solution was increased to 75%, precipitating out the nitrates of lead; the alkaline earth elements; and some aluminum, iron, and silicon. This precipitate was dissolved in distilled water and reprecipitated as the hydroxide which was readily soluble in 1.5 M HCl. The 1.5 M HCl solution was passed through an anion exchange resin column. Lead and bismuth were adsorbed on the column, while the other elements that may have been present passed through. Lead was eluted with distilled water, leaving the bismuth on the column. Atomic absorption analysis of this solution determined the lead recovery. The sample was mounted on a 2-in. diameter stainless

steel slide for beta counting of the ingrowth of bismuth-210. Data reduction by computer analysis determined lead-210 concentration from counting data.

Appendix 5. Sample calculation of radionuclide balance for uranium-234

VALUES USED IN CALCULATIONS

Total gas flow for Unit #2 at 100% capacity (cf. LFE report)	= 437 m ³ /sec
Fuel rate at 100% capacity factor (43.2 kg/sec)	= 343 klb/hr
Average capacity factor for Unit #2	= 80.88%
Percent ash in coal	= 11.91%
Percent of ash which is bottom ash	= 12.76%

CALCULATIONS

$$\begin{aligned}
 \text{U-234 input (pCi/sec)} &= 0.51 \text{ pCi/g} \times 343 \times 10^3 \text{ lb/hr} \\
 &\times 454 \text{ g/lb} \times 1/3600 \text{ hr/sec} \times 0.8088 \text{ capacity} \\
 &= 0.51 \text{ pCi/g} \times 34986 \text{ g coal/sec} \\
 &= 17843 \text{ pCi/sec}
 \end{aligned}$$

$$\begin{aligned}
 \text{U-234 bottom ash (ba) (pCi/sec)} &= 2.72 \text{ pCi/g ba} \\
 &\times 0.1191 \text{ g ash/g coal} \times 0.1276 \text{ g ba/g ash} \\
 &\times 34986 \text{ g coal/sec} = 1446 \text{ pCi/sec}
 \end{aligned}$$

$$\begin{aligned}
 \text{U-234 fly ash (fa) (pCi/sec)} &= 4.36 \text{ pCi/g fa} \\
 &\times 0.1191 \text{ g ash/g coal} \times 0.8724 \text{ g fa/g ash} \\
 &\times 34986 \text{ g coal/sec} = 15849 \text{ pCi/sec}
 \end{aligned}$$

$$\begin{aligned}
 \text{U-234 stack gas (sg) (pCi/sec)} &= 7.48 \text{ pCi/m}^3 \times 437 \text{ m}^3/\text{sec} \\
 0.8088 \text{ capacity} &= 2644 \text{ pCi/sec}
 \end{aligned}$$

$$\begin{aligned}
 \text{Total output} &= \text{ba} + \text{fa} + \text{sg} = 1446 + 15849 + 2644 \\
 &= 19939 \text{ pCi/sec}
 \end{aligned}$$

$$\begin{aligned}
 \text{Relative Imbalance} &= \frac{\text{Input} - \text{Output}}{\text{Input}} \times 100 \\
 &= \frac{17,843 - 19,939}{17,843} \times 100 \\
 &= -12\%
 \end{aligned}$$

Appendix 6. AIREM atmospheric dispersion model, detailed output

WIND FREQUENCY IN PERCENT BY STABILITY CLASS FOR EACH SECTOR AND TOTAL FREQUENCY FOR SECTOR

DIR	A	B	C	D	E	F	TOTAL
N	0.02	0.41	1.29	6.43	1.51	0.0	9.66
NNE	0.03	0.22	0.62	1.98	0.66	0.0	3.51
NE	0.03	0.24	0.58	1.22	0.75	0.0	2.82
ENE	0.03	0.18	0.26	0.95	0.94	0.0	2.26
E	0.01	0.22	0.53	1.94	1.87	0.0	4.56
ESE	0.02	0.20	0.60	2.98	1.64	0.0	5.43
SE	0.02	0.17	0.78	8.27	2.29	0.0	11.52
SSE	0.03	0.18	0.71	6.33	1.76	0.0	9.01
S	0.02	0.20	0.63	5.15	1.45	0.0	7.45
SSW	0.02	0.16	0.25	2.39	0.80	0.0	3.61
SW	0.03	0.13	0.22	1.99	0.56	0.0	2.93
WSW	0.0	0.12	0.28	1.85	0.58	0.0	2.83
W	0.03	0.19	0.43	3.43	1.95	0.0	6.04
WNW	0.01	0.20	0.48	4.20	4.01	0.0	8.90
NW	0.03	0.24	0.92	5.94	3.51	0.0	10.64
NNW	0.03	0.27	0.78	6.13	1.62	0.0	8.82

WIND SPEED IN METERS PER SECOND BY STABILITY CLASS FOR EACH COMPASS DIRECTION

DIR	A	B	C	D	E	F
N	2.06	2.88	5.04	6.53	3.14	0.0
NNE	2.21	2.93	4.99	6.33	2.93	0.0
NE	2.42	3.19	4.37	5.56	2.57	0.0
ENE	1.90	2.73	4.12	5.30	2.62	0.0
E	1.54	3.09	3.76	5.81	2.83	0.0
ESE	1.80	2.73	4.53	6.58	3.04	0.0
SE	2.06	2.88	4.58	7.20	3.09	0.0
SSE	2.06	2.78	4.73	6.79	3.19	0.0
S	2.06	2.73	4.53	6.07	2.73	0.0
SSW	2.06	2.68	4.12	5.50	2.78	0.0
SW	2.06	3.04	4.06	5.25	2.78	0.0
WSW	0.0	3.29	4.06	5.14	2.83	0.0
W	2.42	2.88	3.76	4.99	2.93	0.0
WNW	2.57	3.09	3.76	4.94	3.40	0.0
NW	2.21	2.83	3.86	5.56	3.50	0.0
NNW	2.42	3.04	4.53	6.33	3.24	0.0

OUTPUT DATA:

SIGMA ZEE'S BY STABILITY CLASS AND RADIUS

A	B	C	D	E	F
0.11E 03	0.52E 02	0.32E 02	0.18E 02	0.13E 02	0.85E 01
0.11E 04	0.17E 03	0.85E 02	0.41E 02	0.28E 02	0.18E 02
0.31E 04	0.29E 03	0.14E 03	0.58E 02	0.38E 02	0.24E 02
0.61E 04	0.42E 03	0.19E 03	0.72E 02	0.46E 02	0.29E 02
0.10E 05	0.56E 03	0.24E 03	0.85E 02	0.53E 02	0.33E 02
0.10E 05	0.70E 03	0.29E 03	0.96E 02	0.59E 02	0.36E 02
0.10E 05	0.85E 03	0.34E 03	0.11E 03	0.65E 02	0.39E 02
0.10E 05	0.10E 04	0.39E 03	0.12E 03	0.70E 02	0.42E 02
0.10E 05	0.11E 04	0.43E 03	0.13E 03	0.74E 02	0.44E 02
0.10E 05	0.13E 04	0.48E 03	0.13E 03	0.78E 02	0.46E 02
0.10E 05	0.15E 04	0.53E 03	0.14E 03	0.82E 02	0.48E 02
0.10E 05	0.16E 04	0.57E 03	0.15E 03	0.85E 02	0.50E 02

CHI/Q SUMMED OVER STABILITY CLASSES (UNIT 1)

DIR	500.	1500.	2500.	3500.	4500.	DISTANCE (METERS)		7500.	8500.	9500.	10500.	11500.
						5500.	6500.					
N	3.60E-09	1.87E-08	1.81E-08	1.85E-08	1.82E-08	1.74E-08	1.62E-08	1.50E-08	1.38E-08	1.27E-08	1.18E-08	1.09E-08
NNE	3.52E-09	9.50E-09	8.07E-09	7.38E-09	6.95E-09	6.51E-09	6.04E-09	5.57E-09	5.13E-09	4.73E-09	4.40E-09	4.11E-09
NE	2.87E-09	9.84E-09	7.86E-09	6.68E-09	6.10E-09	5.68E-09	5.29E-09	4.92E-09	4.58E-09	4.26E-09	4.01E-09	3.77E-09
ENE	3.15E-09	6.52E-09	4.93E-09	4.43E-09	4.36E-09	4.33E-09	4.24E-09	4.09E-09	3.92E-09	3.74E-09	3.57E-09	3.40E-09
E	1.14E-09	9.62E-09	8.51E-09	8.16E-09	8.18E-09	8.15E-09	7.96E-09	7.68E-09	7.34E-09	6.99E-09	6.66E-09	6.34E-09
ESE	2.67E-09	9.74E-09	9.12E-09	9.26E-09	9.37E-09	9.23E-09	8.88E-09	8.43E-09	7.95E-09	7.48E-09	7.05E-09	6.65E-09
SE	2.25E-09	1.07E-08	1.41E-08	1.74E-08	1.87E-08	1.86E-08	1.79E-08	1.68E-08	1.57E-08	1.47E-08	1.37E-08	1.28E-08
SSE	3.01E-09	1.04E-08	1.24E-08	1.47E-08	1.55E-08	1.53E-08	1.46E-08	1.37E-08	1.27E-08	1.18E-08	1.10E-08	1.03E-08
S	2.48E-09	1.02E-08	1.17E-08	1.35E-08	1.43E-08	1.41E-08	1.35E-08	1.26E-08	1.18E-08	1.09E-08	1.02E-08	9.53E-09
SSW	2.23E-09	6.35E-09	6.18E-09	7.02E-09	7.39E-09	7.33E-09	7.01E-09	6.60E-09	6.17E-09	5.74E-09	5.36E-09	5.01E-09
SW	2.66E-09	5.12E-09	5.37E-09	6.09E-09	6.36E-09	6.24E-09	5.93E-09	5.54E-09	5.15E-09	4.77E-09	4.43E-09	4.12E-09
WSW	5.99E-10	5.01E-09	5.40E-09	6.00E-09	6.19E-09	6.04E-09	5.72E-09	5.34E-09	4.96E-09	4.59E-09	4.27E-09	3.98E-09
W	2.73E-09	8.86E-09	9.79E-09	1.14E-08	1.22E-08	1.23E-08	1.19E-08	1.13E-08	1.07E-08	1.01E-08	9.47E-09	8.91E-09
WNW	1.03E-09	9.06E-09	1.10E-08	1.37E-08	1.53E-08	1.58E-08	1.57E-08	1.53E-08	1.47E-08	1.39E-08	1.32E-08	1.26E-08
NW	3.17E-09	1.49E-08	1.66E-08	1.87E-08	1.95E-08	1.94E-08	1.87E-08	1.77E-08	1.67E-08	1.56E-08	1.47E-08	1.38E-08
NNW	3.08E-09	1.25E-08	1.39E-08	1.57E-08	1.63E-08	1.59E-08	1.51E-08	1.41E-08	1.30E-08	1.21E-08	1.12E-08	1.04E-08

CHI/Q SUMMED OVER STABILITY CLASSES (UNIT 2)

