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REMOVAL SITE EVALUATION SILO 3

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Removal Site Evaluation

Silo 3

Fernald Environmental Management Project (FEMP)
Fernald, Ohio

September 1991

U. S. DEPARTMENT OF ENERGY

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1.0 INTRODUCTION

The Metal Oxide Waste Storage Silo (Silo 3) is one of four silos that are remedial elements in Operable Unit 4 (OU4). Silo 3 is a concrete storage structure that was built in mid-1952 at the Fernald Environmental Management Project (FEMP) site. Silo 3 is located south of the Waste Pit Area in the northwestern corner of the FEMP property (Figure 1.1). Paddy's Run lies west of the silo area. A fence located between Paddy's Run and the west side of the silo area is part of the site-wide institutional controls to limit access to the overall site. The Silo 3 area is bordered on the west by an access road (outside the fence) and on the east by an access road (inside the fence) and on the south, the K-65 Silos. Silo 4 (never used) borders Silo 3 directly to the north (Figure 1.2).

The silo is 80 feet in diameter and 26 feet high, with a floor of 4-in.-thick concrete over an 8-in. layer of gravel. Below the gravel is a 2-in.-thick layer of asphaltic concrete underlain by approximately 18 in. of compacted clay. The walls are approximately 26 feet high and are constructed of 8-in.-thick concrete with a 0.75-in.-thick gunite coating on the exterior. The domed roof tapers from 8 in.-thick at the silo walls to 4 in.-thick at the apex.

Silo 3 was designed to receive dry materials only. The waste placed in Silo 3 resulted from processing uranium bearing ore concentrates, and thus the uranium in the waste is natural uranium. Slurries from refinery operations were dewatered in an evaporator and then spray calcined to produce a dry waste for storage in Silo 3. The waste was pneumatically conveyed into Silo 3. A dust collection system was installed on the top of the dome to control emissions during this operation. This collector is still in place and contributes to loading on the dome.

There have been several estimates of the amount of material in Silo 3. These are reviewed in Section 2.0, Source Term. For this Removal Site Evaluation (RSE), the estimate of 3850 tons is used. A best estimate of volume is 1502 cubic meters or 1953 cubic yards. The principle contaminant, 179 curies of thorium-230, constitutes 83 percent of the total activity present.

There is no evidence that there has been any significant release of material from Silo 3. Uranium contamination in adjacent soils is from other sources; there are no elevated concentrations of thorium-230. There is some limited potential for eventual penetration of contaminants to ground water and failure of Silo 3 integrity could lead to an airborne release.

There is no evidence of any current significant releases from Silo 3. Due to the similarities existing among the silos, structural analysis data derived from studies for Silos 1, 2, and 4 were used in the absence of structural analysis for Silo 3. In 1985, a nondestructive testing program and structural analysis on the silos were performed by Camargo Associates, Ltd. (Camargo). During the period March through May 15, 1987, WEMCO conducted temperature/pressure studies on Silos 1 and 2. In 1989, Bechtel National Inc. (BNI) was contracted to do additional physical testing of Silo 4 concrete and structural analysis of Silos 1 and 2.

To assess the magnitude of the potential threat, three potential release scenarios were analyzed; catastrophic failure, an acute failure, and a chronic failure.

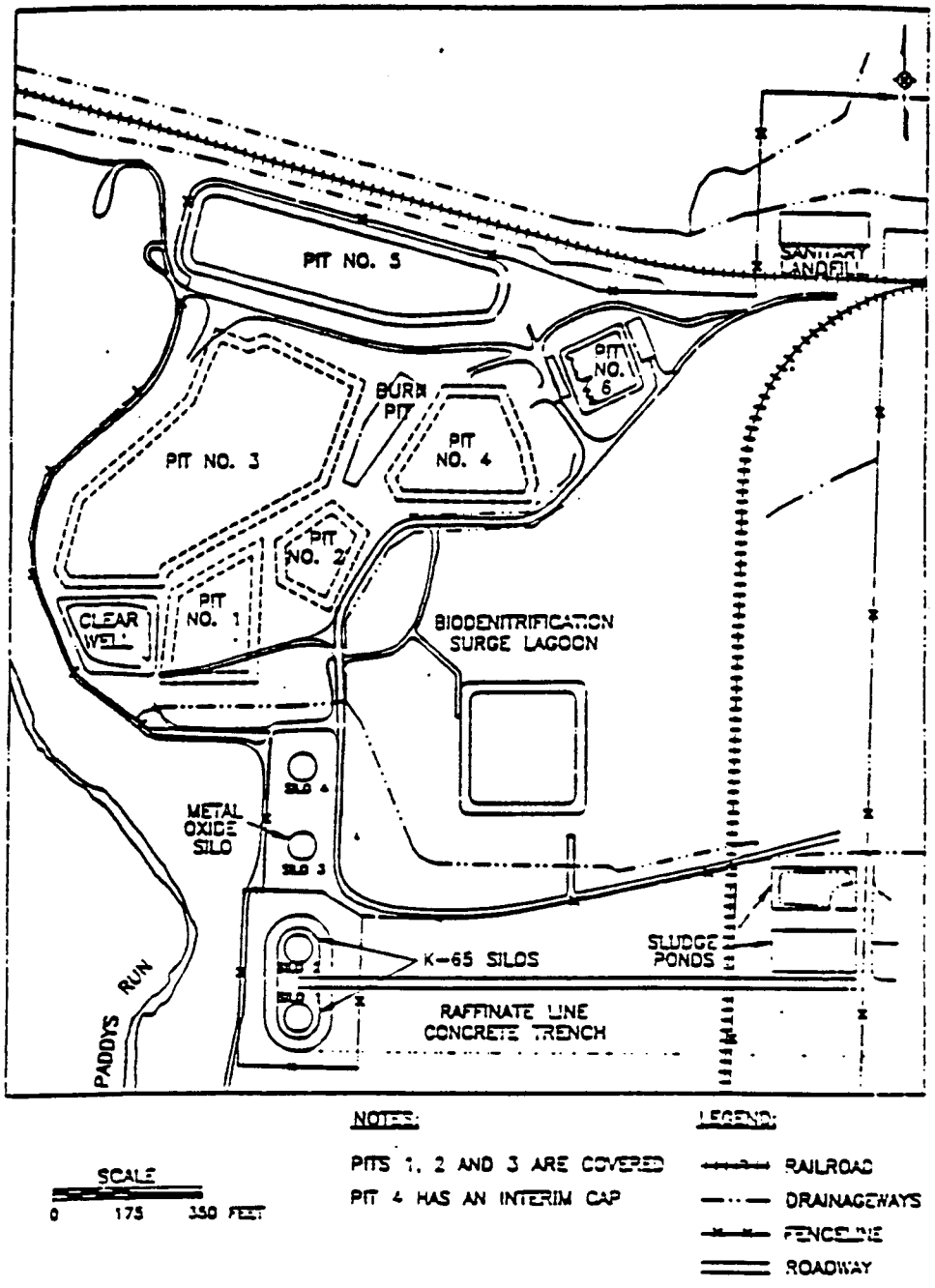

Figure 1.1 Waste Storage Area

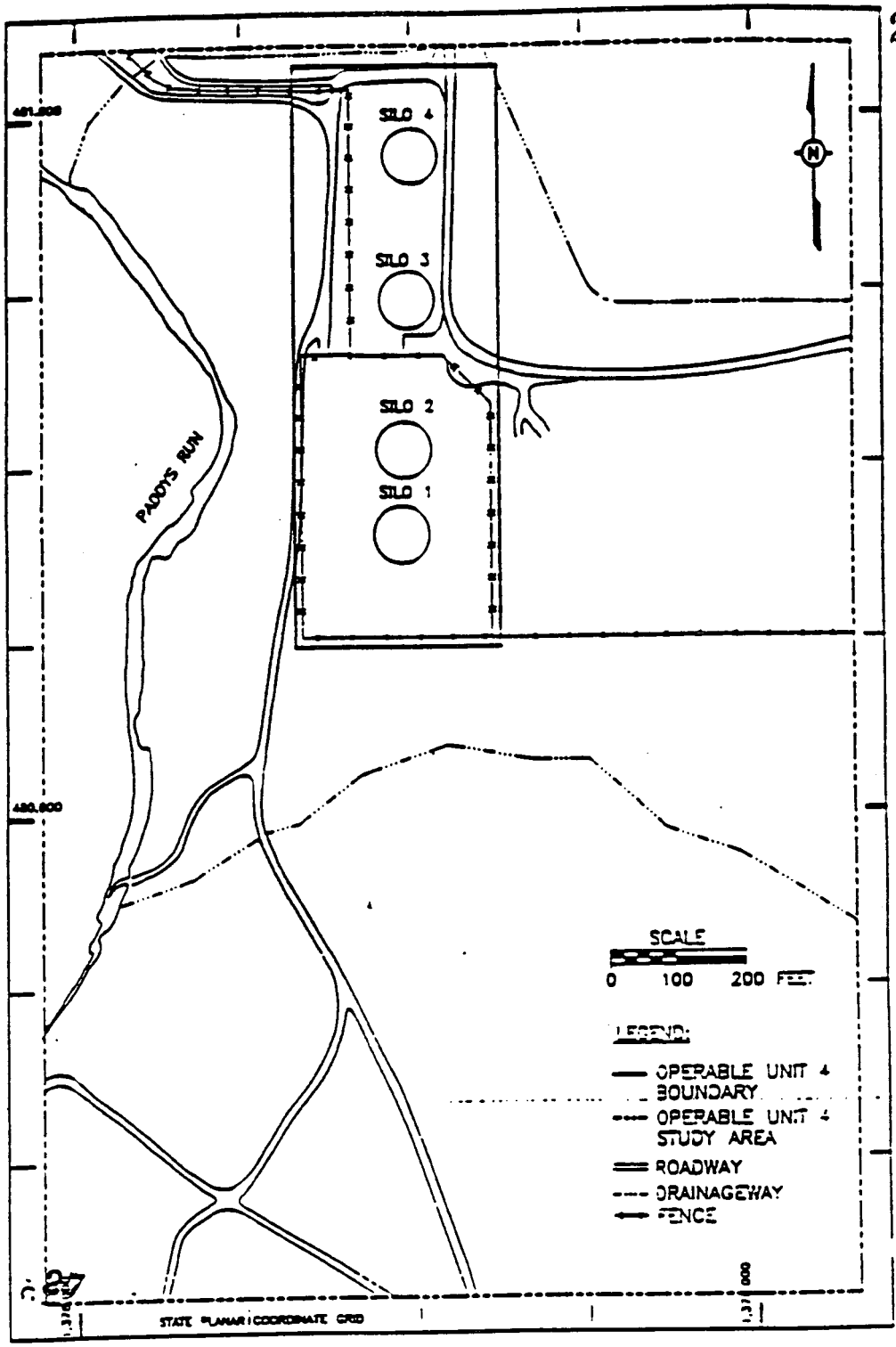

Figure 1.2 Operable Unit 4 Study Area

This Removal Site Evaluation (RSE) has been completed by the Department of Energy under authorities delegated by Executive Order 12580 under Section 104 of CERCLA and is consistent with Section 300.410 of the National Oil and Hazardous Substance Pollution Contingency Plan (NCP). This RSE addresses Silo 3 as a potential source for the exposure of the general population through the uncontrolled release of contaminants to the environment.

