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FEASIBILITY INVESTIGATION FOR CONTROL OF RADON EMISSION FROM THE K-65 SILOS

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FEASIBILITY INVESTIGATION FOR CONTROL

OF RADON EMISSION FROM THE

K-65 SILOS

JULY 30, 1987

PREPARED BY

JOSEPH T. GRUMSKI

WASTE REMEDIATION AND ENVIRONMENTAL ENGINEERING

pg 3 of 4

FEED MATERIALS PRODUCTION CENTER

Westinghouse Materials Company of Ohio

Attachment to: 01

REVISION 1

FEASIBILITY INVESTIGATION FOR CONTROL OF RADON EMISSION FROM THE K-65 SILOS

July 30, 1987

Prepared by

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Waste Remediation and Environmental Engineering

Westinghouse Materials Company of Ohio

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EXECUTIVE SUMMARY

In response to Item B of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Section of the Federal Facilities Compliance Agreement between the Department of Energy (DOE) and the Environmental Protection Agency (EPA), the Feed Materials Production Center (FMPC) has prepared a Feasibility Investigation (FI) that evaluates alternatives for the control of radon emissions from the K-65 Silos.

The alternatives considered in the FI for the control of radon emissions include water column absorption, solid media adsorption, void space filling and temperature control. The four alternatives were evaluated and ranked on the criteria of environmental acceptability, reliability/operability, implementation time, and cost.

Based upon the analysis presented in the FI, the FMPC is within all applicable DOE and EPA guidelines and regulations for the emission of radon from the K-65 Silos. However, it is the FMPC's goal to continue to meet the dose standards in Subpart A of 40 CFR 191 (Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste) and therefore additional radon control is recommended.

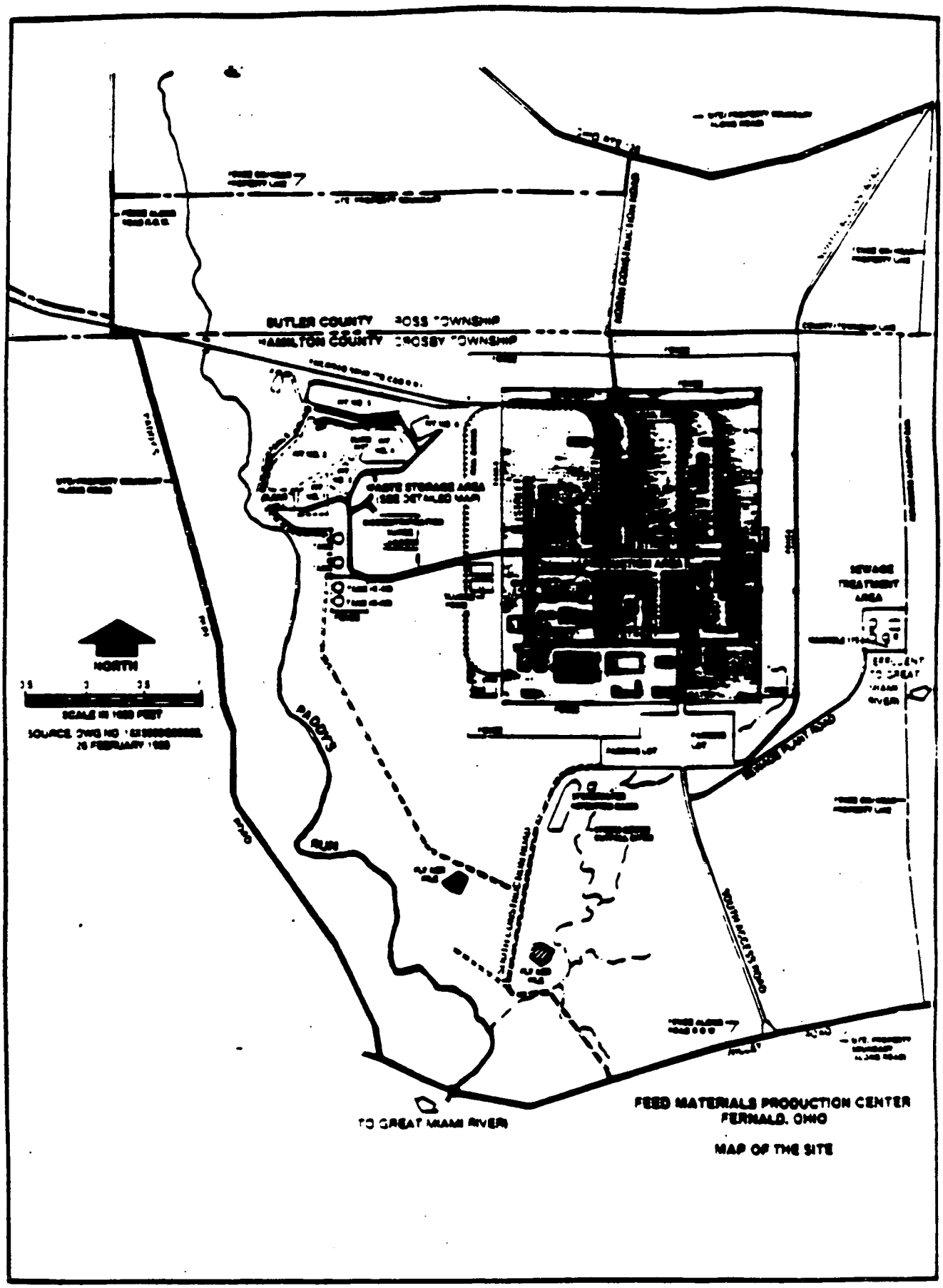
Specifically, the FMPC recommends that final detailed design for the system to fill the void space in the K-65 Silos with foam, including a temporary solid media adsorption system to treat the initial displaced radon gas be completed and the system installed and operational by the end of November, 1987. In addition, the FMPC recommends that completion of the weatherproofing project be initiated after the silos are filled; as soon as the weather permits.