DIR						DISTANCE (METERS)						
	500.	1500.	2500.	3500.	4500.	5500.	6500.	7500.	8500.	9500.	10500.	11500.
N	4.87E-10	7.53E-09	8.06E-09	7.04E-09	6.79E-09	6.87E-09	6.88E-09	6.80E-09	6.63E-09	6.42E-09	6.22E-09	6.02E-09
NNE	6.55E-10	4.05E-09	4.12E-09	3.39E-09	3.03E-09	2.87E-09	2.75E-09	2.64E-09	2.53E-09	2.41E-09	2.33E-09	2.25E-09
NE	5.99E-10	4.13E-09	4.28E-09	3.45E-09	2.93E-09	2.66E-09	2.46E-09	2.31E-09	2.18E-09	2.07E-09	2.00E-09	1.94E-09
ENE	7.57E-10	3.22E-09	2.79E-09	2.14E-09	1.84E-09	1.73E-09	1.66E-09	1.61E-09	1.57E-09	1.54E-09	1.52E-09	1.49E-09
E	1.42E-11	3.75E-09	4.16E-09	3.50E-09	3.16E-09	3.03E-09	2.96E-09	2.90E-09	2.85E-09	2.80E-09	2.77E-09	2.74E-09
ESE	5.39E-10	4.01E-09	4.22E-09	3.62E-09	3.43E-09	3.42E-09	3.42E-09	3.39E-09	3.34E-09	3.27E-09	3.22E-09	3.15E-09
SE	4.70E-10	3.77E-09	4.70E-09	4.78E-09	5.38E-09	6.02E-09	6.45E-09	6.66E-09	6.71E-09	6.65E-09	6.55E-09	6.40E-09
SSE	6.99E-10	3.99E-09	4.54E-09	4.39E-09	4.74E-09	5.18E-09	5.47E-09	5.60E-09	5.60E-09	5.51E-09	5.41E-09	5.27E-09
S	4.73E-10	4.03E-09	4.41E-09	4.15E-09	4.43E-09	4.81E-09	5.06E-09	5.17E-09	5.16E-09	5.08E-09	4.99E-09	4.87E-09
SSW	4.70E-10	2.82E-09	2.56E-09	2.24E-09	2.34E-09	2.53E-09	2.66E-09	2.71E-09	2.71E-09	2.67E-09	2.62E-09	2.55E-09
SW	6.95E-10	2.37E-09	2.20E-09	1.96E-09	2.05E-09	2.21E-09	2.31E-09	2.35E-09	2.34E-09	2.30E-09	2.24E-09	2.18E-09
WSW	7.46E-12	1.94E-09	2.15E-09	1.97E-09	2.03E-09	2.16E-09	2.24E-09	2.26E-09	2.24E-09	2.19E-09	2.14E-09	2.09E-09
W	5.97E-10	3.65E-09	3.82E-09	3.53E-09	3.71E-09	4.02E-09	4.23E-09	4.34E-09	4.37E-09	4.33E-09	4.28E-09	4.21E-09
WNW	1.28E-11	3.40E-09	3.88E-09	3.77E-09	4.16E-09	4.65E-09	5.02E-09	5.25E-09	5.37E-09	5.41E-09	5.42E-09	5.38E-09
NW	6.56E-10	5.33E-09	6.53E-09	6.15E-09	6.31E-09	6.64E-09	6.87E-09	6.97E-09	6.95E-09	6.85E-09	6.75E-09	6.62E-09
NNW	6.02E-10	4.93E-09	5.39E-09	5.02E-09	5.26E-09	5.64E-09	5.88E-09	5.96E-09	5.92E-09	5.81E-09	5.68E-09	5.52E-09

CHI/Q SUMMED OVER STABILITY CLASSES (UNIT 3)

DIR						DISTANCE (METERS)						
	500.	1500.	2500.	3500.	4500.	5500.	6500.	7500.	8500.	9500.	10500.	11500.
N	1.39E-10	3.73E-09	5.09E-09	4.64E-09	4.10E-09	3.84E-09	3.74E-09	3.71E-09	3.69E-09	3.66E-09	3.65E-09	3.63E-09
NNE	1.94E-10	2.12E-09	2.68E-09	2.38E-09	2.04E-09	1.83E-09	1.69E-09	1.60E-09	1.53E-09	1.48E-09	1.45E-09	1.42E-09
NE	1.77E-10	2.12E-09	2.77E-09	2.48E-09	2.10E-09	1.83E-09	1.64E-09	1.50E-09	1.40E-09	1.32E-09	1.27E-09	1.24E-09
ENE	2.25E-10	1.86E-09	1.96E-09	1.59E-09	1.31E-09	1.15E-09	1.05E-09	9.86E-10	9.38E-10	9.01E-10	8.82E-10	8.67E-10
E	9.44E-14	1.77E-09	2.59E-09	2.40E-09	2.08E-09	1.87E-09	1.74E-09	1.65E-09	1.60E-09	1.55E-09	1.54E-09	1.53E-09
ESE	1.59E-10	2.04E-09	2.69E-09	2.44E-09	2.13E-09	1.97E-09	1.89E-09	1.85E-09	1.83E-09	1.81E-09	1.81E-09	1.80E-09
SE	1.39E-10	1.74E-09	2.76E-09	2.74E-09	2.62E-09	2.71E-09	2.90E-09	3.10E-09	3.26E-09	3.37E-09	3.47E-09	3.52E-09
SSE	2.08E-10	1.99E-09	2.79E-09	2.64E-09	2.46E-09	2.47E-09	2.58E-09	2.70E-09	2.81E-09	2.88E-09	2.94E-09	2.97E-09
S	1.39E-10	2.02E-09	2.75E-09	2.54E-09	2.34E-09	2.33E-09	2.42E-09	2.52E-09	2.61E-09	2.67E-09	2.72E-09	2.74E-09
SSW	1.39E-10	1.57E-09	1.74E-09	1.45E-09	1.28E-09	1.26E-09	1.30E-09	1.35E-09	1.39E-09	1.42E-09	1.44E-09	1.45E-09
SW	2.08E-10	1.36E-09	1.49E-09	1.27E-09	1.13E-09	1.11E-09	1.14E-09	1.18E-09	1.21E-09	1.24E-09	1.25E-09	1.26E-09
WSW	4.95E-14	9.24E-10	1.33E-09	1.23E-09	1.12E-09	1.09E-09	1.11E-09	1.14E-09	1.16E-09	1.18E-09	1.20E-09	1.20E-09
W	1.77E-10	1.90E-09	2.43E-09	2.20E-09	2.00E-09	1.98E-09	2.03E-09	2.11E-09	2.18E-09	2.23E-09	2.27E-09	2.30E-09
WNW	8.53E-14	1.60E-09	2.36E-09	2.23E-09	2.09E-09	2.13E-09	2.25E-09	2.39E-09	2.52E-09	2.61E-09	2.69E-09	2.75E-09
NW	1.94E-10	2.48E-09	3.90E-09	3.82E-09	3.51E-09	3.40E-09	3.42E-09	3.49E-09	3.55E-09	3.59E-09	3.65E-09	3.67E-09
NNW	1.77E-10	2.47E-09	3.36E-09	3.11E-09	2.84E-09	2.80E-09	2.87E-09	2.97E-09	3.06E-09	3.11E-09	3.16E-09	3.17E-09

U-238 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 1

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	4.36	3.65	3.48	3.82	1.38	3.23	2.72	3.65	3.00	2.71	3.22	0.73	3.30	1.25	3.83	3.73
1500.	22.64	11.49	11.90	7.89	11.64	11.78	13.01	12.63	12.37	7.32	6.20	6.06	10.72	10.97	18.00	15.09
2500.	21.80	9.71	9.46	5.92	10.24	10.98	17.01	15.00	14.07	7.45	6.46	6.51	11.80	13.31	20.06	16.72
3500.	22.22	8.87	8.02	5.31	9.80	11.13	20.93	17.66	16.32	8.45	7.33	7.23	13.69	16.48	22.47	18.94
4500.	21.92	8.34	7.30	5.21	9.81	11.25	22.48	18.62	17.16	8.88	7.64	7.44	14.62	18.36	23.48	19.62
5500.	20.37	7.79	6.79	5.17	9.75	11.06	22.36	18.35	16.91	8.78	7.48	7.24	14.68	19.00	23.26	19.13
6500.	19.40	7.20	6.30	5.05	9.51	10.61	21.40	17.44	16.08	8.37	7.07	6.83	14.20	18.83	22.34	18.05
7500.	17.85	6.62	5.84	4.86	9.14	10.05	20.11	16.30	15.04	7.85	6.58	6.34	13.48	18.21	21.10	16.77
8500.	16.36	6.07	5.41	4.64	8.70	9.44	18.72	15.11	13.96	7.29	6.08	5.86	12.66	17.38	19.76	15.47
9500.	14.98	5.57	5.01	4.40	8.24	8.83	17.36	13.97	12.91	6.75	5.60	5.39	11.84	16.45	18.43	14.25
10500.	13.82	5.16	4.68	4.17	7.82	8.29	16.13	12.96	11.98	6.27	5.17	4.99	11.07	15.54	17.23	13.17
11500.	12.77	4.79	4.38	3.95	7.40	7.78	15.00	12.02	11.12	5.82	4.79	4.62	10.35	14.65	16.11	12.20

U-234 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 1

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	4.32	3.63	3.45	3.79	1.37	3.21	2.70	3.62	2.98	2.69	3.19	0.72	3.28	1.24	3.80	3.71
1500.	22.48	11.40	11.81	7.83	11.56	11.70	12.91	12.53	12.28	7.27	6.15	6.02	10.64	10.89	17.86	14.98
2500.	21.63	9.64	9.39	5.88	10.17	10.90	16.88	14.89	13.97	7.39	6.42	6.47	11.71	13.21	19.91	16.60
3500.	22.05	8.81	7.96	5.27	9.73	11.05	20.77	17.53	16.20	8.39	7.28	7.18	13.59	16.36	22.30	18.80
4500.	21.76	8.28	7.25	5.18	9.74	11.16	22.31	18.48	17.03	8.82	7.58	7.38	14.52	18.22	23.30	19.48
5500.	20.71	7.73	6.74	5.14	9.68	10.98	22.20	18.21	16.78	8.71	7.42	7.19	14.57	18.86	23.09	18.99
6500.	19.25	7.15	6.25	5.01	9.43	10.53	21.24	17.31	15.96	8.31	7.02	6.78	14.10	18.69	22.17	17.91
7500.	17.71	6.57	5.80	4.83	9.07	9.57	19.96	16.18	14.93	7.79	6.53	6.30	13.38	18.08	20.94	16.64
8500.	16.23	6.02	5.37	4.60	8.64	9.37	18.58	15.00	13.86	7.24	6.03	5.81	12.57	17.25	19.61	15.36
9500.	14.87	5.53	4.57	4.37	8.18	8.77	17.23	13.87	12.82	6.70	5.56	5.35	11.75	16.33	18.29	14.14
10500.	13.71	5.12	4.65	4.14	7.76	8.23	16.01	12.86	11.89	6.22	5.14	4.95	10.99	15.43	17.10	13.08
11500.	12.63	4.76	4.35	3.92	7.34	7.72	14.89	11.93	11.03	5.78	4.75	4.59	10.28	14.55	15.99	12.11