Currently, there is an ongoing CERCLA Remedial Investigation/Feasibility Study (RI/FS) for OU4 that is assessing the environmental conditions and possible remedial actions for the silo area.

2.0 SOURCE TERM

2.1 WASTE DESCRIPTION

The extent and nature of contamination was determined by reviewing data from the Roy F. Weston Inc. Characterization Investigation Study, current RI/FS information, and the annual Environmental Monitoring Reports for the FEMP site. Based on the draft Remedial Investigation (RI) Report data, OU4 represents a potential source of contamination to groundwater and other environmental media. Surface water and sediment samples collected within the OU4 study area contain elevated concentrations of uranium. Currently, there are no data to suggest that the Metal Oxide Silo 3 is the source of this contamination.

The material in this silo is brown with a tone that varies from dark to reddish. As a result of the evaporation and calcination of this waste, the water content is very low, ranging from 3.7 to 10.2 percent. The specific gravity varies between 2.08 and 2.75. Approximately 90 percent of the Silo 3 residues pass through a 200-mesh sieve (0.074 mm). This size designation is the break between sand and silt (WMCO, 1990).

2.2 WASTE ANALYSIS

There have been several studies to characterize the Silo 3 residues and the quantity of material present.

Table 2.1 Silo 3 Material Estimates

Reference	Quantity (Tons)
NLO 1963	2000-2300
NLO 1985	3850
DOE 1989	3020

In 1987, the DOE estimated a volume of 3902 cubic meters, however, this seems excessive. The RI/FS Geotechnical analysis of the Silo 3 residues showed densities of 2.33 $\pm$0.21 g/cc (four samples) and a composite sample showed 2.75 g/cc. With 2.33 g/cc, the volume of 3902 cubic meters would amount to 10,000 tons; considerably more than the other estimates. If the NLO 1985 weight of 3850 tons is coupled with the 2.33 g/cc, the volume is 1500 cubic meters. For this RSE, the highest estimate of 3850 tons is being utilized.

Table 2.2 Silo 3 Source Term

Isotope	Mean * Concentration (pCi/g)	Standard Deviation (pCi/g)	Total ** (curies)
Th-230	51,208	16,386	179
Ra-226	2,973	1,645	10.4
Pb-210	2,617	1,572	9.16
U-238	1,500	503	5.25
U-234	1,478	456	5.17
Th-232	784	309	2.74
Ra-228	357	164	1.25
Th-228	752	225	2.63
Ra-224	290	142	1.02

* Average of 11 samples
** Assumes 3850 tons

The principal inorganic constituents in Silo 3 are aluminum, calcium, iron, magnesium, potassium, and sodium. The results of the inorganic analyses for Silos 1, 2, and 3 are summarized in Table 2 of Appendix B. This table shows the differences in the concentrations of metals contained in residues from Silos 1 and 2 from those of Silo 3. Silos 1 and 2 have a higher lead content while Silo 3 residues contain distinctly higher concentrations of aluminum, arsenic, chromium, magnesium, manganese, potassium, and sodium. These characteristic differences help determine whether contamination originates from Silos 1 and 2 or from Silo 3 (WMCO, 1989a).

Extraction Procedure (EP) Toxicity was measured by using the U. S. EPA extraction procedure designed to simulate the leaching a waste could undergo if it were disposed of in a commercial landfill. After extraction, the extract from each sample was analyzed for the EP Toxic metals. The results are summarized in Table 3 in Appendix B. Note that the maximum allowable concentrations for arsenic, cadmium, chromium, and selenium are exceeded. Similar results could be expected with the newer Toxic Characteristic Leach Procedure tests because a more aggressive acid is used in the TCLP test than is used for the EP Tox test.

3.0 EVALUATION OF THE MAGNITUDE OF THE POTENTIAL THREAT

3.1 CURRENT RELEASES

Estimates of radon flux from Silo 3 and the K-65 silos have been developed in several studies. An estimate of radon flux from Silo 3 was made by Borak (1985) using the Nuclear Regulatory Commission-approved RADON computer code. The calculated value was 19.04 pCi/m^2-sec. The investigators concluded that, given the uncertainties of the calculations, the 20 pCi/m^2-sec. flux standard (NESHAP Part Q) is probably exceeded.

Lee Wan Associates also estimated radon flux from Silo 3 following the method of Borak. By using an estimated head space volume of 516 m^3, the flux was estimated at 109 pCi/m^2-sec. Subsequently, the head space volume was measured and found to be 105 m^3. Substitution of this value into the Lee Wan calculations results in an estimate of 21.8 pCi/m^2-sec. which is in close agreement with the RADON-generated estimate of Borak (1985). These studies have been included as Appendix C. Radon-222 releases from Silos 1 and 2 are much greater than those from Silo 3 since they contain about 100 times as much radium-226. Borak (1985) estimated flux from the K-65 silos at 2,400 pCi/m^2-sec.

The FEMP site has an ongoing air monitoring program which includes the use of EMP air samplers. The closest EMP air monitoring station to Operable Unit 4 is designated AMS 6. None of the 1989 air samples at that location showed measurable airborne concentrations of thorium-230 (< 9.5E-06 pCi/m3). Very low concentrations of thorium-230 were detected at AMS 1, 2, and 11. The highest detected concentration, at AMS 2, was 1.0±0.7E-05 pCi/m3. This can be compared to the limit of 5.0E-02 pCi/m3 in DOE Order 5400.5.

Although thorium and uranium are present in higher concentrations in the Silo 3 contents than in the contents of Silos 1 and 2, these radionuclides are not indicative of a specific source. The area around OU4 and the FEMP site boundary fenceline has been monitored for direct exposure to penetrating radiation (gamma radiation). During 1988, the boundary monitoring station exhibiting the highest average radiation exposure rate was the station directly west of OU4 at a distance of 340 meters (1,116 ft.), along the western site boundary (WMCO 1989b). The dose equivalent rate measurement for this location was an annual average of 15.3 μrem/hr, the maximum was 23.53 μrem/hr, and the minimum was 11.56 μrem/hr. Essentially all of the gamma exposure rates noted by the dosimeters are from Silos 1 and 2. Natural background radiation for the area surrounding the FEMP site has been estimated to range from 10 to 12 μrem/hr (WMCO, 1989a).

3.2 STRUCTURAL ANALYSIS

Several studies have been conducted to assess the structural integrity of the K-65 silos. Camargo completed a study in 1985 and Bechtel National Inc. completed a study in 1990. Other independent assessments of this work have been developed. The results of these investigations, as they pertain to Silo 3, are summarized in this section.

The initial Camargo investigation consisted of three phases and was completed in 1985. Phase I involved computer analysis of the original silo design based on the original drawings. Phase II consisted of field work that was divided into three areas: soil exploration study; a survey using the Echo Pulse system to test the silo domes, walls, and base slabs; and a ground penetrating radar study of the earthen embankment around Silos 1 & 2. Phase III consisted of a computer analysis based on the field data collected in Phase II. The pertinent conclusions of the Camargo investigation are summarized as follows:

- The base slab and walls at the time of investigation were stable under the existing static loads being applied to them and should continue to remain stable for approximately five to ten years.

- The center 20-ft. diameter portion of the dome top is structurally unsound for a load greater than the existing static dead load, but no life expectancy was assigned to it.

Based on field investigation of Silos 3 and 4, conducted by Bechtel (1990), the domes seem to be in good condition, exhibiting little distress or deterioration. Slight inconsistencies in concrete thickness and in the diameter of existing field measured steel reinforcements are judged to be the result of construction tolerances.

Finite Element Analysis was used to model Silo 3 (Bechtel, 1990). Using the condition that the silo is filled with oxide waste, the dome exhibits hoop stress ranging from 173-psi compression at the perimeter to 35-psi tension at the dome center.

Non-destructive testing of the silo walls in Silo 3 and Silo 4 indicates only minor concrete thinning has occurred. Also, vertical post-tensioning unit reinforcement steel bundles show no deterioration. However, the horizontal post-tensioning wires do indicate some reduction of area. This loss of area is most prevalent in regions where the silo walls have through cracking.

Field investigation revealed several through-slab cracks in both Silos 3 and 4, however, the steel reinforcement shows little deterioration. The presence of these cracks would not adversely affect the structural behavior of the silos. However, the cracks would preclude storing a liquid-type material in the silos since it would leak through the cracks.

Thus, while the walls of Silo 3 have retained their structural integrity, the potential exists for dome failure, particularly during severe weather events. The existing dust collection system adds to loading on the dome.

3.3 EARTHQUAKE ANALYSIS RESULTS

The dynamic analysis of Silos 3 and 4 were similar to that performed on the two K-65 storage tanks and presented in "K-65 Silos Study and Evaluation," February 25, 1986, by Camargo Associates, Ltd. The method of analysis was a time history finite element analysis using the ASHSD2 program.

All silo models assumed zero damping during the computer runs. Such an assumption is slightly conservative because, unlike the K-65 silos, there is no earth berm built up around the silos. Therefore, the only damping present in the system is the natural damping of the silos themselves, which for a structure of this type is approximately three percent. Under the induced 50-year earthquake, both silos proved to be very ductile structures. As the ground moved with the earthquake, the silos did not attempt to resist these movements. This produced rather large displacements with relatively low stresses.