1.0 INTRODUCTION

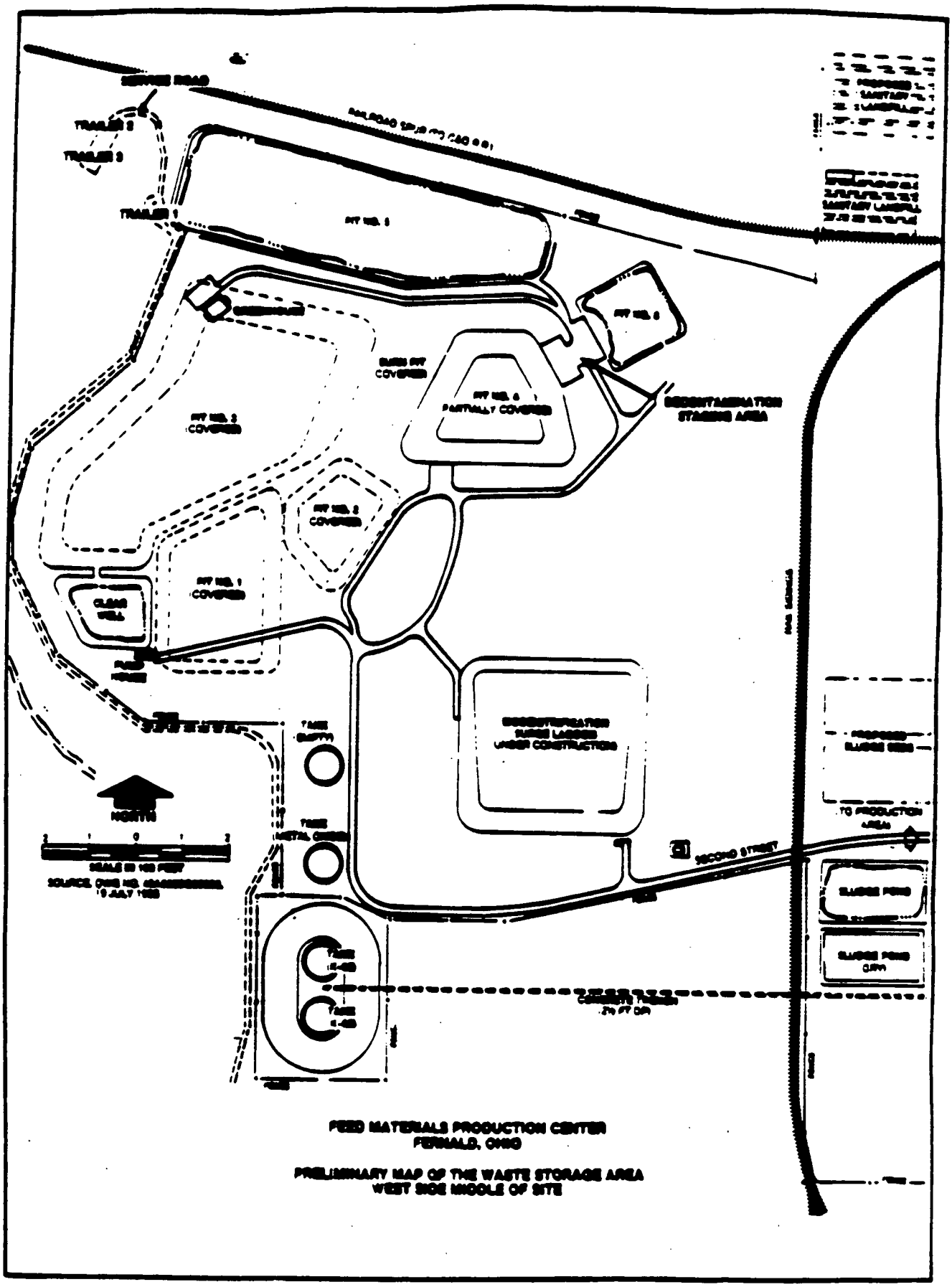
Westinghouse Materials Company of Ohio (WMCO) operating under its prime contract with the United States Department of Energy (DOE), coordinates activities, including waste management, at the Feed Materials Production Center (FMPC) located in Fernald, Ohio.