RN-222 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 1

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	29.16	24.47	23.27	25.57	9.27	21.62	18.21	24.44	20.07	18.11	21.53	4.86	22.12	8.37	25.66	25.00
1500.	151.62	76.95	79.70	52.83	77.94	78.92	87.11	84.56	82.82	49.03	41.52	40.59	71.76	73.41	120.50	101.04
2500.	146.50	65.35	63.67	39.93	68.91	73.87	114.19	100.74	94.54	50.07	43.46	43.76	79.31	89.39	134.82	112.32
3500.	149.51	59.79	54.11	35.84	66.07	74.96	140.59	118.70	109.72	56.86	49.32	48.62	92.10	110.74	151.17	127.37
4500.	147.71	56.27	49.35	35.23	66.19	75.82	151.14	125.29	115.48	59.82	51.44	50.10	98.49	123.51	158.17	132.09
5500.	140.88	52.70	45.97	35.01	65.88	74.66	150.66	123.68	114.04	59.28	50.51	48.90	99.09	128.11	157.07	129.07
6500.	131.33	48.81	42.78	34.23	64.35	71.81	144.56	117.89	108.81	56.71	47.93	46.27	96.17	127.32	151.22	122.11
7500.	121.22	44.99	39.77	33.06	62.03	68.16	136.20	110.52	102.13	53.35	44.78	43.17	91.62	123.58	143.30	113.83
8500.	111.51	41.43	36.96	31.65	59.28	64.25	127.24	102.86	95.15	49.80	41.56	40.04	86.46	118.38	134.70	105.45
9500.	102.57	38.19	34.39	30.15	56.36	60.36	118.47	95.48	88.41	46.34	38.48	37.06	81.21	112.57	126.17	97.51
10500.	94.98	35.52	32.29	28.75	53.70	56.90	110.55	88.90	82.39	43.22	35.74	34.45	76.37	106.88	118.49	90.54
11500.	88.21	33.13	30.40	27.38	51.11	53.64	103.25	82.88	76.88	40.36	33.25	32.08	71.81	101.29	111.33	84.22

PD-218 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 1

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	15.30	13.11	11.69	15.03	4.24	12.63	10.03	13.76	11.10	10.17	12.16	2.13	11.48	3.83	13.80	12.65
1500.	114.44	58.75	61.85	43.78	62.50	61.94	65.46	64.34	64.48	40.28	33.46	31.60	58.37	58.64	96.23	77.37
2500.	123.86	56.36	56.81	36.51	62.08	63.88	93.31	83.79	80.94	44.39	38.66	38.80	71.38	80.01	119.39	95.46
3500.	135.03	54.85	51.10	34.20	62.32	68.47	123.36	105.73	100.21	53.07	46.32	45.76	87.30	104.92	141.24	115.45
4500.	139.50	53.67	47.99	34.47	64.24	72.09	140.04	117.32	110.06	57.78	49.90	48.69	96.12	120.60	152.84	125.13
5500.	136.56	51.40	45.37	34.68	64.94	72.68	144.27	119.28	111.26	58.30	49.79	48.26	98.04	126.83	154.50	125.40
6500.	129.15	48.17	42.52	34.10	63.92	70.80	141.07	115.57	107.45	56.27	47.62	46.01	95.75	126.80	150.06	120.27
7500.	120.15	44.69	39.66	33.01	61.84	67.67	134.34	109.34	101.49	53.16	44.66	43.07	91.47	123.40	142.80	112.94
8500.	110.99	41.29	36.93	31.64	59.21	64.02	126.28	102.27	94.87	49.73	41.51	40.00	86.42	118.34	134.51	105.04
9500.	102.33	38.13	34.38	30.15	56.34	60.26	117.98	95.19	88.29	46.32	38.47	37.06	81.22	112.59	126.12	97.33
10500.	94.89	35.50	32.30	28.76	53.71	56.86	110.31	88.77	82.36	43.23	35.75	34.46	76.40	106.92	118.50	90.47
11500.	88.18	33.13	30.41	27.39	51.12	53.64	103.15	82.84	76.88	40.37	33.26	32.09	71.84	101.34	111.37	84.21

PB-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 1

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.71	0.63	0.50	0.84	0.16	0.70	0.50	0.71	0.56	0.52	0.63	0.07	0.52	0.14	0.66	0.55
1500.	10.59	5.59	6.14	5.22	6.77	6.33	5.99	6.07	6.45	4.68	3.67	3.16	6.58	6.28	10.30	7.42
2500.	15.73	7.66	8.78	6.29	10.00	8.76	10.66	10.10	10.72	6.69	5.90	5.85	11.45	12.53	17.90	12.33
3500.	21.99	9.61	10.52	7.56	12.73	11.75	17.85	16.23	17.18	10.18	9.22	9.22	18.41	22.06	27.26	19.11
4500.	28.73	11.82	12.46	9.58	16.36	15.53	25.81	22.93	24.11	14.07	12.65	12.57	25.94	32.74	37.37	26.29
5500.	34.37	13.78	14.27	11.69	20.01	19.09	32.73	28.67	29.92	17.35	15.35	15.17	32.27	42.26	46.09	32.27
6500.	38.39	15.14	15.57	13.48	23.02	21.89	38.04	32.92	34.13	19.71	17.25	17.08	37.04	49.56	52.68	36.60
7500.	41.05	16.10	16.39	14.64	25.20	24.05	41.82	35.93	36.97	21.21	18.53	18.20	40.24	54.95	57.14	39.51
8500.	42.49	16.60	17.32	15.68	26.91	25.52	44.47	37.83	38.87	22.23	18.83	18.45	42.04	58.46	60.09	41.36
9500.	43.20	16.85	17.09	15.70	27.77	26.48	46.02	38.84	39.59	22.62	19.21	19.30	43.39	60.95	61.85	42.25
10500.	43.96	17.07	18.20	16.44	29.14	26.95	46.99	39.51	40.55	23.75	19.94	19.28	44.59	61.85	62.76	42.58
11500.	43.55	17.25	17.26	15.78	27.81	27.93	47.70	40.21	40.03	22.29	18.68	18.10	42.50	63.64	64.00	42.95

BI-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 1

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.03	0.03	0.02	0.04	0.01	0.03	0.02	0.03	0.02	0.02	0.03	0.00	0.02	0.00	0.03	0.02
1500.	0.81	0.44	0.50	0.51	0.60	0.53	0.46	0.48	0.53	0.44	0.33	0.26	0.61	0.55	0.91	0.59
2500.	1.63	0.84	1.09	0.87	1.29	0.97	1.00	0.99	1.15	0.81	0.73	0.71	1.47	1.58	2.16	1.30
3500.	2.87	1.34	1.71	1.31	2.06	1.61	2.09	2.00	2.35	1.55	1.45	1.47	3.06	3.66	4.17	2.53
4500.	4.67	2.05	2.53	2.08	3.26	2.63	3.78	3.55	4.16	2.68	2.51	2.53	5.46	6.93	7.15	4.36
5500.	6.76	2.88	3.49	3.06	4.79	3.91	5.83	5.40	6.27	4.01	3.67	3.70	8.24	10.93	10.69	6.49
6500.	8.87	3.69	4.43	4.14	6.43	5.26	8.00	7.30	8.41	5.36	4.85	4.92	11.13	15.05	14.35	8.65
7500.	10.88	4.50	5.27	5.07	7.99	6.63	10.11	9.16	10.45	6.58	5.98	5.99	13.82	19.12	17.77	10.72
8500.	12.63	5.19	6.37	6.12	9.57	7.91	12.15	10.86	12.39	7.76	6.68	6.66	16.08	22.74	20.98	12.66
9500.	14.21	5.81	6.69	6.47	10.78	9.08	13.95	12.33	13.88	8.68	7.56	7.95	18.39	26.23	23.86	14.31
10500.	15.95	6.45	8.19	7.53	12.57	10.02	15.60	13.74	15.71	10.39	8.87	8.61	20.90	28.70	26.36	15.72
11500.	16.93	7.11	7.83	7.29	12.03	11.51	17.27	15.34	16.49	9.81	8.38	8.15	20.24	32.51	29.47	17.29

PO-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 1

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.03	0.03	0.02	1.04	0.01	0.03	0.02	0.03	0.02	0.02	0.03	0.00	0.02	0.00	0.03	0.02
1500.	0.81	0.44	0.50	0.51	0.60	0.53	0.46	0.48	0.53	0.44	0.33	0.26	0.61	0.55	0.91	0.59
2500.	1.63	0.84	1.09	0.87	1.29	0.97	1.00	0.99	1.15	0.81	0.73	0.71	1.47	1.58	2.16	1.30
3500.	2.87	1.34	1.71	1.31	2.06	1.61	2.09	2.00	2.35	1.55	1.45	1.47	3.06	3.66	4.17	2.53
4500.	4.67	2.05	2.53	2.08	3.26	2.63	3.78	3.55	4.16	2.68	2.51	2.53	5.46	6.93	7.15	4.36
5500.	6.76	2.88	3.49	3.06	4.79	3.91	5.83	5.40	6.27	4.01	3.67	3.70	8.24	10.93	10.69	6.49
6500.	8.87	3.69	4.43	4.14	6.43	5.26	8.00	7.30	8.41	5.36	4.85	4.92	11.13	15.05	14.35	8.65
7500.	10.88	4.50	5.27	5.07	7.99	6.63	10.11	9.16	10.45	6.58	5.98	5.99	13.82	19.12	17.77	10.72
8500.	12.63	5.19	6.37	6.12	9.57	7.91	12.15	10.86	12.39	7.76	6.68	6.66	16.08	22.74	20.98	12.66
9500.	14.21	5.81	6.69	6.47	10.78	9.08	13.95	12.33	13.88	8.68	7.56	7.95	18.39	26.23	23.86	14.31
10500.	15.95	6.45	8.19	7.53	12.57	10.02	15.60	13.74	15.71	10.39	8.87	8.61	20.90	28.70	26.36	15.72
11500.	16.93	7.11	7.83	7.29	12.03	11.51	17.27	15.34	16.49	9.81	8.38	8.15	20.24	32.51	29.47	17.29

PB-210 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 1

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	8.43	7.08	6.73	7.40	2.68	6.26	5.27	7.07	5.80	5.24	6.23	1.41	6.40	2.42	7.42	7.23
1500.	43.85	22.25	23.05	15.27	22.55	22.82	25.19	24.45	23.95	14.18	12.00	11.74	20.75	21.24	34.85	29.22
2500.	42.21	18.81	18.32	11.47	19.84	21.27	32.94	29.04	27.25	14.42	12.52	12.61	22.85	25.77	38.85	32.38
3500.	43.02	17.18	15.53	10.28	18.98	21.55	40.53	34.20	31.60	16.37	14.20	14.00	26.52	31.91	43.51	36.68
4500.	42.45	16.14	14.14	10.10	18.99	21.78	43.52	36.06	33.22	17.20	14.79	14.40	28.32	35.55	45.46	38.00
5500.	40.40	15.09	13.14	10.02	18.88	21.41	43.30	35.53	32.74	17.00	14.48	14.02	28.42	36.79	45.05	37.05
6500.	37.56	13.94	12.20	9.78	18.41	20.55	41.45	33.77	31.14	16.21	13.70	13.22	27.50	36.46	43.25	34.95
7500.	34.56	12.81	11.31	9.41	17.69	19.45	38.93	31.56	29.13	15.19	12.74	12.29	26.10	35.26	40.85	32.47
8500.	31.67	11.75	10.47	8.98	16.85	18.28	36.25	29.27	27.03	14.12	11.77	11.34	24.52	33.65	38.26	29.97
9500.	29.01	10.79	9.70	8.52	15.96	17.11	33.62	27.06	25.00	13.08	10.84	10.45	22.92	31.85	35.68	27.60
10500.	26.75	9.99	9.07	8.08	15.14	16.05	31.24	25.09	23.19	12.14	10.02	9.66	21.44	30.10	33.36	25.51
11500.	24.73	9.28	8.49	7.65	14.33	15.06	29.05	23.28	21.53	11.27	9.27	8.95	20.05	28.38	31.19	23.62