Silos 3 with its design contents load behaves somewhat different than Silo 4, which is empty. The contents tend to add mass to the system without increasing the stiffness, thus intensifying the earthquake's effect on the silo over time. At the end of the earthquake's duration (10 seconds), stresses and displacements at the top of the wall and dome were still increasing due to resonance. Maximum stresses were still below allowable stresses at 9.9 seconds and decreased very rapidly once the earthquake ended. Since the earthquake modeled had the longest anticipated duration for the Fernald, Ohio, region, the encountered resonance should not be a problem.

When filled, the base slab of Silo 3 experiences very little displacement or stress. The silo wall incurred a maximum shear stress of 79.9 psi at 9.9 seconds, with maximum displacements of 1.5 in. horizontally and 2.25 in. vertically. The walls will remain serviceable, but should experience some cracking due to the high displacements.

The dome experienced extremely low longitudinal stresses (1.5 psi maximum) and hoop stresses (1 psi maximum). In-plane stresses were larger, reaching 264 psi at 9.9 seconds near the dome center. Maximum displacements in the dome were 1.5 in. horizontally and 2.25 in. vertically near the dome edge. The dome, like the wall, should remain serviceable but will experience some cracking.

The base slab experienced virtually no displacement and very little stress (only as high as 4-psi shear) throughout the earthquake's duration. Likewise, the silo wall experienced small stresses. A maximum hoop stress of 19 psi occurred near the base of the wall at 6.3 seconds into the earthquake. Displacements were large, however, with maximum deflections of 1.6 in. radially and 2.0 in. vertically. The walls, while remaining serviceable, should experience some cracking due to these movements.

The dome also had large deflections, but unlike the wall, showed some large stresses as well. Shear stresses in particular were large, reaching a maximum 378 psi near the dome center. Longitudinal and hoop stresses remained very low (less than 1 psi), which were a result of the silos' ductility.

Both silos should remain serviceable with some microcracking occurring in the dome and wall. Therefore, a significant environmental release from Silo 3 is not anticipated during an earthquake.

3.4 TORNADO ANALYSIS RESULTS

Tornado suction loading acts symmetrically on the exposed silos due to a pressure drop around the exterior of the exposed silos. This resulting load is 432 psf acting outward. This load is applied as a nodal load on the outside nodes of the dome and silo wall.

Under tornado suction, the silo domes experience both radial and hoop compressive stresses in excess of 300 psi over the major portion of their span. The maximum tensile stress encountered in the domes is over 400 psi in both radial direction and hoop stress.

The silo walls experience significant tensile bending stress in their upper regions. Hoop stresses are not adversely affected in the wall of Silo 3. The silo dome remains as the critical element under tornado suction loading.

A study conducted by Eckart, et.al, (1990) estimated the tornado occurrence probability per square mile for the FMPC area at 1.2E-4 per year and 6.2E-4 over five years. While this probability is not great, the likely failure mode under tornado conditions would be dome failure.

3.5 POTENTIAL FOR EXPOSURE

Under current conditions, Silo 3 accounts for a small contribution as a radon source for OU4. The radon flux from Silo 3 is several orders of magnitude less than that from the K-65 silos. However, the potential for a significant release due to structural failure cannot be discounted. To quantify risks associated with such a release, a risk assessment was conducted and is included as Appendix D. Three scenarios were addressed in the risk assessment. The assumptions for each scenario are stated in the appendix, and dose was calculated using the AIRDOS-EPA computer code.

Scenario 1 involves a catastrophic release due to dome failure during a tornado. The second scenario estimates dose from dome failure due to natural deterioration from normal ageing and weathering. The last scenario concerns chronic radon emission dose under existing conditions. Table 3.1 shows doses that result from the scenarios at a distance of 500 meters from Silo 3. The table shows the total dose for both direct inhalation and the inhalation from resuspension pathways.

Table 3.1 Estimated Dose

Percent of release settled b/w 300 and 2500 feet	Scenario 1 results for the following stability classes (rem/year)			Scenario 2 results (mrem/year)	Scenario 3 results (mrem/year)
	A	C	F		
9 %	4.45	11.4	22.7	31.3	0.10
100 %	4.58	11.5	22.8	-	-

Scenario 1 is the catastrophic failure which is assumed to result in dispersal of 10% of the silo contents. To bound the estimated dose, values were calculated for three wind stability classifications (A, C, and F), and two settling percentages for the downwind sector between the distances from 300 to 2500 feet from the emission source. The calculations assume that all the dispersed particulates settle in a single downwind sector 22.5 degrees wide. The dose is based on ^{230}Th being the principal radionuclide of concern. Wind turbulence has a significant impact on the calculated dose, and wind stability classification A is the category that best describes the tornadic wind condition.

The radiation standard for whole body dose to an off-site receptor is 25 mrem/year (10 CFR 61, 40 CFR 192, and 40 CFR 190). Thus, the standard is grossly exceeded for the first scenario. However, recall that the probability of a tornado per square mile in the vicinity of the FEMP site is 1.2E-4 per year. Thus, while a significant dose could occur hypothetically, the probability of such an event is not great. Furthermore, in the event of such a catastrophe, local residents could be temporarily evacuated to reduce the inhalation risk from the airborne residues.

Scenario 2 represents a failure that permits approximately 30 pounds of particulates to escape unnoticed each day for one month. This represents a release of 0.01% of the silo inventory. While no mechanism is postulated that would result in a release of this magnitude to occur unnoticed for a one month duration, the scenario does represent a very conservative upper bound condition for cracks and partial dome failure. Winds were assumed to be 6.3 m/sec (14.1 mph) and 9.7 m/sec (20.8 mph). Deposition was assumed to be to a single downwind sector 22.5 degrees wide.

The scenario 2 dose slightly exceeds the 25 mrem/yr standard, but the calculated dose is based on conservative assumptions that are not expected to occur for any postulated failure mode. Foremost is the assumption that all of the release would be deposited in only one 22.5 degree wide sector. Also the assumption that a failure and subsequent release would not be observed for a period of one month by either site personnel or radiation monitoring instruments is extremely conservative. Once observed immediate corrective actions would be taken to prevent dispersal and any further emission of particulates. There is, however, a distinct possibility that an open pathway through a vent pipe and/or the dust collector may currently exist between the interior of Silo 3 and the environment.

Scenario 3 is a straight forward calculation of dose for the estimated annual release of radon from the silo. The calculated value, 0.1 mrem/yr is a negligible fraction of the 25 mrem/yr standard for the nearest receptor. For 1989 the contribution of radon from all site sources was reported to be 72 mrem/yr above background at the site fenceline (WMCO 1990).

Using accepted methods, as described in Appendix D, the calculated dose was translated into risk for each case that was calculated. The results are given in Table 3.2. For scenarios one and two the risk value represents the potential for lifetime cancer incidents; for scenario three the risk value represents the potential for excess cancer fatalities.

Table 3.2: Estimated Risk

Percent of release settled b/w 300 and 2500 feet	Scenario 1 risk for the following stability classes			Scenario 2 risk	Scenario 3 risk
	A	C	F		
9 %	1.38e-04	3.53e-04	7.04e-04	9.70e-07	5e-08
100 %	1.42e-04	3.57e-04	7.07e-04	-	-

4.0 ASSESSMENT ON THE NEED FOR A REMOVAL ACTION

Consistent with Section 40 CFR 300.410 of the NCP, the DOE shall determine the appropriateness of the removal action. Eight factors to be considered in this determination are listed in 40 CFR 300.415 (b)(2). The following apply specifically to the concentrations of contaminants and the structural instability present in Silo 3.

40 CFR 300.415 (b)(2)(i)
Actual or potential exposure to hazardous substances or pollutants or contaminants to nearby populations, animals, or food chains.

40 CFR 300.415 (b)(2)(iii)
High levels of hazardous substances or pollutants or contaminants in drums, barrels, tanks, or other bulk storage containers, that may pose a threat of release.

40 CFR 300.415 (b)(2)(v)
Weather conditions that may cause hazardous substances or pollutants or contaminants to migrate or be released.

While these factors could potentially apply to Silo 3, the doses estimated under these conditions are not large.

5.0 APPROPRIATENESS OF A RESPONSE

If a planning period of less than six months exists prior to initiation of a response action, DOE will issue an Action Memorandum. The Action Memorandum will describe the selected response and provide supporting documentation for the decision.

If it is determined that there is a planning period greater than six months before a response is initiated, DOE will issue an Engineering Evaluation/Cost Analysis (EE/CA) Approval Memorandum. This memorandum is to be used to document the threat of public health and the environment and to evaluate viable alternative response actions. It will also serve as a decision document to be included in the Administrative Record.

The FEMP site is currently on the National Priorities List and is in the RI/FS process. The final remedial action will address the means of removing or further stabilizing the silo and its contents.