As part of the comprehensive waste management and environmental program for the FMPC, specific alternatives are being developed and evaluated for the final disposition of the low-level radioactive waste inventory currently stored at the site. The Waste Storage Areas under evaluation in this program consist of six storage pits, the clear well, the burn pit, two fly ash piles, and adjoining areas (Figure 1.0-1).

This Feasibility Investigation (FI) evaluates alternatives that could be utilized to mitigate radon emissions from the two concrete silos in the Waste Storage Area which contain K-65 residues (Figure 1.0-2). The FI consists of a description of the K-65 Silos and the residues, current structural status, summaries of both the Monsanto-Mound and FMPC Environmental Monitoring Reports as related to radon emissions, an evaluation of radiation doses associated with radon releases, a discussion of the pressure and temperature monitoring of the silos, an evaluation of the alternatives considered, and recommendations relating to the alternatives.



MAP OF THE SITE
FEED MATERIALS PRODUCTION CENTER, FERNALD, OHIO



MAP OF THE FMPC WASTE STORAGE AREA

FIGURE 1.0-2

The primary objective of the FI is to identify if additional radon emission controls are necessary for the K-65 Silos and recommend the best evaluated alternative if additional controls are required. The interim controls would be necessary until the ongoing Remedial Investigation/Feasibility Study (RI/FS) can be evaluated and alternatives implemented (3-5 years). The purpose of the RI/FS is to characterize the FMPC site through sampling and analysis to identify elements requiring remediation efforts.

2.0 BACKGROUND

2.1 Historical Information

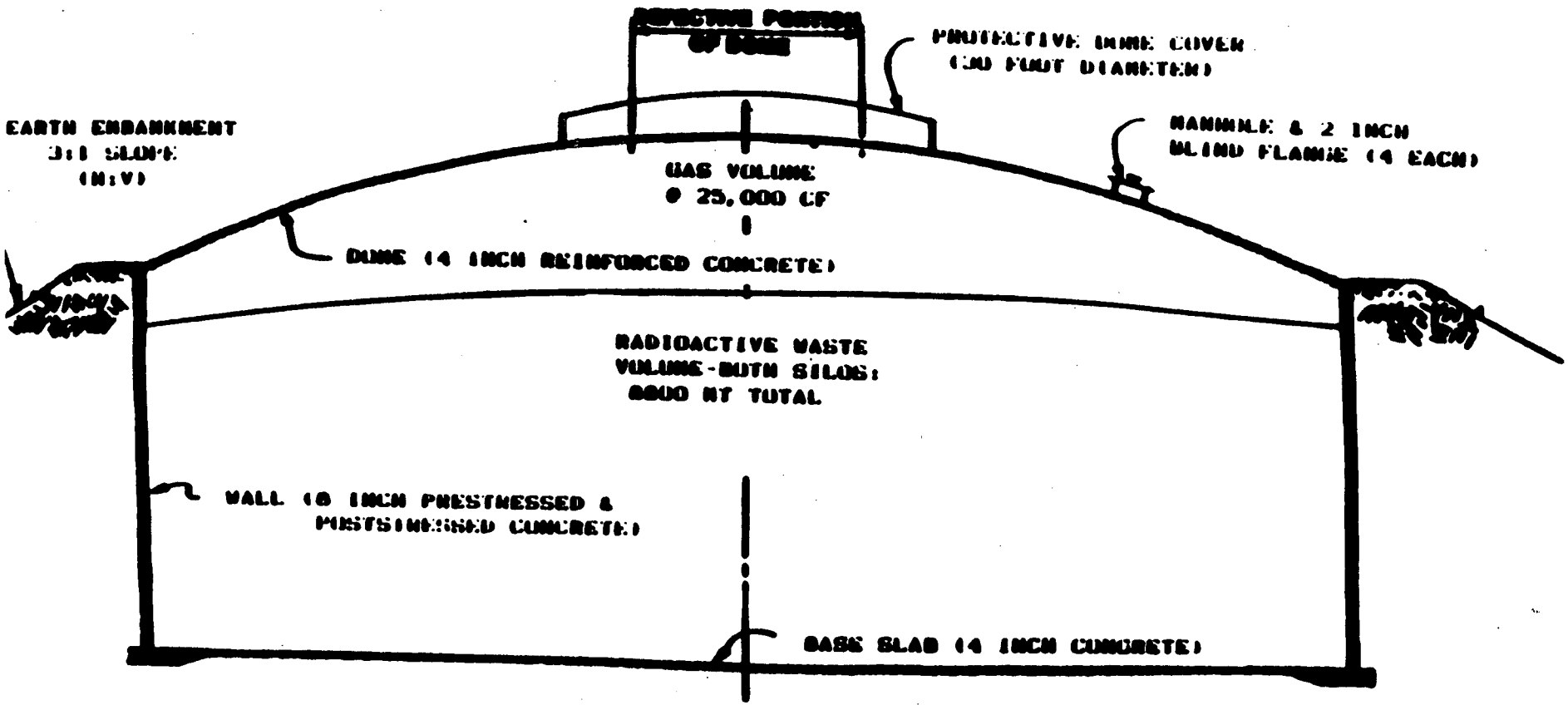
The two K-65 Silos, located on the west side of the Fernald site, were constructed in 1951 and 1952. The silos are used for storage of radium bearing residues, a by-product of uranium ore processing. The silos are of cylindrical concrete construction, 80 feet in diameter and approximately 27 feet high. The silo domes were originally designed to be 8 inches thick at the dome wall tapering to 4 inches thick at the center. Figure 2.0-1 shows the major structural details of the K-65 Silos.