PO-210 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 1

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	5.30	4.45	4.23	4.65	1.68	3.93	3.31	4.44	3.65	3.29	3.91	0.88	4.02	1.52	4.66	4.54
1500.	27.54	13.98	14.48	9.59	14.16	14.33	15.82	15.36	15.04	8.90	7.54	7.37	13.03	13.34	21.89	18.35
2500.	26.51	11.82	11.51	7.21	12.46	13.36	20.69	18.24	17.12	9.06	7.86	7.92	14.35	16.19	24.40	20.34
3500.	27.02	10.79	9.75	6.46	11.92	13.54	25.46	21.48	19.85	10.28	8.92	8.79	16.66	20.04	27.33	23.04
4500.	26.66	10.14	8.88	6.34	11.93	13.68	27.34	22.65	20.87	10.80	9.29	9.05	17.79	22.33	28.56	23.87
5500.	25.38	9.48	8.26	6.29	11.86	13.45	27.20	22.31	20.56	10.68	9.10	8.81	17.85	23.11	28.30	23.27
6500.	23.59	8.76	7.56	6.14	11.56	12.91	26.03	21.21	19.56	10.18	8.60	8.30	17.27	22.90	27.17	21.95
7500.	21.70	8.05	7.10	5.91	11.11	12.22	24.45	19.82	18.30	9.54	8.00	7.72	16.39	22.15	25.66	20.39
8500.	19.89	7.38	6.58	5.64	10.59	11.48	22.77	18.38	16.98	8.87	7.39	7.12	15.40	21.13	24.03	18.82
9500.	18.22	6.78	6.09	5.35	10.02	10.74	21.12	17.00	15.70	8.22	6.81	6.56	14.40	20.01	22.41	17.33
10500.	16.80	6.28	5.70	5.08	9.51	10.08	19.62	15.76	14.56	7.62	6.29	6.07	13.47	18.90	20.95	16.02
11500.	15.53	5.83	5.33	4.81	9.00	9.46	18.24	14.62	13.52	7.08	5.82	5.62	12.59	17.82	19.59	14.83

U-238 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 2

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	1.30	1.74	1.63	2.02	0.04	1.44	1.25	1.86	1.26	1.25	1.85	0.02	1.59	0.03	1.75	1.60
1500.	20.07	10.79	10.99	8.59	9.99	10.67	10.03	10.63	10.75	7.52	6.32	5.16	9.72	9.07	14.21	13.13
2500.	21.40	10.93	11.37	7.38	11.04	11.20	12.48	12.07	11.70	6.78	5.84	5.70	10.13	10.31	17.35	14.31
3500.	18.63	8.97	9.12	5.63	9.26	9.59	12.67	11.62	11.00	5.92	5.19	5.23	9.33	9.99	16.29	13.29
4500.	17.95	7.99	7.73	4.84	8.33	9.04	14.24	12.54	11.70	6.17	5.41	5.38	9.80	11.00	16.66	13.90
5500.	18.14	7.56	6.99	4.54	7.98	9.02	15.95	13.71	12.72	6.68	5.83	5.70	10.61	12.30	17.54	14.92
6500.	18.16	7.24	6.46	4.35	7.78	9.01	17.08	14.46	13.37	7.01	6.10	5.90	11.17	13.27	18.13	15.54
7500.	17.92	6.94	6.06	4.22	7.62	8.93	17.62	14.78	13.63	7.15	6.19	5.96	11.45	13.87	18.36	15.74
8500.	17.45	6.63	5.72	4.11	7.48	8.79	17.72	14.76	13.60	7.13	6.15	5.90	11.49	14.16	18.28	15.62
9500.	16.86	6.32	5.42	4.01	7.33	8.59	17.52	14.52	13.37	7.01	6.03	5.76	11.38	14.23	18.00	15.28
10500.	16.32	6.09	5.22	3.95	7.25	8.43	17.22	14.21	13.09	6.86	5.87	5.62	11.22	14.22	17.70	14.90
11500.	15.74	5.86	5.04	3.88	7.15	8.24	16.81	13.83	12.74	6.67	5.69	5.45	10.99	14.09	17.31	14.45

U-234 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 2

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	1.29	1.73	1.58	2.00	0.04	1.43	1.24	1.85	1.25	1.24	1.84	0.02	1.58	0.03	1.74	1.59
1500.	19.91	10.70	10.91	8.52	9.91	10.59	9.95	10.55	10.66	7.46	6.27	5.12	9.64	9.00	14.10	13.02
2500.	21.23	10.85	11.28	7.32	10.96	11.11	12.38	11.97	11.61	6.73	5.80	5.66	10.05	10.22	17.22	14.20
3500.	18.48	8.90	9.05	5.59	9.19	9.51	12.57	11.53	10.91	5.88	5.15	5.18	9.25	9.91	16.17	13.18
4500.	17.81	7.92	7.67	4.80	8.26	8.97	14.13	12.44	11.61	6.12	5.37	5.33	9.73	10.91	16.53	13.80
5500.	17.99	7.50	6.93	4.50	7.91	8.95	15.82	13.60	12.62	6.63	5.79	5.66	10.53	12.20	17.40	14.80
6500.	18.02	7.18	6.41	4.32	7.72	8.94	16.94	14.35	13.26	6.96	6.05	5.86	11.08	13.17	17.99	15.42
7500.	17.77	6.88	6.01	4.19	7.56	8.86	17.48	14.66	13.53	7.09	6.14	5.91	11.36	13.76	18.21	15.62
8500.	17.32	6.58	5.67	4.08	7.42	8.72	17.58	14.64	13.50	7.07	6.10	5.85	11.40	14.05	18.14	15.49
9500.	16.72	6.27	5.37	3.98	7.28	8.52	17.38	14.40	13.27	6.96	5.98	5.71	11.29	14.12	17.85	15.16
10500.	16.19	6.04	5.18	3.92	7.19	8.36	17.09	14.10	12.99	6.81	5.83	5.57	11.13	14.10	17.56	14.78
11500.	15.61	5.81	5.00	3.85	7.09	8.18	16.68	13.72	12.64	6.62	5.65	5.40	10.91	13.98	17.17	14.33

RN-222 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 2

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	8.68	11.67	10.69	13.50	0.25	9.62	8.38	12.47	8.43	8.38	12.40	0.13	10.66	0.23	11.71	10.73
1500.	134.25	72.17	73.55	57.47	66.84	71.42	67.13	71.12	71.89	50.32	42.30	34.54	65.04	60.65	95.09	87.83
2500.	143.61	73.37	76.26	49.61	74.08	75.19	83.67	80.97	78.54	45.54	39.24	38.25	68.02	69.12	116.38	95.99
3500.	125.32	60.38	61.40	38.01	62.34	64.54	85.15	78.13	73.99	39.91	34.94	35.14	62.77	67.18	109.60	89.37
4500.	120.96	53.89	52.22	32.76	56.20	60.59	95.76	84.37	78.80	41.58	36.45	36.19	66.04	74.02	112.27	93.60
5500.	122.26	51.09	47.28	30.74	53.92	60.88	107.25	92.27	85.62	45.02	39.30	38.41	71.49	82.77	118.24	100.43
6500.	122.49	48.95	43.79	29.53	52.60	60.84	114.87	97.38	90.03	47.28	41.12	39.78	75.30	89.32	122.28	104.67
7500.	120.93	46.94	41.07	28.67	51.61	60.36	118.58	99.56	91.88	48.23	41.78	40.17	77.21	93.40	123.87	106.09
8500.	117.95	44.92	38.81	27.96	50.67	59.44	119.37	99.52	91.78	48.18	41.57	39.81	77.62	95.49	123.49	105.36
9500.	114.06	42.91	36.83	27.30	49.70	58.17	118.17	98.01	90.36	47.46	40.79	38.97	76.98	96.12	121.72	103.23
10500.	110.61	41.39	35.55	26.88	49.19	57.15	116.35	96.13	88.64	46.53	39.85	38.08	76.06	96.18	119.92	100.87
11500.	106.90	39.91	34.39	26.46	48.58	55.97	113.75	93.70	86.41	45.34	38.71	37.02	74.69	95.50	117.54	98.01

PO-218 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 2

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	5.16	6.69	5.78	8.49	0.12	6.22	5.02	7.48	5.05	5.02	7.43	0.06	5.77	0.10	6.71	5.80
1500.	108.75	58.86	59.44	49.58	54.93	59.69	54.25	58.40	59.78	43.31	35.55	27.68	54.81	49.82	79.24	71.18
2500.	128.09	65.91	69.61	46.68	68.94	68.67	74.91	72.76	71.48	42.67	36.56	35.07	63.70	64.24	107.97	86.86
3500.	117.27	56.97	58.92	36.94	60.32	61.26	78.91	72.90	69.93	38.40	33.65	33.73	60.76	64.84	105.41	84.24
4500.	116.02	52.09	51.16	32.27	55.12	58.91	90.43	80.35	75.98	40.57	35.65	35.41	64.84	72.60	109.59	90.00
5500.	119.18	50.09	46.79	30.50	53.29	59.53	103.20	89.41	83.78	44.39	38.84	37.98	70.82	81.97	116.60	98.02
6500.	120.66	48.40	43.56	29.42	52.26	60.02	112.12	95.54	88.95	46.93	40.87	39.56	74.96	88.92	121.37	103.20
7500.	119.91	46.64	40.97	28.62	51.43	59.90	116.87	98.46	91.29	48.06	41.67	40.07	77.06	93.23	123.42	105.26
8500.	117.41	44.77	38.77	27.94	50.59	59.19	118.36	98.91	91.48	48.11	41.53	39.78	77.57	95.44	123.28	104.93
9500.	113.79	42.84	36.82	27.30	49.67	58.04	117.61	97.68	90.22	47.43	40.78	38.96	76.98	96.13	121.65	103.02
10500.	110.49	41.36	35.55	26.89	49.18	57.10	116.05	95.97	88.59	46.53	39.86	38.09	76.09	96.21	119.92	100.78
11500.	106.86	39.91	34.40	26.47	48.59	55.96	113.60	93.63	86.41	45.35	38.72	37.03	74.72	95.55	117.57	97.98