6.0 REFERENCES

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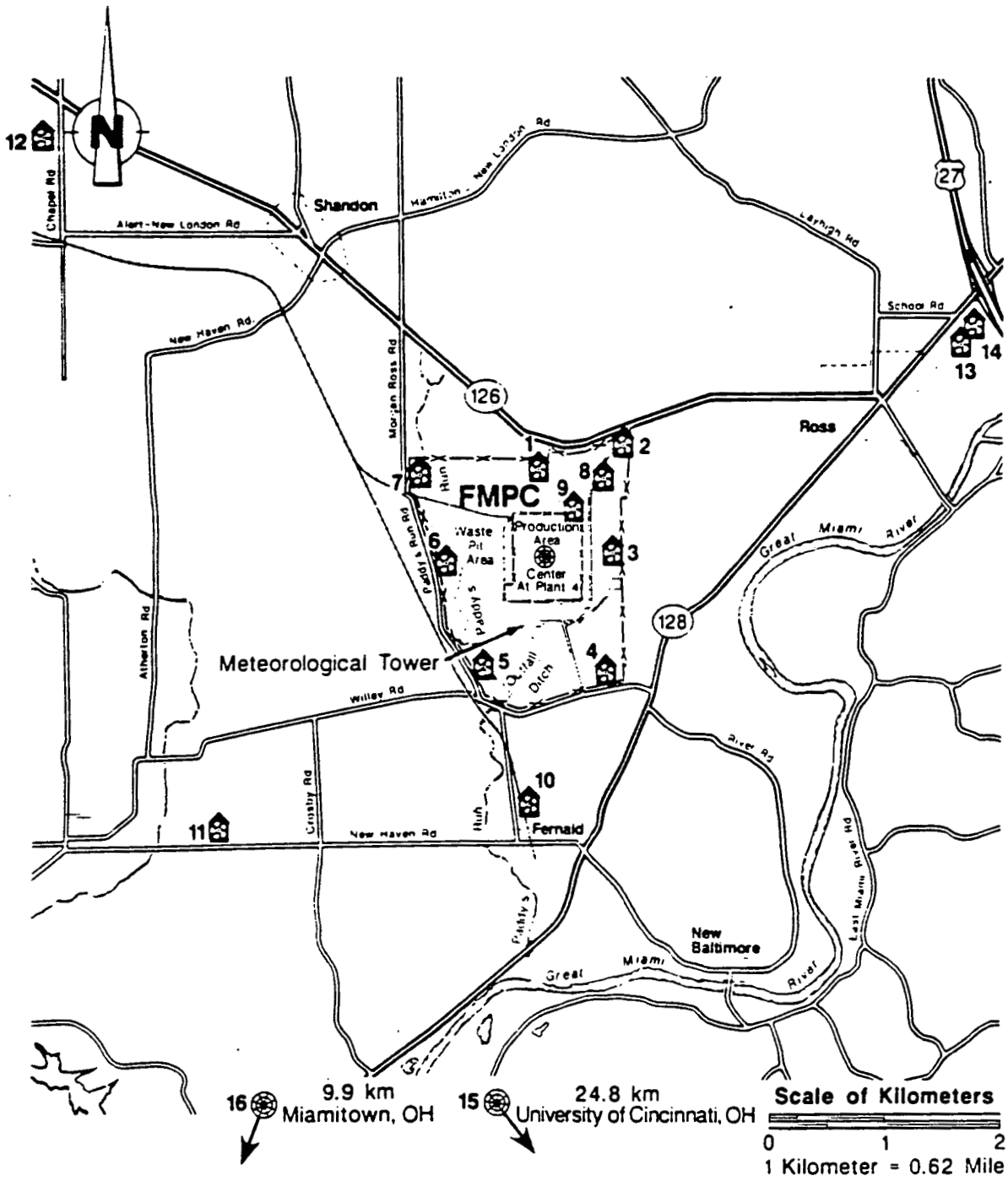
APPENDIX A

ENVIRONMENTAL MONITORING DATA

ENVIRONMENTAL MONITORING DATA

This appendix presents the concentration of airborne radionuclides at air monitoring stations as measured for calendar year 1989. The location of the air monitoring stations with respect to the FEMP site is included as Figure 9 and the data is a reproduction of Table 2 from the document, "Feed Materials Production Center Annual Environmental Report for Calendar Year 1989" (FMPC-2200), which is dated October, 1990. Explanatory notes are included at the end of the table.

Radionuclides of concern with respect to Silo 3 are those listed in Table 1 of Appendix B.



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Air Monitoring Location

Distance from Center of Production Area to Sampling Locations off Map

Plant Perimeter

Production Area Perimeter

Figure 9. Air Monitoring Locations

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TABLE 2
RADIONUCLIDES IN AIR, 1989
(page 1 of 3)

Radionuclide	Derived Concentration Guides[d] $\mu Ci/m^3 \times 10^{-6}$	Concentration of Airborne Radionuclides at Air Monitoring Stations[a,b,c] in $\mu Ci/m^3 \times 10^{-12}$					
		AMS 1	AMS 2	AMS 3	AMS 4	AMS 5	AMS 6
Sr-90	9	12 ± 6.2	33 ± 7.8	NA[e]	24 ± 6.3	NA[e]	52 ± 9.5
Tc-99	2000	< 180	< 120	160 ± 110	< 160	< 160	< 160
Ru-106[f]	30	< 11000	< 9500	< 11000	< 9700	< 9400	< 9500
Cs-137	400	< 100	< 94	< 110	< 97	< 94	< 95
Ra-226	1	9.8 ± 1.9	15 ± 2.9	< 0.53	1.0 ± 0.23	8.0 ± 1.7	16 ± 3.1
Ra-228	3	< 10	< 9.4	< 11	< 9.7	< 9.4	9.5 ± 4.0
Th-228	0.04	< 7.3	< 8.0	< 11	< 9.7	8.3 ± 6.0	11 ± 7.5
Th-230	0.04	8.8 ± 5.8	10 ± 6.5	< 11	< 9.7	< 8.0	< 9.5
Th-232	0.007	< 7.3	< 8.0	< 11	< 9.7	< 8.0	< 9.5
Np-237	0.02	NA[e]	NA[e]	NA[e]	NA[e]	NA[e]	NA[e]
Pu-238	0.03	< 2.1	< 2.0	3.0 ± 2.1	< 2.5	< 2.7	< 2.6
Pu-239	0.02	0.22 ± 0.0023	0.23 ± 0.0023	0.49 ± 0.0033	0.20 ± 0.0021	0.20 ± 0.0020	0.20 ± 0.001
Pu-240	0.02	0.064 ± 0.00083	0.065 ± 0.00086	0.13 ± 0.0012	0.060 ± 0.00077	0.057 ± 0.00064	0.060 ± 0.00
Pu-241	1	0.85 ± 0.048	0.90 ± 0.044	2.0 ± 0.055	0.77 ± 0.055	0.69 ± 0.024	0.68 ± 0.034
Pu-242[b]	0.02	37 ± 2.1	37 ± 1.9	71 ± 2.1	32 ± 1.9	37 ± 1.5	48 ± 1.5
U-234	0.09	86 ± 31	110 ± 37	200 ± 72	76 ± 27	43 ± 15	120 ± 41
U-235	0.1	6.0 ± 0.17	7.3 ± 0.21	13 ± 0.38	4.0 ± 0.11	4.5 ± 0.13	6.0 ± 0.17
U-236	0.1	2.4 ± 0.36	3.6 ± 0.55	8.4 ± 1.3	1.6 ± 0.24	1.8 ± 0.27	2.7 ± 0.41
U-238	0.1	150 ± 0.03	190 ± 0.04	360 ± 0.07	100 ± 0.02	110 ± 0.02	160 ± 0.03

TABLE 2
RADIONUCLIDES IN AIR, 1989
(page 2 of 3)

Radionuclide	Derived Concentration Guides[a] $\mu Ci/m^3 \times 10^{-6}$	Concentration of Airborne Radionuclides at Air Monitoring Stations[a,b,c] in $\mu Ci/m^3 \times 10^{-12}$					
		AMS 7	AMS 8	AMS 9	AMS 10	AMS 11	AMS 12
Sr-90	9	7.7 ± 6.0	36 ± 7.2	18 ± 7.9	8.5 ± 3.1	7.1 ± 2.9	57 ± 6.9
Tc-99	2000	170 ± 99	< 160	330 ± 120	< 2.4	< 1.9	< 2.1
Ru-106[f]	30	< 10000	< 9200	< 10000	< 1600	< 1400	< 1600
Cs-137	400	< 100	< 92	< 100	< 180	< 160	< 170
Ra-226	1	20 ± 3.6	< 0.46	< 0.52	55 ± 9.0	39 ± 6.6	39 ± 6.6
Ra-228	3	13 ± 4.5	< 9.2	< 10	< 20	< 24	< 13
Th-228	0.04	< 7.6	< 19	< 13	13 ± 4.0	4.0 ± 1.4	12 ± 3.4
Th-230	0.04	< 7.6	< 19	< 13	< 2.2	2.6 ± 1.2	< 1.7
Th-232	0.007	< 7.6	< 19	< 13	< 2.2	< 1.2	< 1.7
Np-237	0.02	NA[e]	NA[e]	NA[e]	0.22 ± 0.16	< 0.21	< 0.21
Pu-238	0.03	5.5 ± 2.6	< 7.8	< 3.2	< 0.17	< 0.25	< 0.19
Pu-239	0.02	0.14 ± 0.0016	0.40 ± 0.0029	1.4 ± 0.013			
Pu-240	0.02	0.044 ± 0.00046	0.11 ± 0.0010	0.23 ± 0.0024			
Pu-239/240					< 0.16	< 0.24	< 0.17
Pu-241	1	0.39 ± 0.021	1.6 ± 0.033	3.5 ± 0.054			
Pu-242[b]	0.02	30 ± 1.4	81 ± 1.6	200 ± 4.1			
U-234	0.09	77 ± 27	69 ± 25	530 ± 190	37 ± 13	20 ± 6.9	16 ± 5.7
U-235	0.1	3.3 ± 0.09	13 ± 0.38	35 ± 1.0	2.4 ± 0.07	1.3 ± 0.04	1.1 ± 0.03
U-236	0.1	1.3 ± 0.19	6.4 ± 0.98	20 ± 3.0	1.1 ± 0.17	0.60 ± 0.09	0.49 ± 0.07
U-238	0.1	83 ± 0.02	370 ± 0.07	940 ± 0.18	63 ± 0.01	34 ± 0.01	28 ± 0.01

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TABLE 2
RADIONUCLIDES IN AIR, 1989
(page 3 of 3)