The walls were post-tensioned reinforced with 0.162 inch diameter wire stressed to 140,000 pounds per square inch (PSI) (with assumed 30% loss, for a design stress of 100,000 PSI). These post-tensioning wires were covered by a 3/4 inch thick gunite coating. The minimum 28-day compressive strength used was 4500 PSI for the dome and walls and 3000 PSI for the floor and footing. The maximum allowable soil pressure was 4000 pounds per square foot (PSF).

The silos were designed to be loaded with the metal oxides in slurry form at a maximum rate of 8000 gallons per day. The radioactive residues were allowed to settle and the water was decanted, leaving a sludge with a density of 100 pounds per cubic foot (PCF) and angle of repose of 0 degrees. The maximum allowable height of solid material was 23 feet and the water was decanted to a plant to be reused in the production of additional slurry.

TYPICAL SECTION THRU

K-65 SILO



8 INCH GRAVEL BASE & UNDERDRAIN SYSTEM

2 INCH ASPHALTIC CONCRETE

17 INCH COMPACTED CLAY

In 1963, the silos were showing signs of exterior surface deterioration. Large areas of spalling occurred in the exterior surface gunite coating, particularly on the north silo, leaving post-tensioning wires exposed to weather. Subsequently, patches of the wires became severely corroded and broken. Various options were investigated as remedial actions for the silos. Repairs began in 1964 by first chipping away all loose gunite material and then patching the surface with 3/4 inch coat of cement mortar. After the gunite was repaired, and a waterproofing sealant was applied to the external silo walls, an earth embankment was built to the top of the wall on a one and one-half to one (1-1/2:1) slope (horizontal:vertical). The earthen embankment was to provide relief from tensile stress within the walls by counterbalancing the load from the internal contents, since the broken wires were not replaced. A soil was chosen with roughly the same density (125 PCF) as the contents of the silos (100 PCF). Additional purposes of the embankment were to provide weather protection and to reduce the radon emission from the silos, and to reduce direct radiation doses from the silos.

All of the vents on the silos were sealed in 1979 in an attempt to reduce radon emissions from the silos. In the subsequent years problems with soil erosion on the soil embankment were frequent. The eroded areas were repaired, but with heavy rains the problem reoccurred. In 1983, the embankment was enlarged to achieve a 3:1 slope. No further evidence of large scale erosion has occurred.

2.2 K-65 Silo Waste Characteristics

The current volume of K-65 residues contained in the silos (1&2) at the FMPC is estimated to be 195,000 cubic feet (8800 M.T.). The best available data to date concerning the chemical and radiological characteristics of the K-65 residues are summarized in sections 2.2.1 and 2.2.2 (Reference 1).

2.2.1 Chemical Characteristics

Inorganic constituent analyses for nonradiological elements in the K-65 residue at the FMPC are summarized in Table 2.2.1. Approximately 40 percent of the K-65 waste is composed of silicates (SiO_2). The other constituents comprising one percent or more of the residue include calcium, iron, magnesium, and lead. No data for organic constituents of the FMPC K-65 residues are available.