PB-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 2

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.29	0.36	0.28	0.53	0.00	0.41	0.29	0.43	0.29	0.29	0.43	0.00	0.28	0.00	0.36	0.28
1500.	12.12	6.69	6.58	6.74	6.38	7.30	6.00	6.77	7.29	5.84	4.43	2.99	6.89	5.78	9.61	7.94
2500.	19.78	10.49	11.90	9.39	13.01	11.77	11.75	11.59	12.05	8.37	6.95	6.13	12.46	12.04	20.04	14.27
3500.	22.84	11.66	13.59	9.54	14.93	13.04	14.56	13.96	14.47	9.05	7.99	7.80	15.09	15.69	24.75	17.14
4500.	26.66	12.77	14.46	9.84	15.80	14.35	18.61	17.51	18.23	10.92	9.87	9.85	18.85	20.82	29.65	21.09
5500.	31.76	14.29	15.47	10.67	17.18	16.43	24.33	22.43	23.32	13.74	12.51	12.36	23.91	27.50	36.17	26.48
6500.	36.79	15.73	16.36	11.66	18.93	18.74	30.31	27.50	28.51	16.59	14.97	14.73	28.85	34.26	42.85	31.92
7500.	41.33	16.93	17.21	12.50	20.58	21.05	35.93	32.12	33.11	19.20	17.33	16.78	33.26	40.54	49.09	36.81
8500.	45.08	18.03	17.83	13.23	22.34	23.03	40.78	36.17	36.94	21.43	19.22	18.76	36.99	46.10	54.01	41.02
9500.	47.97	18.85	18.35	14.22	23.79	24.64	44.91	39.28	39.92	22.64	20.40	19.46	40.08	51.13	58.43	44.23
10500.	50.60	19.56	18.51	15.54	24.76	26.62	48.39	42.14	42.60	24.23	22.02	21.12	44.43	54.25	62.44	46.92
11500.	52.55	20.78	19.25	15.34	26.50	28.27	51.09	44.19	44.99	24.84	21.44	20.59	43.80	62.62	65.05	48.61

BI-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 2

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.01	0.02	0.01	0.03	0.00	0.02	0.01	0.02	0.01	0.01	0.02	0.00	0.01	0.00	0.02	0.01
1500.	1.11	0.62	0.60	0.74	0.61	0.73	0.55	0.64	0.71	0.64	0.45	0.27	0.71	0.55	0.95	0.73
2500.	2.45	1.34	1.63	1.49	1.95	1.61	1.48	1.48	1.62	1.30	1.05	0.85	1.93	1.79	2.95	1.88
3500.	3.52	1.89	2.46	1.92	2.89	2.19	2.13	2.12	2.36	1.67	1.49	1.41	2.93	2.97	4.56	2.76
4500.	4.81	2.45	3.18	2.33	3.52	2.74	3.03	3.00	3.43	2.29	2.13	2.13	4.26	4.64	6.25	3.88
5500.	6.60	3.17	3.97	2.90	4.30	3.53	4.50	4.40	5.05	3.30	3.13	3.12	6.26	7.16	8.71	5.58
6500.	8.71	3.97	4.77	3.59	5.32	4.54	6.39	6.16	7.09	4.55	4.25	4.26	8.62	10.25	11.74	7.67
7500.	11.05	4.77	5.63	4.26	6.40	5.74	8.58	8.13	9.32	5.96	5.61	5.47	11.20	13.75	15.18	9.99
8500.	13.44	5.64	6.42	4.91	7.70	6.96	10.90	10.27	11.60	7.46	6.96	6.94	13.84	17.50	18.47	12.46
9500.	15.75	6.48	7.21	5.86	8.94	8.15	13.32	12.28	13.79	8.49	8.05	7.66	16.51	21.58	22.04	14.80
10500.	18.13	7.26	7.63	7.20	9.83	9.73	15.71	14.45	16.09	9.98	9.70	9.34	20.84	24.45	25.73	17.11
11500.	20.33	8.56	8.60	7.13	11.50	11.27	17.96	16.35	18.54	10.83	9.47	9.13	20.64	33.67	28.69	18.99

PO-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 2

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.01	0.02	0.01	0.03	0.00	0.02	0.01	0.02	0.01	0.01	0.02	0.00	0.01	0.00	0.02	0.01
1500.	1.11	0.62	0.60	0.74	0.61	0.73	0.55	0.64	0.71	0.64	0.45	0.27	0.71	0.55	0.95	0.73
2500.	2.45	1.34	1.63	1.49	1.95	1.61	1.48	1.48	1.62	1.30	1.05	0.85	1.93	1.79	2.95	1.88
3500.	3.52	1.89	2.46	1.92	2.89	2.19	2.13	2.12	2.36	1.67	1.49	1.41	2.53	2.97	4.56	2.76
4500.	4.81	2.45	3.18	2.33	3.52	2.74	3.03	3.00	3.43	2.29	2.13	2.13	4.26	4.64	6.25	3.88
5500.	6.60	3.17	3.97	2.90	4.30	3.53	4.50	4.40	5.05	3.30	3.13	3.12	6.26	7.16	8.71	5.58
6500.	8.71	3.97	4.77	3.59	5.32	4.54	6.39	6.16	7.09	4.55	4.25	4.26	8.62	10.25	11.74	7.67
7500.	11.05	4.77	5.63	4.26	6.40	5.74	8.58	8.13	9.32	5.96	5.61	5.47	11.20	13.75	15.18	9.99
8500.	13.44	5.64	6.42	4.91	7.70	6.96	10.90	10.27	11.60	7.46	6.96	6.94	13.84	17.50	18.47	12.46
9500.	15.75	6.48	7.21	5.86	8.94	8.15	13.32	12.28	13.79	8.49	8.05	7.66	16.51	21.58	22.04	14.80
10500.	18.13	7.26	7.63	7.20	9.83	9.73	15.71	14.45	16.09	9.98	9.70	9.34	20.84	24.45	25.73	17.11
11500.	20.33	8.56	8.60	7.13	11.50	11.27	17.96	16.35	18.54	10.83	9.47	9.13	20.64	33.67	28.69	18.99

PB-210 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 2

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	2.51	3.38	3.09	3.91	0.07	2.78	2.43	3.61	2.44	2.43	3.59	0.04	3.08	0.07	3.39	3.11
1500.	38.86	20.88	21.28	16.63	19.35	20.67	19.43	20.58	20.81	14.56	12.24	10.00	18.82	17.56	27.52	25.42
2500.	41.44	21.17	22.01	14.29	21.38	21.69	24.16	23.36	22.66	13.13	11.31	11.04	19.62	19.95	33.60	27.70
3500.	36.06	17.36	17.66	10.91	17.93	18.56	24.53	22.49	21.30	11.47	10.05	10.12	18.06	19.34	31.55	25.73
4500.	34.76	15.46	14.98	9.38	16.12	17.51	27.57	24.27	22.66	11.94	10.47	10.41	18.98	21.30	32.27	26.92
5500.	35.11	14.64	13.53	8.79	15.44	17.46	30.88	26.55	24.62	12.93	11.29	11.04	20.55	23.82	33.97	28.88
6500.	35.16	14.02	12.51	8.43	15.06	17.44	33.06	28.01	25.88	13.58	11.81	11.43	21.63	25.69	35.11	30.09
7500.	34.69	13.43	11.73	8.18	14.76	17.30	34.11	28.61	26.40	13.84	11.99	11.53	22.16	26.85	35.55	30.47
8500.	33.80	12.84	11.07	7.97	14.49	17.02	34.31	28.58	26.34	13.81	11.91	11.41	22.25	27.42	35.40	30.23
9500.	32.64	12.24	10.49	7.77	14.20	16.64	33.92	28.11	25.89	13.58	11.67	11.15	22.03	27.56	34.84	29.58
10500.	31.59	11.79	10.11	7.64	14.03	16.32	33.35	27.52	25.35	13.28	11.37	10.88	21.73	27.53	34.27	28.85
11500.	30.47	11.35	9.76	7.51	13.84	15.96	32.55	26.77	24.67	12.92	11.02	10.55	21.29	27.28	33.52	27.97

PO-210 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 2

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	1.58	2.12	1.94	2.45	0.05	1.75	1.52	2.27	1.53	1.52	2.25	0.02	1.94	0.04	2.13	1.95
1500.	24.40	13.12	13.37	10.44	12.15	12.98	12.20	12.93	13.07	9.15	7.69	6.28	11.82	11.03	17.29	15.96
2500.	26.03	13.29	13.82	8.98	13.43	13.62	15.17	14.67	14.23	8.24	7.11	6.94	12.32	12.53	21.10	17.40
3500.	22.65	10.91	11.09	6.85	11.26	11.66	15.41	14.13	13.38	7.20	6.31	6.35	11.34	12.15	19.81	16.16
4500.	21.83	9.71	9.41	5.89	10.13	11.00	17.31	15.25	14.23	7.50	6.58	6.54	11.92	13.38	20.27	16.91
5500.	22.05	9.20	8.50	5.52	9.70	10.97	19.39	16.67	15.46	8.12	7.09	6.94	12.90	14.96	21.33	18.14
6500.	22.08	8.80	7.86	5.29	9.46	10.95	20.77	17.59	16.26	8.53	7.42	7.18	13.59	16.14	22.05	18.90
7500.	21.79	8.43	7.36	5.14	9.27	10.86	21.42	17.97	16.58	8.69	7.53	7.24	13.92	16.86	22.32	19.14
8500.	21.23	8.06	6.95	5.00	9.10	10.69	21.55	17.95	16.54	8.67	7.48	7.17	13.98	17.22	22.23	18.99
9500.	20.50	7.69	6.59	4.88	8.92	10.45	21.31	17.65	16.26	8.53	7.33	7.00	13.84	17.31	21.88	18.58
10500.	19.84	7.41	6.35	4.80	8.81	10.25	20.94	17.28	15.92	8.34	7.14	6.83	13.65	17.29	21.52	18.12
11500.	19.14	7.13	6.13	4.72	8.69	10.02	20.44	16.81	15.49	8.11	6.92	6.62	13.37	17.13	21.05	17.57

U-238 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 3

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.61	0.84	0.77	0.98	0.0	0.69	0.60	0.91	0.61	0.60	0.91	0.0	0.77	0.0	0.84	0.77
1500.	16.25	9.23	9.24	8.05	7.73	8.91	7.61	8.67	8.80	6.87	5.92	4.03	8.27	6.99	10.81	10.75
2500.	22.14	11.65	12.03	8.53	11.27	11.72	12.01	12.12	11.95	7.56	6.48	5.78	10.57	10.26	16.96	14.62
3500.	20.14	10.32	10.75	6.88	10.41	10.58	11.89	11.46	11.04	6.29	5.49	5.35	9.55	9.68	16.57	13.51
4500.	17.73	8.81	9.08	5.65	8.99	9.22	11.36	10.63	10.11	5.54	4.87	4.85	8.65	9.03	15.17	12.30
5500.	16.60	7.87	7.90	4.96	8.07	8.51	11.73	10.67	10.07	5.45	4.78	4.73	8.53	9.19	14.68	12.11
6500.	16.13	7.27	7.05	4.51	7.47	8.15	12.54	11.13	10.43	5.60	4.90	4.79	8.76	9.72	14.75	12.40
7500.	15.97	6.87	6.44	4.21	7.10	7.97	13.40	11.68	10.88	5.81	5.08	4.92	9.10	10.33	15.03	12.83
8500.	15.87	6.57	5.99	4.00	6.84	7.86	14.10	12.13	11.26	5.99	5.23	5.02	9.40	10.86	15.30	13.19
9500.	15.73	6.32	5.63	3.84	6.64	7.76	14.58	12.42	11.50	6.11	5.32	5.08	9.59	11.25	15.46	13.40
10500.	15.70	6.19	5.43	3.75	6.58	7.75	14.97	12.67	11.71	6.20	5.39	5.14	9.78	11.60	15.68	13.59
11500.	15.59	6.06	5.27	3.68	6.53	7.71	15.19	12.78	11.80	6.23	5.40	5.16	9.87	11.83	15.77	13.65