Radionuclide	Derived Concentration Guides[d] $\mu Ci/m^3 \times 10^{-6}$	Concentration of Airborne Radionuclides at Air Monitoring Stations[a,b,c] in $\mu Ci/m^3 \times 10^{-12}$			
		AMS 13	AMS 14	AMS 15	AMS 16
Sr-90	9	11 ± 2.9	22 ± 12	20 ± 9.6	34 ± 8.9
Tc-99	2000	< 1.9	< 1.9	< 6.8	NA[e]
Ru-106[f]	30	< 1400	< 1500	< 5100	< 4700
Cs-137	400	< 160	< 170	< 560	< 520
Ra-226	1	14 ± 3.0	34 ± 5.9	84 ± 15	80 ± 15
Ra-228	3	< 16	< 9.9	< 50	< 41
Th-228	0.04	7.8 ± 2.8	11 ± 4.4	12 ± 5.4	< 9.4
Th-230	0.04	< 1.9	< 3.2	< 5.2	< 9.4
Th-232	0.007	< 1.9	< 3.2	< 5.2	< 9.4
Np-237	0.02	0.14 ± 0.085	0.14 ± 0.091	< 0.62	0.64 ± 0.43
Pu-238	0.03	< 0.14	< 0.14	< 0.48	< 0.46
Pu-239/240		< 0.13	< 0.13	< 0.44	< 0.43
U-234	0.09	26 ± 9.3	21 ± 7.6	23 ± 8.1	30 ± 11
U-235	0.1	1.7 ± 0.05	1.4 ± 0.04	1.5 ± 0.04	2.0 ± 0.06
U-236	0.1	0.81 ± 0.12	0.66 ± 0.10	0.70 ± 0.11	0.92 ± 0.14
U-238	0.1	45 ± 0.01	37 ± 0.01	39 ± 0.01	52 ± 0.01

a. See Figure 9.
b. Reported in units of μCi
10^{-12} of air; the plus/mi
values are the uncertai
the analytical results a
95% confidence level.
242 data reported in un
$\mu Ci/m^3 \times 10^{-18}$).
c. A composite of 50 weel
samples at AMS 14; 51
weekly samples at AMS
and AMS 6; 15 weekly
samples at AMS 15; 16
weekly samples at AMS
52 weekly samples at a
other air monitoring sta
d. Derived concentration
guides from DOE Draft
5400.xx, 3-18-88.
Continuous inhalation c
concentration will result
effective dose equivale
100 mrem/yr (1 mSv/yr)
e. Not analyzed.
f. Composite sample activ
adjusted to midpoint of
sampling.

APPENDIX B

ANALYTICAL DATA

ANALYTICAL DATA

This appendix presents the analytical data that has been generated to date to support the Remedial Investigation for OU4. Table 1 presents the analysis of Silo 3 samples with the sample identification numbers being keyed to specific locations under the Silo 3 manways. Table 2 shows the range of values for various inorganic constituents. Table 3 gives the results of the EP Toxic Metals evaluation. For further explanation of the data refer to the Draft Final issue of the "Remedial Investigation Report for Operable Unit 4" dated October, 1990.

TABLE 1

SILO 3

Nuclide (pCi/g)	#21	#22	#23	#24	#25	#26
Ac-227	523	416	234	1363	534	706
Pa-231	521	401	266	NA	556	889
Th-228	907	*	554	•	459	859
Th-230	41911	33881	21010	71650	40968	41555
Th-232	1451	•	815	911	411	*
Ra-224	453	451	64	213	295	335
Ra-226	2589	2192	467	6435	3073	1862
Ra-228	525	559	82	ND	392	441
Pb-210	2437	2221	454	6427	2493	1910
U-234	1935	1618	348	1524	1467	1910
U-235/236	152	117	ND	127	54	76
U-238	2043	1649	320	1600	1392	1860
U-Total (ppm)	4040	4305	738	2595	3064	4554

SILO 3

Nuclide (pCi/g)	#27	#28	#29	#30	#33
Ac-227	421	412	443	773	566
Pa-231	458	NA	564	931	431
Th-228	*	996	537	•	949
Th-230	53227	63649	61190	68759	65488
Th-232	*	755	672	581	672
Ra-224	370	106	137	449	313
Ra-226	1518	3702	4169	2240	4451
Ra-228	325	ND	117	360	415
Pb-210	1084	2589	3553	1942	3674
U-234	1317	1052	1843	1643	1600
U-235/236	80	42	158	75	118
U-238	1243	994	1951	1574	1878
U-Total (ppm)	2740	1463	1114	4050	3854

NA = Not Analyzed
ND = Not Detected
* = Interferences from thorium-230

Note: Data validation is currently in progress

TABLE 2

Contaminant (ppm)	Silo 1	Silo 2	Silo 3
Aluminum	60.4 - 1430	464 - 2570	10800 - 23700
Antimony	ND	ND - 7.2	ND
Arsenic	14.7 - 68.4	57.5 - 1960	532 - 6380
Barium	1970 - 7860	89.2 - 8370	118 - 332
Beryllium	0.88 - 2.8	0.66 - 6.0	10.0 - 39.9
Cadmium	2.1 - 8.0	3.4 - 19.1	21.5 - 204
Calcium	2150 - 5700	2430 - 301000	21300 - 39900
Chromium	21.0 - 165	12.9 - 68.8	139 - 560
Cobalt	349 - 1260	6.2 - 2430	ND - 3520
Copper	122 - 473	ND - 1790	1610 - 7060
Iron	4340 - 75100	4010 - 37800	13900 - 67600
Lead	35800 - 85100	153 - 29800	646 - 4430
Magnesium	1500 - 6020	1520 - 8740	38200 - 80900
Manganese	33.5 - 257	74.2 - 403	2420 - 6500
Mercury	0.23 - 2.8	ND - 2.3	ND - 0.69
Nickel	629 - 2580	14.6 - 2200	1200 - 6170
Potassium	158 - 492	37.8 - 289	1300 - 22800
Selenium	106 - 180	ND - 118	101 - 349
Silver	5.0 - 23.3	ND - 22.8	9.2 - 23.8
Sodium	360 - 13100	226 - 4070	22900 - 51700
Thallium	ND - 0.52	ND - 1.4	3.1 - 73.9
Vanadium	72.2 - 240	21.9 - 214	418 - 4550
Zinc	14.4 - 212	11.2 - 154	301 - 672
Cyanide	0.52 - 4.4	ND - 4.5	ND

ND = Not Detected

Note: Data validation is currently in progress

TABLE 3

Analyte	Silo 1	Silo 2	Silo 3	Maximum Allowable Concentration
Arsenic (ppm)	ND - 0.484	0.163 - 0.592	ND - 41.5	5.0
Barium (ppm)	0.079 - 14.5	0.095 - 2.62	0.020 - 0.156	100
Cadmium (ppm)	ND - 0.100	0.017 - 0.278	0.108 - 6.32	1.0
Chromium (ppm)	0.020 - 0.964	ND - 1.02	0.336 - 11.9	5.0
Lead (ppm)	0.159 - 904	0.155 - 714	ND - 1.01	5.0
Selenium (ppm)	0.217 - 0.997	0.240 - 1.56	0.92 - 11.7	1.0
Silver (ppm)	ND - 0.121	ND - 0.213	ND - 0.032	5.0
Mercury (ppm)	ND	ND	ND - 0.003	0.2

ND = Not Detected

Note: Data validation is currently in progress

APPENDIX C

RADON FLUX CALCULATIONS

RADON FLUX CALCULATIONS

This appendix includes three reference documents that address radon flux estimates for Silo 3. They are; 1) an estimate based on the RADON computer code calculation, 2) a radon diffusion calculation prepared by Lee Wan & Associates, and 3) a radon flux calculation prepared by Lee Wan & Associates. The RADON computer code calculations were transmitted to the USEPA under DOE cover letter DOE-417-91 dated December 17, 1990.

Department of Energy
FMPC Site Office
P.O. Box 398705
Cincinnati, Ohio 45239-8705
(513) 738-6319

2245

DEC 17 1990
DOE-417-91

Mr. David Kee
U.S. Environmental Protection Agency
Region V, 5AR-26
Air and Radiation Division
230 S. Dearborn Street
Chicago, Illinois 60604

Dear Mr. Kee:

REPORT ON RADON FLUX ESTIMATES

Reference: Letter, DOE-157-91, Gerald W. Westerbeck to D. Kee, "Proposed Provisions to be Included in the Clean Air Act Compliance Agreement," dated November 6, 1990.

As part of the on-going negotiations of the FFCA/NESHAP, the DOE has agreed to submit a report on radon flux estimates from potential sources other than the K-65 silos at the Feed Materials Production Center (FMPC). The subject report is enclosed, with supporting documentation.

The estimated radon flux from Silo 3 currently exceeds 20 pCi/m^2-s. Based on this estimate and the fact that a measurement program is not practical, DOE agrees to initiate an evaluation of the need for a removal action under CERCLA for Silo 3, in accordance with our proposed language for the FFCA/NESHAP as referenced above. The results of this evaluation will be provided to U.S. EPA when completed.

The "RADON" model used to estimate flux from Waste Pits 1, 2 and 3 proved to be inappropriate. The model predicted a range of values for flux, from 0.03 to 197 pCi/m^2-s. This was because a wide range of radium was measured in the pits and cover thicknesses also varied considerably. The model was not able to evaluate sources covered with water, so values for Pit 5 and the Clearwell are not available.

To rectify the problems inherent in the model, DOE is developing a program for directly measuring radon flux from the pits.

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If you have any questions, please contact Behram Shroff at FTS 774-6003.

Sincerely,

2245

Ray Hansen for

Gerald W. Westerbeck
FMPC Site Manager

DP-84: Shroff

Enclosure: As stated

cc w/encl.:

R. B. Allen, EM-422, GTN
E. G. Feldt, EH-232, FORS
A. Wallo, EM-231, FORS
W. Dillow, SE-31, ORO
G. Gulezian, USEPA-V
L. Hamsing, USEPA-V
C. A. McCord, USEPA-V
M. Bulter, USEPA-V
S. Lee, USEPA-V
G. E. Mitchell, OEPA-Dayton
H. St. Clair, SWOAPCA
W. H. Britton, WMCO

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ESTIMATES OF RADON FLUX FROM FMPC WASTE PITS 1, 2, 3, AND SILO #3

Estimates of radon flux from FMPC Waste Pits 1, 2, 3, have been made using the NRC-approved RADON computer code (see table). The RADON code was developed for use at uranium mill tailings sites where both the radium concentration and the pertinent geophysical parameters are relatively homogeneous. In attempting to apply the RADON code to the FMPC waste pits, it was found that the wide range of radium concentrations measured in the pits and the estimated variations in cover thicknesses resulted in a very wide range of possible radon flux value. A typical computer run for Pit 2 is attached as requested.

The RADON computer code is not able to account for water cover; hence radon flux estimates are not available for Pit 5 and the Clearwell, both of which have water covers. As previously discussed, Pits 4 and 6 are not sources per definition in 40 CFR 61.91; therefore, they are not included in this report.