2.2.2 Radiological Characteristics

The radiological constituents of the K-65 residue at the FMPC have been estimated to include 11,200 kg of uranium (0.71 percent U-235) and 1,652 Ci of radium (Ra-226). The radium concentration is 2.0×10^5 pCi/g. Radon flux measurements made in October 1984 at 24 locations on each silo ranged from 13 pCi/m^2/sec to greater than 3×10^7 pCi/m^2/sec. The highest flux values were obtained on surfaces which contained obvious cracks.

TABLE 2.2.1

ELEMENTAL CHARACTERIZATION OF THE FMPC
K-65 WASTES[1]
September 1970

Constituent	Percentage	Weight (Metric Tons)
Metals:		
Ag	<0.002	0.176
Al	0.875	77
As	<0.03	<2.64
Au	<0.005	0.44
B	0.015	1.32
Ba	0.07	6.16
Be	ND*	--
Bi	ND*	--
Ca	3.89	342
Cd	ND*	--
Cl	No Data	--
Co	0.175	15.4
Cr	0.012	1.06
Cu	0.05	4.4
F	No Data	--
Fe	1.2	105.6
Hg	ND*	--
La	0.089	7.83
Mg	1.25	110
Mn	0.02	1.76
Mo	0.02	1.76
Na	0.7	61.6
Ni	0.225	19.8
Pb	5.1	448.8
PO4	ND*	--
Sb	ND*	--
Se	No Data	--
SiO2	40.76	3,587
Sn	0.008	0.7
SO4	No Data	--
Ti	0.07	6.16
V	0.021	1.85
Zn	ND*	--
Zr	0.02	1.76

*ND = Not Detected

TABLE 2.2.1

(Continued)

ELEMENTAL CHARACTERIZATION OF THE FMPC
K-65 WASTES[1]
September 1970

Constituent	Percentage	Weight (Metric Tons)
Rare Earths:		
Dy	0.003	0.26
Er	ND*	--
Eu	ND*	--
Gd	0.004	0.35
Ho	<0.0015	0.13
Lu	ND*	--
Sm	0.0048	0.42
Tb	ND*	--
Tm	<0.0008	0.07
Y	0.004	0.35
Yb	0.0006	0.05

*ND = Not Detected

[1]Percentage and weight are based on sample analysis and do not account for total reported amount (8800 m.t.) of K-65 residues.

3.0 CURRENT K-65 SILO STRUCTURAL STATUS

3.1 Structural Investigation and Analysis

In July of 1985, Camargo Associates, Ltd (Camargo) was subcontracted to perform a nondestructive testing program and structural analysis on the K-65 Silos (Silos 1 and 2) using state-of-the-art testing equipment and computer modeling techniques.

The silo investigation consisted of three phases. The first phase was a computer analysis of the storage silos depicting the original "designed" condition of the silos based on the original construction drawings and specifications.

The second phase consisted of field work that was divided into three areas. These were; the soil exploration study, the "Echo Pulse" system of testing the silo domes, walls and base slabs, and the "Ground-Radar Survey" of the earth embankment around the K-65 Silos. The field work activities were subcontracted by Camargo to Muenow and Associates and Soil & Materials Engineers, Inc.

The third phase was a detailed computer analysis of the K-65 Silos utilizing the results of the initial "designed" computer analysis and the field work data. This work was done by Camargo utilizing three-dimensional modeling programs. The final report of Camargo's study was issued on February 25, 1986 (Reference 2).

Based on their investigation and analysis of the K-65 Silos, Camargo made recommendations and conclusions concerning the silos. A summary of the Camargo recommendations and conclusions are as follows:

1. The base slab and walls at the time of the investigation were structurally stable under the existing static loads being applied to them and should continue to remain stable for approximately 5 to 10 years.

2. If either the contents of the silos or the silo embankment were to be removed, they must be removed simultaneously or failure of the walls or base slab could result.

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

4. The application of a three foot thick earth fill load on the dome or the application of tornado suction or pressure loads, would cause a structural failure of the dome.

5. The application of the "defined" synthetic earthquake would induce some additional cracking in the base slab and at the base of the silo wall, but the silo would still be in a serviceable condition. The dome would be unaffected, and should simply move with the ground motions.

6. If a cover is chosen to cover the center portion of each silo dome, the weight should be as light as possible and in no case should it be greater than that allowed by the buckling capacity of the dome (approximately 11,000 pounds).

Additionally, the Camargo report concluded that the dome of the silos were the most critical part of the entire silo structure system. The critical buckling load of the domes was calculated to be approximately 284 PSF for the existing concrete outside the center 20 foot critical dome area. Using a safety factor of 4 the allowable load would be 71 PSF. Inside the critical 20 foot diameter area, the buckling load was calculated to be approximately 104 PSF for the existing concrete. Using a safety factor of 4, the allowable load would be 26 PSF (based on a 2 inch thick area of concrete). The allowable buckling load for the center 20 foot area, therefore, is nearly the same as the dead weight of the dome itself.