U-234 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 3

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.60	0.84	0.77	0.97	0.0	0.69	0.60	0.90	0.60	0.60	0.90	0.0	0.76	0.0	0.84	0.77
1500.	16.13	9.16	9.17	8.03	7.67	8.84	7.55	8.60	8.73	6.81	5.87	4.00	8.21	6.94	10.72	10.67
2500.	21.96	11.56	11.94	8.46	11.18	11.63	11.92	12.03	11.86	7.50	6.43	5.73	10.49	10.18	16.83	14.51
3500.	19.98	10.24	10.67	6.83	10.33	10.50	11.80	11.37	10.95	6.24	5.45	5.31	9.47	9.60	16.44	13.40
4500.	17.59	8.74	9.00	5.61	8.92	9.15	11.27	10.55	10.04	5.50	4.83	4.81	8.58	8.96	15.05	12.20
5500.	16.47	7.81	7.83	4.92	8.01	8.44	11.64	10.59	9.99	5.40	4.74	4.69	8.46	9.12	14.56	12.02
6500.	16.01	7.21	6.99	4.48	7.42	8.08	12.44	11.04	10.34	5.55	4.86	4.75	8.70	9.64	14.63	12.31
7500.	15.85	6.81	6.39	4.18	7.04	7.91	13.29	11.59	10.79	5.77	5.04	4.88	9.03	10.25	14.91	12.73
8500.	15.75	6.52	5.95	3.97	6.79	7.80	13.99	12.03	11.17	5.95	5.19	4.98	9.32	10.77	15.18	13.08
9500.	15.61	6.27	5.59	3.81	6.59	7.70	14.47	12.33	11.41	6.06	5.27	5.04	9.52	11.16	15.34	13.29
10500.	15.58	6.14	5.39	3.72	6.53	7.69	14.86	12.57	11.62	6.15	5.34	5.10	9.70	11.51	15.55	13.49
11500.	15.47	6.01	5.23	3.65	6.47	7.65	15.07	12.68	11.71	6.18	5.36	5.12	9.79	11.74	15.65	13.55

RN-222 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 3

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	4.05	5.65	5.16	6.57	3.0	4.63	4.05	6.06	4.05	4.05	6.06	3.0	5.16	0.0	5.65	5.16
1500.	108.71	61.73	61.79	54.14	51.69	59.59	50.89	57.97	58.88	45.93	39.59	26.97	55.33	46.75	72.30	71.94
2500.	148.38	78.12	80.64	57.19	75.52	78.55	80.50	81.26	80.09	50.70	43.43	38.69	70.88	68.76	113.65	98.01
3500.	135.26	69.36	72.24	46.33	69.89	71.09	79.84	77.00	74.15	42.30	36.93	35.94	64.17	64.97	111.27	90.72
4500.	119.39	59.33	61.14	38.17	60.58	62.15	76.43	71.58	68.11	37.37	32.83	32.62	58.25	60.77	102.12	82.80
5500.	111.97	53.15	53.34	33.60	54.50	57.45	78.98	71.93	67.89	36.79	32.28	31.85	57.54	61.53	99.00	81.64
6500.	108.94	49.16	47.72	30.63	50.59	55.08	84.44	75.05	70.32	37.83	33.12	32.32	59.17	65.52	99.57	83.66
7500.	107.90	46.51	43.70	28.65	48.09	53.93	90.23	78.73	73.38	39.27	34.31	33.16	61.44	69.61	101.50	86.54
8500.	107.27	44.54	40.69	27.25	46.37	53.22	94.95	81.76	75.92	40.49	35.31	33.88	63.43	73.16	103.32	88.93
9500.	106.35	42.89	38.31	26.18	45.06	52.57	98.20	83.76	77.58	41.27	35.92	34.29	64.78	75.82	104.44	90.39
10500.	106.21	41.99	36.98	25.61	44.64	52.50	100.89	85.47	79.03	41.91	36.41	34.73	66.05	78.23	105.94	91.74
11500.	105.56	41.17	35.92	25.15	44.32	52.31	102.39	86.31	79.71	42.15	36.57	34.88	66.75	79.86	106.68	92.24

PD-218 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 3

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	2.44	3.25	2.80	4.15	0.0	3.02	2.43	3.64	2.43	2.43	3.64	0.0	2.80	0.0	3.25	2.80
1500.	92.06	52.49	51.37	47.78	43.12	51.83	43.20	49.97	50.96	40.43	34.10	21.97	47.58	38.99	62.12	60.35
2500.	135.00	71.49	74.38	54.40	70.74	72.94	73.52	74.55	74.19	48.15	40.93	35.76	67.00	64.40	106.52	90.11
3500.	128.52	66.17	69.72	45.33	68.18	68.49	76.20	73.55	71.32	41.30	36.01	34.80	62.75	63.35	108.33	87.09
4500.	116.10	57.91	60.19	37.80	59.92	60.92	74.16	69.63	66.65	36.88	32.43	32.15	57.65	60.07	100.79	80.94
5500.	110.12	52.45	52.96	33.45	54.18	56.73	77.17	70.56	66.97	36.49	32.05	31.62	57.22	61.54	98.22	80.45
6500.	107.81	48.78	47.56	30.56	50.40	54.62	83.01	74.05	69.72	37.64	32.98	32.19	58.99	65.31	99.09	82.86
7500.	107.22	46.30	43.63	28.62	47.99	53.64	89.18	78.05	73.01	39.17	34.24	33.10	61.36	69.51	101.23	86.02
8500.	106.88	44.43	40.66	27.24	46.32	53.04	94.25	81.33	75.71	40.44	35.28	33.86	63.40	73.13	103.19	88.63
9500.	106.14	42.83	38.30	26.18	45.04	52.48	97.77	83.51	77.47	41.26	35.92	34.29	64.79	75.83	104.40	90.23
10500.	106.11	41.97	36.99	25.61	44.64	52.46	100.64	85.34	78.99	41.91	36.42	34.74	66.08	78.26	105.94	91.67
11500.	105.53	41.16	35.93	25.16	44.33	52.29	102.26	86.25	79.71	42.17	36.58	34.89	66.78	79.89	106.71	92.22

PB-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 3

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.14	0.17	0.14	0.26	0.0	0.20	0.14	0.21	0.14	0.14	0.21	0.0	0.14	0.0	0.17	0.14
1500.	11.75	6.79	6.18	7.07	5.25	7.26	5.56	6.78	7.01	5.92	4.61	2.49	6.40	4.74	8.33	7.47
2500.	22.73	12.37	13.39	11.75	13.86	13.60	12.60	13.06	13.66	10.29	8.32	6.51	13.88	12.61	20.94	15.96
3500.	27.56	14.60	16.86	12.60	18.32	16.32	16.86	16.37	16.76	11.20	9.63	8.67	17.33	16.93	28.48	20.15
4500.	30.16	15.65	18.18	12.67	19.61	17.33	18.84	18.15	18.56	11.59	10.36	9.89	19.09	19.42	31.72	22.26
5500.	32.77	16.46	18.85	12.90	19.96	18.01	21.11	20.27	20.89	12.66	11.41	11.23	21.28	22.40	34.31	24.67
6500.	35.64	17.10	19.14	12.94	19.95	18.86	24.56	23.18	23.98	14.24	12.82	12.61	24.06	26.45	37.73	27.86
7500.	39.02	17.82	19.24	13.15	20.55	20.06	28.77	26.78	27.60	16.36	14.69	14.40	27.63	31.00	42.04	31.57
8500.	42.51	18.63	19.21	13.41	21.22	21.32	33.33	30.53	31.28	18.30	16.49	16.24	30.81	35.80	46.62	35.63
9500.	45.73	19.15	19.12	13.63	21.96	22.98	37.81	34.15	34.59	20.65	18.70	17.85	34.87	40.59	51.28	39.36
10500.	49.18	20.38	20.56	13.33	23.24	24.72	42.18	37.83	38.23	21.82	20.28	19.42	40.04	45.46	55.16	43.19
11500.	52.51	20.60	20.03	14.72	24.31	25.69	46.16	40.91	41.50	25.98	20.35	19.50	40.32	46.23	59.53	46.32

BI-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 3

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.01	0.01	0.01	0.01	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.0	0.01	0.0	0.01	0.01
1500.	1.22	0.71	0.61	0.84	0.52	0.82	0.58	0.74	0.78	0.70	0.51	0.23	0.70	0.47	0.91	0.75
2500.	3.06	1.71	1.92	2.00	2.15	2.01	1.73	1.82	2.00	1.73	1.34	0.94	2.27	1.95	3.26	2.25
3500.	4.65	2.53	3.19	2.73	3.84	3.05	2.93	2.87	3.09	2.37	2.01	1.69	3.73	3.53	5.84	3.66
4500.	6.11	3.30	4.27	3.30	4.98	3.84	3.74	3.69	4.03	2.83	2.57	2.36	4.90	4.87	7.75	4.77
5500.	7.58	4.01	5.21	3.86	5.71	4.44	4.50	4.53	5.06	3.41	3.15	3.09	6.14	6.33	9.30	5.88
6500.	9.14	4.65	5.99	4.27	6.14	5.06	5.65	5.64	6.40	4.18	3.87	3.84	7.64	8.33	11.16	7.27
7500.	11.02	5.33	6.62	4.73	6.86	5.83	7.20	7.13	8.10	5.32	4.92	4.89	9.73	10.80	13.59	8.99
8500.	13.14	6.08	7.12	5.19	7.61	6.66	9.15	8.90	10.06	6.48	6.04	6.11	11.77	13.79	16.47	11.14
9500.	15.36	6.69	7.52	5.62	8.42	7.85	11.36	10.87	12.07	8.15	7.71	7.36	14.91	17.25	19.82	13.39
10500.	17.85	7.78	9.12	5.49	9.58	9.13	13.77	13.10	14.54	8.99	9.01	8.67	19.61	21.20	22.73	15.96
11500.	20.58	8.13	8.91	6.92	10.62	9.93	16.29	15.23	17.10	12.97	9.03	8.70	19.66	21.47	26.50	18.35

PO-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 3

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.01	0.01	0.01	0.01	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.0	0.01	0.0	0.01	0.01
1500.	1.22	0.71	0.61	0.84	0.52	0.82	0.58	0.74	0.78	0.70	0.51	0.23	0.70	0.47	0.91	0.75
2500.	3.06	1.71	1.92	2.00	2.15	2.01	1.73	1.82	2.00	1.73	1.34	0.94	2.27	1.95	3.26	2.25
3500.	4.65	2.53	3.19	2.73	3.84	3.05	2.93	2.87	3.09	2.37	2.01	1.69	3.73	3.53	5.84	3.66
4500.	6.11	3.30	4.27	3.30	4.98	3.84	3.74	3.69	4.03	2.83	2.57	2.36	4.90	4.87	7.75	4.77
5500.	7.58	4.01	5.21	3.86	5.71	4.44	4.50	4.53	5.06	3.41	3.15	3.09	6.14	6.33	9.30	5.88
6500.	9.14	4.65	5.99	4.27	6.14	5.06	5.65	5.64	6.40	4.18	3.87	3.84	7.64	8.33	11.16	7.27
7500.	11.02	5.33	6.62	4.73	6.86	5.83	7.20	7.13	8.10	5.32	4.92	4.89	9.73	10.80	13.59	8.99
8500.	13.14	6.08	7.12	5.19	7.61	6.66	9.15	8.90	10.06	6.48	6.04	6.11	11.77	13.79	16.47	11.14
9500.	15.36	6.69	7.52	5.62	8.42	7.85	11.36	10.87	12.07	8.15	7.71	7.36	14.91	17.25	19.82	13.39
10500.	17.85	7.78	9.12	5.49	9.58	9.13	13.77	13.10	14.54	8.99	9.01	8.67	19.61	21.20	22.73	15.96
11500.	20.58	8.13	8.91	6.92	10.62	9.93	16.29	15.23	17.10	12.97	9.03	8.70	19.66	21.47	26.50	18.35