Ranges of Radium Concentration, Cover Thickness and Radon Flux

	^{226}Ra (pCi/g)				Cover (cm)		Rn Flux (pCi/m^2 sec)	
Pit	Max	Min	AVG	+/- 2 SD	Max	Min	Max	Min
1	60.2	12.0	30.5	123%	30	15	47	5.6
2	412	12.2	117.7	283	60	15	197	1.7
3	369	3.1	124.2	218	240	22.5	159	.03

The large range of possible radon flux values illustrates the problems encountered in attempting to apply a computer model to a situation where assumed homogeneity does not exist. The range of flux values would decrease somewhat if, instead of maximum and minimum radium concentrations, the average ± 2-sigma standard deviation was used. However, the two-standard-deviation range goes from ± 123% to ± 283% for the waste pits. And if uncertainties in the other parameters (such as soil density and moisture) were included, the maximum and minimum flux values would be even further apart.

The estimate of the flux from Silo #3 is based on a number of assumptions, measurements and calculations listed below. A conservative, yet reasonable, approach was utilized in arriving at this estimate.

ASSUMPTIONS

1. The primary mechanism for release of radon from Silo #3 is the thermal expansion of the air in the headspace.

2. Silo #3 does not act as a pressure vessel to any significant degree, and is unable to contain the warming headspace air.

3. The area through which radon escapes is the area of the Silo #3 dome, 496 m^2.

4. Data on internal temperature of Silos #1 and #2 on May 8-11, 1987 after adjustment for percent sunshine during those days, represents average annual internal temperatures for Silo #3.

MEASUREMENTS:

1. The radon concentration in the Silo #3 headspace is 2.07×10^5 pCi/L ($\pm$ 12%).

2. The average internal maximum temperature fluctuation in Silos #1 and #2 measured on May 8-11, 1987 is 32.2 F (17.9 C).

3. The average internal maximum temperature fluctuation in Silo #3 for 7 days in December, 1990 was 10.5 C.

4. The daily temperature fluctuation at a point 2.5 ft. below the surface of the Silo #3 residues averaged approximately 0.1 C. There is no detectable pressurization of Silo #3.

CALCULATIONS:

1. The headspace volume was calculated to be 105 m^3 (see attachment). This was based on observations by at approximately 8 locations below the Silo #3 dome.

2. For the May 8-11, 1987 time period, the percent sunshine recorded at Greater Cincinnati Airport was 92.5%. The average for years 1984-1989 is 53%. Therefore, the sunshine factor for the May 8-11, 1987 time period is 1.745. When the observed temperature rise of 32.2 F is adjusted by this factor, the resulting average temperature fluctuation of 10.25 C is very close to the measured average for Silo #3 for 7 days in December, 1990 of 10.5 C.

THE ESTIMATE:

1. A temperature change each day of 18.45 F (10.25 C) will cause 105 m^3 of air to increase in volume to:
$$[(273 + 10.25)/(273)] \times [105] = 108.94\ m^3$$

2. The extra volume (3.94 m^3) will escape. This air will contain
$$3.94\ m^3 \times 2.07 \times 10^8\ pCi/m^3 = 8.161 \times 10^8\ pCi \text{ of } {}^{222}Rn$$

3. Averaged over the area of the Silo #3 dome,
$$[8.161 \times 10^8\ pCi] / [496\ m^2] = 1.645 \times 10^6\ pCi/m^2 \text{ each day}$$

4. And averaged over the 86,400 seconds per day,
$$[1.645 \times 10^6\ pCi/m^2 \cdot day] / [86{,}400\ sec/day] = 19.04\ pCi/m^2 \cdot sec$$

The uncertainty in the measurement of headspace radon concentration was ±12%. Combined with the uncertainties inherent in the estimation of temperature fluctuation and headspace volume, as well as the potential contribution to flux due to diffusion through four inches of concrete, it can be concluded that radon flux from Silo #3 exceeds 20pCi/m^2 sec.

*****! RADON !*****

Version 1.2 - May 22, 1989 - G.F. Birchard tel./ (301)492-7000
U.S. Nuclear Regulatory Commission Office of Research

RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

2245

Pit 2/18 12/9/90

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	2	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Pit 2 Waste

THICKNESS	400	cm
CALCULATED POROSITY	0.479	
MEASURED MASS DENSITY	1.38	g cm -3
MEASURED RADIUM ACTIVITY	412	pCi/g
DEFAULT LAYER EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	8.720D-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.747	%
MOISTURE SATURATION FRACTION	.367	
CALCULATED DIFFUSION COEFFICIENT	2.200D-02	cm^2 s^-1

LAYER 2 Pit 2 Cover

THICKNESS	15	cm
CALCULATED POROSITY	0.219	
MEASURED MASS DENSITY	2.07	g cm -3
MEASURED RADIUM ACTIVITY	0	pCi/g
DEFAULT LAYER EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	0.000D+00	pCi cm^-3 s^-1
WEIGHT % MOISTURE	5.6208	%
MOISTURE SATURATION FRACTION	.532	
CALCULATED DIFFUSION COEFFICIENT	7.800D-03	cm^2 s^-1

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DATA SENT TO THE FILE RNDATA' ON DRIVE A: 2245

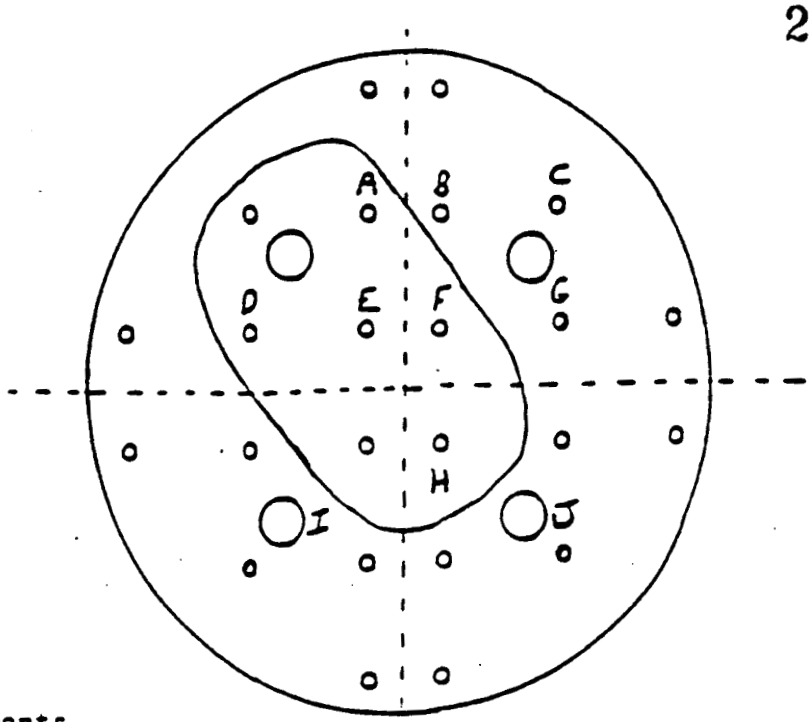
N	FO1	CN1	ICOST	CRITJ	ACC
2	-1.000D+00	0.000D+00	0	0.000D+00	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	4.000D+02	2.200D-02	4.792D-01	8.720D-04	3.671D-01	1.380
2	1.500D+01	7.800D-03	2.189D-01	0.000D+00	5.316D-01	2.070

BARE SOURCE FLUX FROM LAYER 1: 4.189D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi L^-1)
1	4.000D+02	2.029D+02	2.099D+05
2	1.500D+01	1.969D+02	0.000D+00



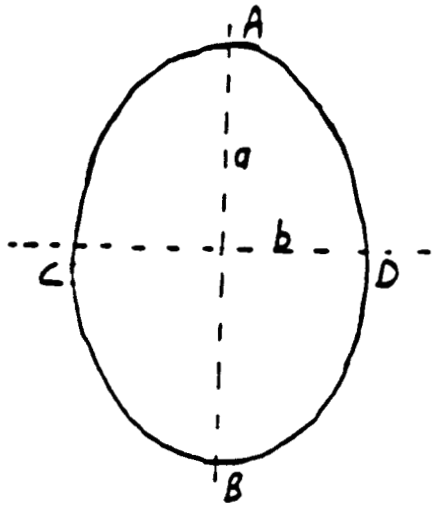
Silo 3 Dome
(Top View)

Actual Measurements
(underneath dome to
top of residue):

A=3'
B=1/2'
C=0'
D=3'
E=5 1/4'
F=2'
G=0'
H=3 1/4"
I=0'
J=0'

<u>Assumptions</u>

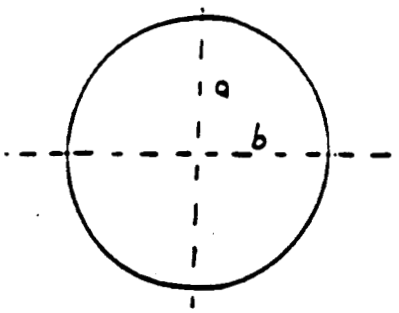
1) Location E is the center of the headspace.
2) The area of the headspace is elliptical in shape.
3) The dome surface used in the calculations is symmetrical.
4) The surface of the residues is level for calculations.
5) Radon is emitted from the silo as a result of thermal expansion of the air in the headspace.
6) The silo does not act as a pressure vessel.
7) Radon is being emitted through the entire dome. 496m^2



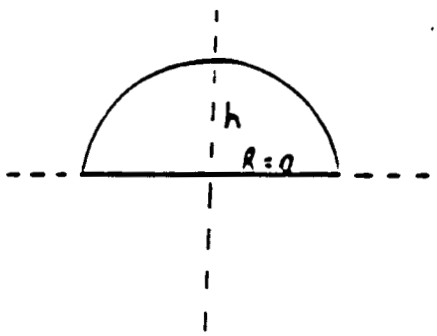
Scaled off engineering drawing
AB = 52 ft.
CD = 34 ft.

Area of an ellipse:

Area = π ab
= π(26)(17)
= 1388.6 ft.^{2}



a=b=R
πR^2 = 1388.6 ft.^{2}
R = 21 ft.