3.2 Structural Remedial Actions

In response to the Camargo recommendations, the FMPC had a temporary dome, 30 feet in diameter, designed and installed to span across the weakened portion of the concrete domes. The cover is self supporting and sits on a rolled plate steel skirt. The 30 foot diameter cover is composed of structural steel members which supports 3/4 inch plywood sheeting. The plywood sheeting is covered with a weatherproofing membrane. The dome cover increases the stresses in the existing

concrete, but all str ses are within acceptable limits. The dome cover was installed so that containment of the silos contents will be maintained in the event of a center silo dome collapse. This work was completed in January, 1986.

In addition to the dome cover, the installation of an applied fluid neoprene membrane was initiated to cover the existing concrete dome outside the dome cover on the K-65 Silos. The neoprene membrane is designed to prevent water from seeping into the silo dome cracks; thus, limiting further deterioration. It is postulated that the membrane will also inhibit the escape of radon gas and radon daughter products to the environment. This work is currently on hold due to increased radiological concerns stemming from application of the membrane.

4.0 RADON EMISSIONS FROM THE K-65 SILOS

4.1 Summary of the Radon Monitoring Program Report

From September 20, 1984 to February 5, 1985, Monsanto-Mound conducted radon gas monitoring in the environs of the K-65 Silos (Reference 3). The objective of the monitoring program was to assess the extent of increased radon concentrations due to the radium-bearing K-65 residues stored in silos 1 and 2. The radon monitoring program consisted of two subtasks: 1) measurement of radon flux from the surface of the K-65 Silos; and 2) measurement of radon concentrations in the surrounding K-65 Silo environment.

4.1.1 Radon Flux Measurements from the Dome Surfaces

In order to determine the radon gas flux from the surface of the K-65 Silo domes, Monsanto-Mound employed the use of charcoal canisters which were placed on 24 locations on both the K-65 Silos domes. After a period of exposure, the radon-222 content of each canister was then analyzed in the radon laboratory at Monsanto-Mound.

The flux measurements ranged from approximately 13 $pCi/m^2/sec$ to 3×10^7 $pCi/m^2/sec$. By comparison, the Environmental Protection Agency standard for uranium mill tailings disposal sites is 20 $pCi/m^2/sec$.

Monsanto-Mound reported that although the measured flux values tended to be higher than those found on inactive mill tailings sites, the surface areas of the tanks are substantially less than those of the tailing sites (ten thousand square feet versus many acres). Monsanto-Mound concluded that the annual radon release from the K-65 Silos is probably less than from the inactive mill tailings sites (200 to 11,500 Ci/yr) and the silos represent a very discontinuous source.

4.1.2 Radon Air Measurements in the Vicinity of the Silos

Time-integrated measurements of radon in air around the K-65 Silos were conducted by Monsanto-Mound utilizing Passive Environmental Radon Monitors (PERMs). After the PERMs were exposed from one to two weeks, the lithium fluoride chips located in each PERM were read and the radon concentration calculated. The results of the radon monitoring between September 20, 1984 and December 5, 1985 ranged from 5.1 pCi/liter near the K-65 Silos to 0.24 pCi/liter at locations farthest downwind along the eastern FMPC site perimeter (approximately 0.75 miles). In comparison, the average background radon concentration for other locations in the northeastern United States ranges from 0.2 to 0.3 pCi/liter. The radon concentration values measured near the K-65 Silos are below the DOE guideline value of 3.0 pCi/liter above background for uncontrolled areas and 100 pCi/liter value for occupational exposures.

4.2 Summary of the FMPC Radon Monitoring Network

A radon monitoring program has been implemented by the FMPC for the fenceline and offsite environs. The program monitors both radon-222 and radon-220 (thoron) to determine the radiation exposures to humans from both radon and its decay products.

Radon-222 is monitored with track-etch detectors which consist of alpha sensitive plastic detectors mounted inside inverted cups covered by a membrane to prevent radon decay products from entering the cup and being detected. This membrane also sufficiently retards the diffusion of radon to the extent that the short-lived radon-220 does not enter these cups; however, the radon-222 does diffuse through the membrane. A second track-etch cup is also located at each radon monitoring location. The filter over this cup is permeable to radon, allowing both radon-222 and radon-220 to enter the cup, while preventing entry of decay products. Radon-220 concentrations can, therefore, be determined by subtracting the response of the radon-222 cup from that of the radon-222 plus radon-220 cup.