PB-210 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 3

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	1.17	1.63	1.49	1.90	0.0	1.34	1.17	1.75	1.17	1.17	1.75	0.0	1.49	0.0	1.63	1.49
1500.	31.47	17.87	17.89	15.67	14.96	17.25	14.73	16.78	17.05	13.30	11.46	7.81	16.02	13.53	20.93	20.82
2500.	42.86	22.56	23.30	16.51	21.83	22.69	23.26	23.47	23.14	14.64	12.54	11.18	20.48	19.87	32.85	28.32
3500.	38.99	19.98	20.82	13.33	20.15	20.48	23.03	22.20	21.37	12.17	10.63	10.36	18.49	18.74	32.09	26.15
4500.	34.33	17.05	17.57	10.94	17.41	17.86	22.00	20.59	19.58	10.73	9.43	9.38	16.74	17.48	29.37	23.82
5500.	32.14	15.24	15.29	9.60	15.62	16.47	22.71	20.66	19.49	10.54	9.26	9.15	16.51	17.79	28.42	23.45
6500.	31.24	14.07	13.65	8.74	14.47	15.77	24.27	21.55	20.19	10.84	9.49	9.28	16.97	18.82	28.56	24.02
7500.	30.93	13.30	12.48	8.16	13.74	15.43	25.94	22.61	21.06	11.25	9.83	9.52	17.62	20.00	29.10	24.84
8500.	30.74	12.72	11.60	7.75	13.24	15.22	27.30	23.48	21.79	11.60	10.12	9.72	18.19	21.02	29.62	25.53
9500.	30.46	12.24	10.91	7.44	12.86	15.03	28.23	24.05	22.27	11.82	10.29	9.84	18.58	21.78	29.94	25.94
10500.	30.40	11.98	10.52	7.27	12.74	15.00	28.99	24.53	22.67	12.00	10.43	9.96	18.93	22.46	30.35	26.32
11500.	30.19	11.73	10.21	7.13	12.63	14.94	29.40	24.75	22.85	12.06	10.46	9.99	19.11	22.91	30.54	26.44

PO-210 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - UNIT 3

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.74	1.03	0.94	1.19	0.0	0.84	0.74	1.10	0.74	0.74	1.10	0.0	0.94	0.0	1.03	0.94
1500.	19.76	11.22	11.23	9.84	9.40	10.83	9.25	10.54	10.70	8.35	7.20	4.90	10.06	8.50	13.14	13.08
2500.	26.92	14.17	14.63	10.37	13.71	14.25	14.61	14.74	14.53	9.19	7.87	7.02	12.86	12.48	20.63	17.78
3500.	24.48	12.55	13.08	8.37	12.66	12.86	14.46	13.94	13.42	7.64	6.68	6.51	11.61	11.77	20.15	16.42
4500.	21.56	10.71	11.04	6.87	10.94	11.22	13.81	12.93	12.30	6.74	5.92	5.89	10.51	10.98	18.44	14.96
5500.	20.18	9.57	9.60	6.03	9.81	10.34	14.26	12.98	12.24	6.62	5.81	5.75	10.37	11.17	17.84	14.73
6500.	19.62	8.84	8.57	5.49	9.09	9.90	15.24	13.53	12.68	6.81	5.96	5.83	10.66	11.82	17.93	15.08
7500.	19.42	8.35	7.83	5.12	8.63	9.69	16.29	14.20	13.23	7.07	6.18	5.98	11.07	12.56	18.28	15.60
8500.	19.30	7.99	7.29	4.87	8.32	9.56	17.14	14.75	13.69	7.29	6.36	6.11	11.42	13.20	18.60	16.03
9500.	19.13	7.69	6.85	4.67	8.08	9.44	17.73	15.10	13.98	7.42	6.46	6.18	11.67	13.68	18.80	16.29
10500.	19.09	7.52	6.61	4.56	8.00	9.42	18.21	15.41	14.24	7.53	6.55	6.25	11.89	14.10	19.06	16.52
11500.	18.96	7.37	6.41	4.48	7.93	9.38	18.46	15.54	14.35	7.57	6.57	6.27	12.00	14.38	19.18	16.60

U-238 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - TOTAL

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	6.27	6.23	5.85	6.82	1.42	5.36	4.57	6.42	4.87	4.56	5.98	0.75	5.66	1.28	6.42	6.10
1500.	58.96	31.51	32.13	24.57	29.36	31.36	30.65	31.93	31.92	21.71	18.44	15.25	28.71	27.03	43.02	38.97
2500.	65.34	32.29	32.86	21.83	32.55	33.90	41.50	39.19	37.72	21.79	18.78	17.99	32.50	33.88	54.37	45.65
3500.	60.99	28.16	27.89	17.82	29.47	31.30	45.49	40.74	38.36	20.66	18.01	17.81	32.57	36.15	55.33	45.74
4500.	57.60	25.14	24.11	15.70	27.13	29.51	48.08	41.79	38.97	20.59	17.92	17.67	33.07	38.39	55.31	45.82
5500.	55.61	23.22	21.68	14.67	25.80	28.59	50.04	42.73	39.70	20.91	18.09	17.67	33.82	40.49	55.48	46.16
6500.	53.69	21.71	19.81	13.91	24.76	27.77	51.02	43.03	39.88	20.98	18.07	17.52	34.13	41.82	55.22	45.99
7500.	51.74	20.43	18.34	13.29	23.86	26.95	51.13	42.76	39.55	20.81	17.85	17.22	34.03	42.41	54.49	45.34
8500.	49.68	19.27	17.12	12.75	23.02	26.09	50.54	42.00	38.82	20.41	17.46	16.78	33.55	42.40	53.34	44.28
9500.	47.57	18.21	16.06	12.25	22.21	25.18	49.46	40.91	37.78	19.87	16.95	16.23	32.81	41.93	51.89	42.93
10500.	45.84	17.44	15.33	11.87	21.65	24.47	48.32	39.84	36.78	19.33	16.43	15.75	32.07	41.36	50.61	41.66
11500.	44.10	16.71	14.69	11.51	21.08	23.73	47.00	38.63	35.66	18.72	15.88	15.23	31.21	40.57	49.19	40.30

U-234 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - TOTAL

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	6.21	6.20	5.80	6.76	1.41	5.33	4.54	6.37	4.83	4.53	5.93	0.74	5.62	1.27	6.38	6.07
1500.	58.52	31.26	31.89	24.38	29.14	31.13	30.41	31.68	31.67	21.54	18.29	15.14	28.49	26.83	42.68	38.67
2500.	64.82	32.05	32.61	21.66	32.31	33.64	41.18	38.89	37.44	21.62	18.65	17.86	32.25	33.61	53.96	45.31
3500.	60.51	27.95	27.68	17.69	29.25	31.06	45.14	40.43	38.06	20.51	17.88	17.67	32.31	35.87	54.91	45.38
4500.	57.16	24.94	23.92	15.59	26.92	29.28	47.71	41.47	38.68	20.44	17.78	17.52	32.83	38.09	54.88	45.48
5500.	55.17	23.04	21.50	14.56	25.60	28.37	49.66	42.40	39.39	20.74	17.95	17.54	33.56	40.18	55.05	45.81
6500.	53.28	21.54	19.65	13.81	24.57	27.55	50.62	42.70	39.56	20.82	17.93	17.39	33.88	41.50	54.79	45.64
7500.	51.33	20.26	18.20	13.20	23.67	26.74	50.73	42.43	39.25	20.65	17.71	17.09	33.77	42.09	54.06	44.99
8500.	49.30	19.12	16.99	12.65	22.85	25.89	50.15	41.67	38.53	20.26	17.32	16.64	33.29	42.07	52.93	43.93
9500.	47.20	18.07	15.93	12.16	22.05	24.95	49.08	40.60	37.50	19.72	16.81	16.10	32.56	41.61	51.48	42.59
10500.	45.48	17.30	15.22	11.78	21.48	24.28	47.96	39.53	36.50	19.18	16.31	15.62	31.82	41.04	50.21	41.35
11500.	43.76	16.58	14.58	11.42	20.90	23.55	46.64	38.33	35.38	18.58	15.76	15.11	30.98	40.27	48.81	39.99

RN-222 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - TOTAL

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	41.89	41.79	39.12	45.64	9.52	35.87	30.64	42.97	32.55	30.54	39.99	4.95	37.94	8.60	43.02	40.89
1500.	394.58	210.85	215.04	164.44	196.47	209.93	205.13	213.65	213.59	145.28	123.41	102.10	192.13	180.81	287.89	260.81
2500.	438.49	216.84	220.57	146.73	218.51	227.61	278.36	262.97	253.17	146.31	126.13	120.70	218.21	227.27	364.85	306.32
3500.	410.69	189.53	187.75	120.18	198.30	210.59	305.58	273.83	257.86	139.07	121.19	119.70	219.04	242.89	372.04	307.46
4500.	388.06	169.49	162.71	106.16	182.97	198.96	323.33	281.24	262.39	138.77	120.72	118.91	222.78	258.30	372.56	308.49
5500.	375.11	156.94	146.59	99.35	174.30	192.99	336.89	287.88	267.55	141.09	122.09	119.16	228.12	272.81	374.31	311.14
6500.	362.76	146.92	134.29	94.39	167.54	187.73	343.87	290.32	269.16	141.82	122.17	118.37	230.64	282.16	373.07	310.44
7500.	350.05	138.44	124.54	90.38	161.73	182.45	345.01	288.81	267.39	140.85	120.87	116.50	230.27	286.59	368.67	306.46
8500.	336.73	130.89	116.46	86.86	156.32	176.91	341.56	284.14	262.85	138.47	118.44	113.73	227.51	287.03	361.51	299.74
9500.	322.98	123.99	109.53	83.63	151.12	171.10	334.84	277.25	256.35	135.07	115.19	110.32	222.97	284.51	352.33	291.13
10500.	311.80	118.90	104.82	81.24	147.53	166.55	327.79	270.50	250.06	131.66	112.00	107.26	218.48	281.29	344.35	283.15
11500.	300.67	114.21	100.71	78.99	144.01	161.92	319.39	262.89	243.00	127.85	108.53	103.58	213.25	276.65	335.55	274.47