Volume of a Spherical Segment:

$V = 1/6\ \pi h(h^2+3a^2)$
$V = 1/6\ \pi(5.25)\ [(5.25)^2 + 3(21)^2]$
V = 3712.6 ft.^{3}

$3712.6\ \text{ft.}^3 \times \frac{1\text{m}^3}{35.3147\ \text{ft.}^3} = 105\text{m}^3$

LEE WAN & ASSOCIATES, INC.

LWA-18-91

MEMORANDUM

DATE: November 30, 1990

TO: LWA Central Files

FROM: Thomas N. Tucker, LWA TNT

SUBJECT: RADON DIFFUSION CALCULATIONS FOR SILO #3 USING BORAK EQUATIONS

Reference: "Calculation of Radon Emission; Dispersion and Dosimetry from K-65 Storage Tanks at the Feed Materials Production Center", Thomas Borak, October, 1985.

Borak develops four cases for radon emissions in the referenced paper. Case II - Closed Tank and Case III - Diffusion from Tank Cover are used here. For a closed tank, the concentration of Radon-222 in the headspace can be calculated from the following equation:

$$C_a = \frac{\phi}{\lambda}\left(\frac{\varepsilon \ell}{\varepsilon \ell + h}\right)$$

ϕ = Production of Rn-222 in pores

$$= \frac{[Ra]\ (EF)\ (\rho)\ (\lambda)}{\varepsilon} \quad (pCi/cm^3)$$

Using the values found in Borak's paper, an average Radium concentration of 2973 pCi/g from the sampling of Silo #3 and an average height of 2 feet,

$$\phi = \frac{2973(.2)(1.6)(2.11 \times 10^{-6})}{.3}$$

$$\phi = 6.69 \times 10^{-3}\ pCi/cm^3$$

Therefore

$$Ca = \frac{6.69 \times 10^{-3}}{2.11 \times 10^{-6}}\left[\frac{(.3)(150)}{.3(150) + 61}\right]$$

$$Ca = 1.34 \times 10^{3}\ pCi/cm^3$$

$$= 1.34 \times 10^{6}\ pCi/l$$

$V_d = 650.5m^3$

$V_T = V_b + V_d = 4494m^3$

6) Headspace volume = total silo volume - volume of residues

$V_h = V_T - V_R$

$V_h = 4494 - 3978 = 516m^3$

7) Headspace Rn content

$(207{,}000\ pCi/l)\ (10^{-12}\ Ci/pCi)\ (10^3 l/m^3)\ (516m^3)$

$= .107\ Ci$

8) Volume of air emitted daily

$V_1T_2 = V_2T_1$

$V_2 = V_1 \frac{T_2}{T_1} = 516 \frac{(297.5)}{285.5} = 538m^3$

$V_2 - V_1 = 538m^3 - 516m^3 = 22m^3$

9) Radon Emissions

$(207{,}000\ pCi/l)(10^{-12} Ci/pCi)\ (22m^3)(10^3 l/m^3) =$

$4.55 \times 10^{-3}\ Ci/day$

10) Radon Flux

$(4.55 \times 10^{-3} Ci/day) \frac{(1\ dy)}{86{,}400\ sec} \left(\frac{1}{485m^2}\right)$

$= 1.09 \times 10^{-10}\ Ci/m^2\text{-}S$

$= 109\ pCi/m^2\text{-}S$

APPENDIX D

RISK ASSESSMENT

LEE WAN & ASSOCIATES, INC.

LWA-19-91

M E M O R A N D U M

DATE: December 3, 1990

TO: LWA Central Files

FROM: Thomas Tucker, LWA TNT

SUBJECT: RADON FLUX CALCULATIONS FOR SILO #3

On November 15, 1990, WMCO provided the measured Silo #3 Radon - 222 headspace concentration. An estimate of radon flux was made using this information. The estimate is based on assuming that the average daily temperature change results in the release of a volume of air from the silo at the measured headspace concentration. The methodology used and the results are provided below:

SILO #3 RADON FLUX - "BREATHING LOSS"

1) Silo #3 is basically not a pressure vessel, assume delta P approaches 0.

   delta T = 12 degrees C (annual avg. ambient for FMPC)
   delta V - calculate

2) Surface area of silo domes = 485 m^2
   (from J. Craig calculation 1/90)

3) Silo #3 headspace concentration
   207,000 pCi/l (from measurement)

4) Volume of silo residues
   3900m^3 (RI/FS data)
   Assume 2% void space = 3978m^3

5) Silo volume (V_T) = Silo base (V_b) + silo dome (V_d)

   $V_b = \pi r^2 h$ r = 12.2m h=8.23m

   $V_b = 3848.4 m^3$

   $V_d = 1/6 \ \pi h (3a^2 + h^2)$ [Segment of a sphere]

   a = 40 ft = 12.19m

   h = 9 ft = 2.74m

Note: An average headspace height of 3 feet would result in $\approx 10^6$ pCi/l

To calculate diffusion through the cover, Borak uses the following equation:

$$J = \varepsilon \lambda l \left[\frac{Ca}{\sinh(L/l)} \right]$$

Using the values in Borak's paper and Ca as calculated above:

$$J = .3(2.11 \times 10^{-6})(12) \left(\frac{1.34 \times 10^{3}}{.929}\right)$$

$$= .011 \text{ pCi/cm}^2\text{-s} = 110 \text{ pCi/m}^2\text{-s}$$

However, Silo #3 is not a closed tank, and the silo headspace concentration has been measured. The average value is 207,000 pCi/l. Using this value in Borak's equation yields:

$$J = .3(2.11 \times 10^{-6})(12) \left(\frac{2.07 \times 10^{2}}{.929}\right)$$

$$= 1.68 \times 10^{-3} \text{ pCi/cm}^2\text{-s}$$

$$= 16.8 \text{ pCi/m}^2\text{-s}$$

RISK ASSESSMENT

This appendix summarizes the methods, models, and results of the dose calculations used to assess the health effects from two postulated and one actual scenario for releases from Silo 3.

1.0 AIRDOS Modelling

This study addressed three scenarios:

1) Catastrophic failure - This is the type of failure potentially experienced under severe natural phenomenon conditions. This scenario addresses the dispersal of particulates. Weather patterns typical of a tornado were used to model this scenario.

2) Acute failure - This scenario looks at the impact of sufficient silo cracking to release a relatively small amount of material over a significant period of time.

3) Chronic release - Radon is currently being emitted from Silo 3. This scenario looks at the consequences of allowing that release to continue unabated.

Each of these scenarios was subject to modelling assumptions. These assumptions were critical in determining the model. The AIRDOS-EPA computer package was used in all three cases. Because AIRDOS models chronic releases over time intervals of about one year in duration, input data modifications were made to make the results relevant to short time interval scenarios. The specific input for each case was determined on the basis of the limitations and flexibility of the AIRDOS program. The following section describes the assumptions and models used. Reference 1 provides the printed results for the computer runs made to support this study.

2.0 Assumptions

2.1 Scenario 1 - Catastrophic Failure of Silo 3

This scenario addresses the consequences of dispersal of Silo 3 particulate material. Silo 3 particulates contain Thorium-230,232, Uranium-238,234,235, and Radium-228,226. The average concentration of ^{230}Th in Silo 3 is 51,200 pCi/g. The ^{230}Th concentration is an order of magnitude greater than any other single individual radionuclide and has a total activity greater than all the other radionuclides combined. Based on both the concentration and human health impacts, ^{230}Th was determined to be the principal radionuclide of concern. The models (exposure scenarios and transport processes) were evaluated using only the ^{230}Th isotope. ^{230}Th was the only contaminant considered in the AIRDOS-EPA computer runs.

The total mass of metal oxides is necessary to determine the total ^{230}Th inventory. A study completed in 1963 by NLO concluded that Silo 3 contains between 4.0 and 4.8 million pounds. Another study, completed in 1985 also by NLO, concluded that there are 7.7 million pounds. The largest estimate was used to determine the inventory of ^{230}Th. This produced the most conservative result, i.e. the largest thorium inventory, 179.2 Ci.

Determining the amount of material released in this or any accident scenario is one of the most critical assumptions that is made. Unfortunately, an accepted standard approach to making this approximation does not exist. The recently completed Thorium Warehouse RSE assumed a release fraction of 10% of the total inventory. Without a better defined approach, this amount, 10%, was used as the release fraction for the catastrophic failure scenario.

For the purposes of evaluating atmospheric dispersion of contaminants using the Gaussian Plume model specific dispersion coefficients are required. The dispersion coefficients are modeled using a statistical distribution of atmospheric parameters averaged over a time frame of one year. These atmospheric parameters include stability class, wind speed, and direction. The atmospheric stability class relates issues such as turbulence, quantity of insolation (heat input from the sun), lapse rate, wind speed gradients, and pressure gradients. The stability classes are delineated with letter designations from A through H. The designation is in general from most turbulent to most stable. There are additional variances between the classes which relate to the above atmospheric parameters, however these differences do not significantly affect the use of the dispersion coefficients. The classes from A to F were originally designated by Pasquill in the development of the Pasquill - Gifford system associated with the dispersion coefficients that are used in the AIRDOS-EPA code. For purposes of this RSE the A stability class refers to the greatest dispersion while the F class relates to the least amount of wind turbulence.

The prevailing winds of a tornado are primarily in one direction. That fact, coupled with the relatively short duration and high wind speeds will direct most of the contaminants into one small region. AIRDOS divides the surrounding region into sixteen equally spaced sectors. In determining the particle distribution, AIRDOS uses a wind frequency table that contains, among other things, data related to wind direction frequency. This table was manipulated so that it appeared that the wind always came from only one of the sixteen compass directions. This has the effect of blowing all of the released contaminants into only one of the sixteen sectors. This "single sector" approach is patterned after the approach used in the Probabilistic Risk Assessment (PRA) completed by UC in 1990 to evaluate the exposure that results from a catastrophic failure of the K-65 silos.

The maximally exposed individual is considered to be directly exposed to the contaminant plume for one hour. This exposure time is an approximation based on maximum durations of a typical tornado. The breathing rate used by AIRDOS to calculate inhalation exposure was adjusted to reflect this time interval for direct plume exposure.