The detector inside each cup is sensitive to alpha particles from radon and its decay products. The alpha particles penetrate the plastic detector leaving tracks which are subsequently etched to produce visible tracks in the plastic. The number of alpha tracks counted per unit area is proportional to the average radon concentrations. The advantages of the track-etch monitoring technique over other radon monitoring techniques are that the monitoring is completely passive, no electrical

or mechanical components are involved, and the monitoring is easy to conduct. Once the detectors are exposed, the vendor of the detectors etches the plastic, visually reads the number of tracks per unit area, and reports the measured concentrations.

Track-etch detectors are a widely accepted method for obtaining accurate measurements of radon concentrations. Measurement standard deviations are generally in the range of 20% for typical environmental concentrations. Results are usually obtained within four weeks from submission of the detectors to the vendor for processing.

The monitoring locations were selected to characterize radon concentrations and potential exposures to humans. The monitoring locations are at the FMPC site boundaries, at two schools, at a local business, and at two residences. The residences serve as background monitoring locations which are in the same meteorological wind patterns as the FMPC site but far enough from the site so as not to be affected by radon emitted from the site. Specific monitoring locations are shown in Figure 4.2.

The 1986 average concentrations of radon-222 vary slightly from station to station but were not significantly different from one another nor from the 1985 data. The results also indicate that no distinct trends for radon exist in the prevailing wind direction (Table 4.2).

TABLE 4.2 : *Radon In Ambient Air*

Sampling Location[1]	Radon[2] pCi/l													
	Set 1[3]		Set 2		Set 3		Set 4		Set 5		1986 Average		1985 Average	
AMS 1	0.31	(0.011)	0.14	(0.005)	0.83	(0.031)	0.50	(0.019)	1.40	(0.052)	0.64	(0.024)	0.81	(0.030)
AMS 2	0.37	(0.014)	0.61	(0.023)	1.12	(0.041)	0.50	(0.019)	1.60	(0.059)	0.84	(0.031)	0.82	(0.030)
AMS 3	0.60	(0.022)	1.04	(0.039)	0.54	(0.020)	0.50	(0.019)	0.70	(0.026)	0.68	(0.025)	0.28	(0.010)
AMS 4	0.55	(0.020)	0.40	(0.015)	0.70	(0.026)	0.50	(0.019)	0.60	(0.022)	0.55	(0.020)	0.58	(0.021)
AMS 5	0.43	(0.016)	0.18	(0.007)	0.91	(0.034)	1.00	(0.037)	0.40	(0.015)	0.58	(0.022)	0.80	(0.030)
AMS 6	0.33	(0.012)	0.81	(0.030)	0.91	(0.034)	0.70	(0.026)	0.50	(0.019)	0.65	(0.024)	0.67	(0.025)
AMS 7	0.31	(0.011)	0.98	(0.036)	1.51	(0.056)	1.40	(0.052)	0.60	(0.022)	0.96	(0.036)	1.01	(0.037)
AMS 8	...[4]		...		...		...		0.60	(0.022)	0.60	(0.022)	...	
AMS 9	...		...		...		...		0.50	(0.019)	0.50	(0.019)	...	
OS 1	0.19	(0.007)	1.29	(0.048)	0.50	(0.019)	0.40	(0.015)	0.60	(0.022)	0.60	(0.022)	0.59	(0.022)
OS 2	0.29	(0.011)	1.29	(0.048)	0.56	(0.021)	0.20	(0.007)	0.50	(0.019)	0.57	(0.021)	0.37	(0.014)
OS 3	...		...		...		...		0.80	(0.030)	0.80	(0.030)	...	
OS 4	...		...		...		1.10	(0.041)	0.70	(0.026)	0.90	(0.033)	...	
OS 5	...		...		...		0.60	(0.022)	0.80	(0.030)	0.70	(0.026)	...	

1 See Figure 4.2
2 Bq/l in parentheses.
3 Sets were replaced at about two month intervals.
4 "..." No data collected.

Concentrations of radon-222 are also measured at two residences 6.4 and 10.5 km (4 and 6.6 mi) from the FMPC and also at two nearby elementary schools. In 1986, the average concentration of radon-222 measured at these locations ranged from 0.6 to 0.9 pCi (0.02 to 0.03 Bq) per liter of air, which does not differ significantly from the 1985 averages.

4.3 Evaluation of Radiation Doses

4.3.1 Radiation Doses Based on FMPC Monitoring Data

Determining the dose due to radon emission from the FMPC is an important consideration for the public in the vicinity of the plant. Calculation of dose due to radon emission is not one of the requirements for NESHAP compliance. DOE standards, however, specify that emissions of Rn-222 to uncontrolled areas must be less than 3.0 pCi/l.