PO-218 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - TOTAL

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	22.90	23.05	20.27	27.67	4.36	21.87	17.48	24.88	18.58	17.62	23.23	2.19	20.05	3.93	23.76	21.25
1500.	315.25	170.10	172.66	141.14	160.55	173.46	162.91	172.71	175.22	124.02	103.11	81.25	160.76	147.45	237.59	208.90
2500.	386.95	193.76	200.80	137.59	201.76	205.49	241.74	231.10	226.61	135.21	116.15	109.63	202.08	208.65	333.88	272.43
3500.	380.82	177.99	179.74	116.47	190.82	198.22	278.47	252.18	241.46	132.77	115.98	114.29	210.81	233.11	354.98	286.78
4500.	371.62	163.67	159.34	104.54	179.28	191.92	304.63	267.30	252.69	135.23	117.98	116.25	218.61	253.27	363.22	296.07
5500.	365.86	153.94	145.12	98.63	172.41	188.94	324.64	279.25	262.01	139.18	120.68	117.86	226.08	270.34	369.32	303.87
6500.	357.62	145.35	133.64	94.08	166.58	185.44	336.20	285.16	266.12	140.84	121.47	117.76	225.70	281.03	370.52	306.33
7500.	347.28	137.63	124.26	90.25	161.26	181.21	340.39	285.85	265.79	140.39	120.57	116.24	229.89	286.14	367.45	304.22
8500.	335.28	130.49	116.36	86.82	156.12	176.25	338.89	282.51	262.06	138.28	118.32	113.64	227.39	286.91	360.98	298.60
9500.	322.26	123.80	109.50	83.63	151.05	170.78	333.36	276.38	255.98	135.01	115.17	110.31	222.99	284.55	352.17	290.58
10500.	311.49	118.83	104.84	81.26	147.53	166.42	327.00	270.08	249.94	131.67	112.03	107.29	218.57	281.39	344.36	282.92
11500.	300.57	114.20	100.74	79.02	144.04	161.89	319.01	262.72	243.00	127.89	108.56	104.01	213.34	276.78	335.65	274.41

PB-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - TOTAL

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	1.14	1.16	0.92	1.64	0.16	1.31	0.93	1.36	0.99	0.95	1.27	0.08	0.94	0.15	1.19	0.97
1500.	34.46	19.07	18.90	19.03	18.40	20.89	17.56	19.62	20.66	16.44	12.71	8.64	19.87	16.80	28.24	22.83
2500.	58.24	30.52	34.08	27.44	36.87	34.14	35.02	34.75	36.43	25.35	21.17	18.48	37.79	37.18	58.88	42.56
3500.	72.38	35.87	40.97	29.70	45.98	41.10	49.27	46.57	48.41	30.43	26.83	25.69	50.83	54.68	80.49	56.39
4500.	85.54	40.24	45.10	32.09	51.76	47.20	63.27	58.59	60.90	36.58	32.87	32.30	63.88	72.98	98.73	69.64
5500.	98.90	44.53	48.59	35.26	57.15	53.52	78.17	71.36	74.13	43.75	39.27	38.75	77.46	92.16	116.57	83.42
6500.	110.83	47.97	51.07	38.07	61.90	59.50	92.90	83.60	86.61	50.54	45.04	44.42	89.95	110.27	133.27	96.37
7500.	121.40	50.85	52.83	40.29	66.33	65.16	106.52	94.83	97.68	56.77	50.55	49.39	101.13	126.49	148.27	107.89
8500.	130.08	53.25	54.36	42.31	70.47	69.87	118.58	104.54	107.10	61.96	54.54	53.45	109.83	140.37	160.72	118.01
9500.	136.89	54.85	54.56	43.54	73.52	74.09	128.74	112.27	114.11	65.91	58.31	56.61	118.33	152.67	171.56	125.84
10500.	143.74	57.02	57.27	45.32	77.14	78.30	137.56	119.49	121.39	69.80	62.24	59.83	129.06	161.56	180.37	132.70
11500.	148.61	58.63	56.53	45.84	78.62	81.89	144.95	125.30	126.53	73.10	60.48	58.18	126.62	172.49	188.57	137.88

BI-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - TOTAL

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	0.05	0.05	0.04	0.08	0.01	0.07	0.04	0.06	0.05	0.04	0.06	0.00	0.04	0.00	0.05	0.04
1500.	3.14	1.78	1.71	2.10	1.73	2.09	1.58	1.86	2.02	1.78	1.29	0.76	2.01	1.57	2.77	2.07
2500.	7.14	3.89	4.64	4.36	5.39	4.60	4.20	4.30	4.78	3.84	3.11	2.50	5.67	5.32	8.37	5.42
3500.	11.05	5.76	7.36	5.96	8.78	6.84	7.15	6.99	7.80	5.59	4.94	4.57	9.72	10.16	14.57	8.94
4500.	15.59	7.80	9.97	7.70	11.76	9.21	10.55	10.24	11.61	7.80	7.20	7.03	14.62	16.45	21.15	13.00
5500.	20.94	10.06	12.66	9.82	14.80	11.88	14.83	14.32	16.39	10.73	9.96	9.92	20.65	24.41	28.70	17.94
6500.	26.73	12.31	15.18	12.00	17.89	14.86	20.03	19.09	21.91	14.09	12.98	13.02	27.39	33.64	37.25	23.59
7500.	32.96	14.60	17.52	14.06	21.25	18.20	25.90	24.43	27.87	17.86	16.51	16.36	34.74	43.67	46.55	29.70
8500.	39.22	16.91	19.91	16.22	24.88	21.53	32.20	30.03	34.06	21.69	19.68	19.72	41.68	54.02	55.91	36.26
9500.	45.32	18.98	21.42	17.94	28.14	25.08	38.62	35.48	39.74	25.32	23.31	22.97	49.81	65.05	65.72	42.51
10500.	51.94	21.49	24.93	20.23	31.98	28.88	45.08	41.28	46.34	29.37	27.58	26.62	61.36	74.35	74.81	48.79
11500.	57.85	23.80	25.34	21.34	34.15	32.71	51.52	46.92	52.13	33.60	26.88	25.98	60.54	87.64	84.66	54.63

PO-214 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - TOTAL

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	3.35	0.05	0.04	3.08	0.31	0.07	0.04	0.06	0.05	0.04	0.06	0.00	0.04	0.00	0.05	0.04
1500.	3.14	1.78	1.71	2.10	1.73	2.09	1.58	1.86	2.02	1.78	1.29	0.76	2.01	1.57	2.77	2.07
2500.	7.14	3.89	4.64	4.36	5.39	4.60	4.20	4.30	4.78	3.84	3.11	2.50	5.67	5.32	8.37	5.42
3500.	11.05	5.76	7.36	5.96	8.78	6.84	7.15	6.99	7.80	5.59	4.94	4.57	9.72	10.16	14.57	8.94
4500.	15.59	7.80	9.97	7.70	11.76	9.21	10.55	10.24	11.61	7.80	7.20	7.03	14.62	16.45	21.15	13.00
5500.	20.94	10.06	12.66	9.82	14.80	11.88	14.83	14.32	16.39	10.73	9.96	9.92	20.65	24.41	28.70	17.94
6500.	26.73	12.31	15.18	12.00	17.89	14.86	20.03	19.09	21.91	14.09	12.98	13.02	27.39	33.64	37.25	23.59
7500.	32.96	14.60	17.52	14.06	21.25	18.20	25.90	24.43	27.87	17.86	16.51	16.36	34.74	43.67	46.55	29.70
8500.	39.22	16.91	19.91	16.22	24.88	21.53	32.20	30.03	34.06	21.69	19.68	19.72	41.68	54.02	55.91	36.26
9500.	45.32	18.98	21.42	17.94	28.14	25.08	38.62	35.48	39.74	25.32	23.31	22.97	49.81	65.05	65.72	42.51
10500.	51.94	21.49	24.93	20.23	31.98	28.88	45.08	41.28	46.34	29.37	27.58	26.62	61.36	74.35	74.81	48.79
11500.	57.85	23.80	25.34	21.34	34.15	32.71	51.52	46.92	52.13	33.60	26.88	25.98	60.54	87.64	84.66	54.63

PB-210 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - TOTAL

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	12.11	12.09	11.31	13.21	2.75	10.38	8.87	12.43	9.41	8.84	11.57	1.45	10.97	2.49	12.44	11.83
1500.	114.18	61.00	62.22	47.57	56.86	60.74	59.35	61.81	61.81	42.04	35.70	29.55	55.59	52.33	83.30	75.46
2500.	126.51	62.54	63.63	42.27	63.05	65.65	80.36	75.87	73.05	42.19	36.37	34.83	62.95	65.59	105.30	88.40
3500.	118.07	54.52	54.01	34.52	57.06	60.59	88.09	78.89	74.27	40.01	34.88	34.48	63.07	69.99	107.15	88.56
4500.	111.54	48.65	46.69	30.42	52.52	57.15	93.09	80.92	75.46	39.87	34.69	34.19	64.04	74.33	107.10	88.74
5500.	107.65	44.97	41.96	28.41	49.94	55.34	96.89	82.74	76.85	40.47	35.03	34.21	65.48	78.40	107.44	89.38
6500.	103.96	42.03	38.36	26.95	47.94	53.76	98.78	83.33	77.21	40.63	35.00	33.93	66.10	80.97	106.92	89.06
7500.	100.18	39.54	35.52	25.75	46.19	52.18	98.98	82.78	76.59	40.28	34.56	33.34	65.88	82.11	105.50	87.78
8500.	96.21	37.31	33.14	24.70	44.58	50.52	97.86	81.33	75.16	39.53	33.80	32.47	64.96	82.09	103.28	85.73
9500.	92.11	35.27	31.10	23.73	43.02	48.78	95.77	79.22	73.16	38.48	32.80	31.44	63.53	81.19	100.46	83.12
10500.	88.74	33.76	29.70	22.99	41.91	47.37	93.58	77.14	71.21	37.42	31.82	30.50	62.10	80.09	97.98	80.68
11500.	85.39	32.36	28.46	22.29	40.80	45.96	91.00	74.80	69.05	36.25	30.75	29.49	60.45	78.57	95.25	78.03

PO-210 GROUND-LEVEL AIR CONCENTRATION (ACI/M**3) - TOTAL

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
500.	7.52	7.60	7.11	8.29	1.73	6.52	5.57	7.81	5.92	5.55	7.26	0.90	6.90	1.56	7.82	7.43
1500.	71.70	38.32	39.08	29.87	35.71	38.14	37.27	38.83	38.81	26.40	22.43	18.55	34.91	32.87	52.32	47.39
2500.	79.46	39.28	39.96	26.56	39.60	41.23	50.47	47.65	45.88	26.49	22.84	21.88	39.53	41.20	66.13	55.52
3500.	74.15	34.25	33.92	21.68	35.84	38.06	55.33	49.55	46.65	25.12	21.91	21.65	39.61	43.96	67.29	55.62
4500.	70.05	30.56	29.33	19.10	33.00	35.90	58.46	50.83	47.40	25.04	21.79	21.48	40.22	46.69	67.27	55.74
5500.	67.61	28.25	26.36	17.84	31.37	34.76	60.85	51.96	48.26	25.42	22.00	21.50	41.12	49.24	67.47	56.14
6500.	65.29	26.40	24.09	16.92	30.11	33.76	62.04	52.33	48.50	25.52	21.98	21.31	41.52	50.86	67.15	55.93
7500.	62.91	24.83	22.29	16.17	29.01	32.77	62.16	51.99	48.11	25.30	21.71	20.94	41.38	51.57	66.26	55.13
8500.	60.42	23.43	20.82	15.51	28.01	31.73	61.46	51.08	47.21	24.83	21.23	20.40	40.80	51.55	64.86	53.84
9500.	57.85	22.16	19.53	14.90	27.02	30.63	60.16	49.75	45.94	24.17	20.60	19.74	39.91	51.00	63.09	52.20
10500.	55.73	21.21	18.66	14.44	26.32	29.75	58.77	48.45	44.72	23.49	19.98	19.15	39.01	50.29	61.53	50.66
11500.	53.63	20.33	17.87	14.01	25.62	28.86	57.14	46.97	43.36	22.76	19.31	18.51	37.96	49.33	59.82	49.00

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