Direct plume exposure is one source of inhalation exposure. The other is inhalation of contaminants due to the resuspension of contaminated ground. The method used in this calculation is, again, the same used in the PRA.

$$Dose = Conc(\frac{pCi}{g}) x DCF(\frac{mrem}{pCi}) x FI(\frac{m^3}{yr}) x FO(0.6) x ASR(\frac{g}{m^3})$$

where Dose = Annual dose to the exposed individual (mrem/yr)
Conc = Concentration of the radionuclide in the ground (pCi/g)
DCF = Dose conversion factor (0.262 mrem/pCi for whole body)
FI = Inhalation rate (7300 m^3/yr)
FO = Occupancy factor for the inhalation pathway (0.6)
ASR = Air-to-Soil Concentration Ratio (RESRAD default of 2.0e-04)

In the PRA Janke et al. assumed that the particles are deposited as follows: 90% within 300 feet, 9% between 300 and 2500 feet, and 1% entrained in the atmosphere. It is the 9% in the 300 to 2500 feet range that is available for resuspension at the nearest receptor. There is some question as to the validity of the 9% model as it pertains to the metal oxides contained in Silo 3. The 90/9/1% model was used for a K-65 release, but the material in Silo 3 is much finer and more amenable to airborne dispersion. Therefore, to establish an upper bound, the dose was also determined for 100% settling in the 300 to 2500 feet range. The area was calculated for a wedge of 22.5° between 300 and 2500 feet. Since concentration is required to calculate the resuspension dose, the amount of material deposited on the ground must be in units of Curies per unit volume. This is achieved by dividing the areal concentration by the penetration depth. Values given for typical penetration depths are based on the assumption that sufficient time has elapsed allowing contaminants to penetrate into the soil. The exposure time of one year used for the resuspension model is assumed long enough to allow for sufficient penetration. Fifteen centimeters was used in these calculations for the penetration depth (Till and Meyer). Finally, a soil density of 1.8 grams/cm^3 was used to convert the concentration into units of activity per unit mass (Janke). Figure 1 graphically depicts this calculation.

The nearest receptor is assumed to live 500 meters from the release site. It is assumed that this receptor also lives in the direct path of the tornado, i.e. in the sector that receives all of the contaminants. Although this is not the most probable scenario, it is the most conservative.

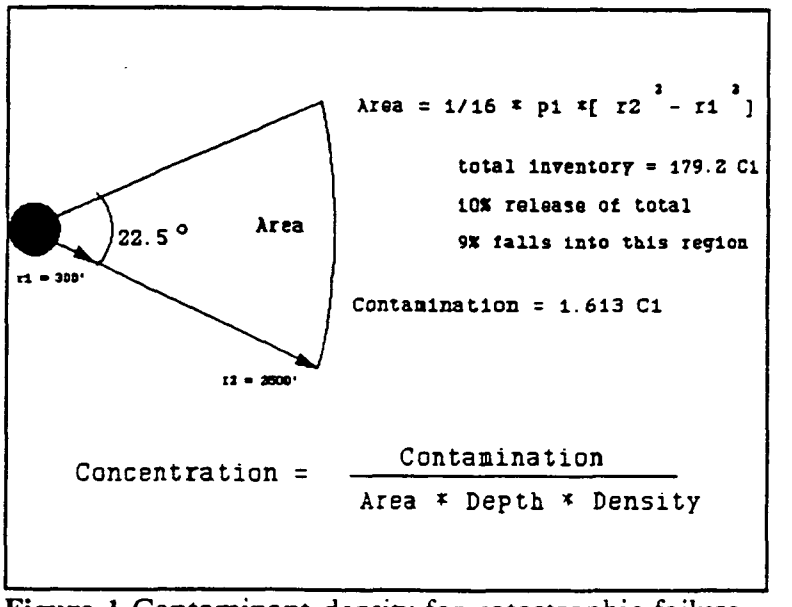


Figure 1 Contaminant density for catastrophic failure

2.2 Scenario 2 - Acute Failure of Silo 3 Integrity

This scenario, like scenario one, addresses the impact of dispersal of Silo 3 particulates. Therefore the scenario one assumption regarding the dominance of ^{230}Th in the total dose is also valid for this scenario. However, the amount assumed released for this situation is much less: 0.01% of the total inventory. This value represents about 25 pounds per day released each day over a one month duration.

The time interval over which this failure occurs is longer than that of scenario one. Material begins escaping as soon as the crack develops and continues until it is discovered, sealed, and the released metal oxides contained. There is no developed approach to determining this time interval, so a conservative estimate of one month for the period of material release is assumed.

The wind frequency table used by AIRDOS was briefly discussed in the previous section. The table is supposed to contain actual meteorological data for the local area, which designates the probability of the occurrence of a particular wind speed, wind direction, and atmospheric stability class. While modeling the K-65 silo release scenarios, Janke et al. compiled this data and generated an applicable wind frequency table. That table was also used for this model.

Resuspension was also determined for this scenario. The same approach as was used in scenario one was used to determine the associated dose. The only differences between scenarios one and two are the source terms and the area over which the contaminants are deposited. The source term in this scenario is 0.01%. The upper bound was not calculated for this scenario, as it would be inconsistent with the scenario to assume that all of the contaminants released could be transported over 300 feet under typical meteorological conditions. The area considered is the whole circular area around the source. Dose is directly proportional to the source and inversely proportional to the area; therefore, the dose from resuspension in scenario two is $16*10^3$ times less than that of scenario one.

2.3 Scenario 3 - Chronic Release

This scenario address the impact of the chronic release of radon. The release of radon from Silo 3 has been estimated to be 19.04 pCi/m^2sec (DOE-417-91). The annual release rate, obtained by multiplying this value by the area of the silo dome, is 0.298 Ci/year.

Janke, et al. modelled the release of radon from the K-65 silos using a steady annual release rate of 650 Ci/year. The relationship between concentration and dose is linear. Therefore, the ratio of the source terms is equal to the ratio of the doses.

$$\frac{Silo3\,source}{K\text{-}65\,source} = \frac{Silo3\,dose}{K\text{-}65\,dose} = \frac{1}{2,183}$$

All of the other assumptions used by Janke apply to this model. Therefore, the results from that study were multiplied by the ratio of the source terms.

3.0 Results

The results of the AIRDOS modelling calculations are presented in Tables 1, 2, and 3. Tables 1a, 1b, and 1c present the results for direct inhalation for the three identified scenarios. Table 2 presents the results for resuspension of particulates and Table 3 sums the data of Tables 1 and 2. The risk associated with each scenario is delineated in Table 4.

3.1 Inhalation Doses

The doses for a catastrophic release were calculated for three wind stability categories. Tornadic conditions are category A (unstable), but categories C and F were also modelled to determine the effect of stability on the dose. As noted in the preceding section, wind stability is internally integrated into the calculations for scenarios two and three.

Table 1a. Catastrophic Failure

Dose at 500 meters (rem/year) in three stability categories for the catastrophic failure scenario		
A	C	F
4.44	11.4	22.7

Table 1b. Acute Failure

Dose at 500 meters (rem/year) for the acute failure scenario
0.0313

Table 1c. Chronic Release of Radon

Dose at 500 meters (rem/year) for the chronic release scenario
$1.0e^{-04}$

3.2 Resuspension Doses

Inhalation doses were calculated for resuspended particulates for scenarios one and two. For scenario one the dose was calculated for the cases of 9% and for 100% of the material being deposited between 300 and 2500 feet downwind of the release point. For the second scenario the 100% deposition case is not applicable.

Table 2: Results for Resuspension

Percent of release settled b/w 300 and 2500 feet	Catastrophic failure resuspension dose at 500 meters (rem/year)	Acute natural failure resuspension dose at 500 meters (rem/year)
9 %	0.0122	7.70e-07
100 %	0.136	NA

3.3 Combined Doses

The combined doses for direct plus inhalation of resuspended particulates is given for the three wind classifications and the two deposition percentages for the catastrophic failure scenario. For the acute failure and the chronic release scenarios there is only a single dose value.

Table 3: Combined Dose from Direct Inhalation and Resuspension

Percent of release settled b/w 300 and 2500 feet	Scenario 1 results for the following stability classes (rem/year)			Scenario 2 results (rem/year)	Scenario 3 results (mrem/year)
	A	C	F		
9 %	4.45	11.4	22.7	0.0313	0.10
100 %	4.58	11.5	22.8	-	-

3.4 Risk

From the Health Effects Assessment Summary Tables (HEAST), the Slope Factor for ^{230}Th is 3.1E-08 per pCi inhaled. Using the Dose Conversion factor of 0.262 mrem/pCi from the resuspension calculation, the calculated doses were converted back into pCi inhaled, then multiplied by the Slope Factor to evaluate the risk. For each dose value in Table 3 there is a corresponding risk value in Table 4 for scenarios one and two. HEAST numbers for radon and its progeny were not applicable when these calculations were made. For radon a risk conversion factor that is consistent with BEIR V (5e-07 risk per mrem) was used to convert dose into a lifetime fatal cancer risk.

Table 4: Risk

Percent of release settled b/w 300 and 2500 feet	Scenario 1 risk for the following stability classes			Scenario 2 risk	Scenario 3 risk
	A	C	F		
9 %	1.38e-04	3.53e-04	7.04e-04	9.70e-07	5e-08
100 %	1.42e-04	3.57e-04	7.07e-04	-	-

4.0 References for Appendix D

1. Memorandum WEMCO:ER:OU4:91-116, "AIRDOS Calculations for the Removal Site Evaluation for Silo 3," dated September 25, 1991

2. Letter WEMCO:EMT:91-391, "Removal Site Evaluation - Thorium Storage Warehouses," dated July 29, 1991

3. Janke, R. J., Janke, R. C., and Ijaz, Talaat, 1990. A Probabilistic Risk Assessment for the K-65 Silos at the FMPC.

4. Till, John E. and Meyer, Robert H., 1983. Radiological Assessment: A Textbook on Environmental Dose Analysis. U. S. NRC NUREG/CR-3332.

5. Letter, DOE-417-91, G. W. Westerbeck to David Kee, "Report on Radon Flux Measurements," dated December 17, 1990

6. Health Effects Assessment Summary Tables - Third Quarter FY - 1990, U. S. EPA, July, 1990

7. "Health Effects of Exposure to Low Levels of Ionizing Radiation", BEIR V, National Academy Press (1989)