During 1986, background radon measurements at locations that are 6.4 and 10.5 km from the FMPC (OS 1 and OS 2 respectively Figure 4.2) averaged 0.58 pCi/l (Table 4.2). AMS 6, which is in the same direction and closer to the K-65 Silos than the nearest residence, recorded an average radon concentration of 0.65 pCi/l. All radon measurements include an error term of about ±20%. Therefore, there are no significant differences in radon concentration between background locations and AMS 6 in 1986. A dose calculation based on this data does not yield significant results.

In addition to FMPC measurements of outdoor radon concentrations, the Ohio Department of Health (ODH) monitored indoor radon concentrations at nine locations around the FMPC between July 1985 and July 1986. These concentrations ranged from 1.1 pCi/l to 12.8 pCi/l with no apparent correlation between average concentration and proximity to the K-65 Silos. The FMPC Health and Environmental Advisory Committee examined this data and issued a press release indicating that the FMPC is not the source of elevated radon levels found in this study (Reference 5).

In addition to radiation doses due to radon inhalation, exposure assessments were made for external radiation by using a pressurized ionization chamber and thermoluminescent dosimeters (TLDs). At each onsite high -volume air monitoring station (AMS) shown on figure 4.2, TLDs measure ambient beta-gamma radiation levels (Table 4.3.1). The maximum annual exposure was measured at AMS 6, the closest station to the waste materials stored in the K-65 Silos on the west side of the site. To assess external exposures to individuals living near the site, a pressurized ionization chamber was used to collect data at various locations around the FMPC. The data indicate that the annual dose to the nearest resident (in the unlikely scenario of that resident remaining at home 100% or the time) was conservatively calculated at 18 mrem (0.18 mSv) in 1986. This is 18% of the DOE standard. It should be noted that the background dose from natural sources measured at several locations surrounding the FMPC was 79 mrem (0.79 mSv) per year.

TABLE 4.3.1: *External Radiation Exposure, 1986*

Sampling Location[1]	Exposure Rate[2] in µR/hr		
	Minimum	Maximum	Average
AMS 1	5.5	12.7	8.9
AMS 2	8.4	11.0	9.3
AMS 3	7.7	11.1	8.9
AMS 4	7.1	11.1	8.7
AMS 5	7.7	11.6	9.0
AMS 6	12.3	15.0	13.6
AMS 7	7.4	10.4	8.7
Background[3]			9.0

1. See Figure 4.2
2. Continuous monitoring with environmental TLD's processed quarterly.
3. Background average exposure rate obtained from pressurized ionization chamber data at two offsite locations.

Source: 1986 FMPC Environmental Monitoring Report

4.3.2 Radiation Doses Based on K-65 Accident Analysis

In order to estimate the radiological consequences resulting from radon emissions from the K-65 Silos, an analysis was performed utilizing dispersion models (AIRDOS) for various credible accidents. The complete analysis, which is summarized in this section and Table 4.3.2, is contained in Appendix A. Four conditions are summarized in Table 4.3.2; the existing state of the silos, advanced cracking of the silo domes, a partial dome collapse and a complete dome collapse. The probabilities of occurrence were obtained from the Camargo report (Reference 2) and a follow up Camargo correspondence (Reference 4). As shown in Table 4.3.2, the probability of occurrence for advanced cracking of the dome and a partial dome collapse are certain due to the deterioration of the silo domes and the existing cracks. The probability of a complete dome collapse caused by an earthquake, tornado or airplane crash is very low. The most significant data presented in Table 4.3.2 is that the nearest offsite residence in the most probable wind direction (Northeast), located 1.3 km from the K-65 Silos, receives the highest projected (calculated) dose (37 mrem/year) from the Rn-222 releases. The total body dose to the nearest offsite resident (500 m) for the existing condition, however, would be approximately 18 mrem higher (38 mrem total) if the direct gamma radiation dose from the K-65 Silos was considered (1986 FMPC Environmental Monitoring Report - Reference 6).

TABLE 4.3.2

SUMMARY OF ACCIDENT ANALYSIS INVOLVING THE K-65 SILOS

ESTIMATED RADIATION DOSES mrem/yr FROM RADON EMISSIONS[1]
(TOTAL BODY)

ACCIDENT	PROBABILITY OF OCCURRENCE	PLANTSITE (730m)	NEAREST OFFSITE RESIDENCE (500m) (DISTANCE)	NEAREST OFFSITE RESIDENCE (1300M) (WIND FREQUENCY)	ESTIMATED TOTAL CURIES RELEASED (YR) Rn-222
Existing Condition[2]	---	6	20	37	650
Advanced Cracking	Certain	19	54	92	1300
Partial Dome Collapse	Certain	19	54	92	1300[3]
Complete Dome Collapse	Very Low	66	127	331	6000[3]

1. Radiation Doses calculated by Airdos, using the estimated Rn-222 releases.
2. No significant differences in radon concentration exists between background locations around the FMPC and the air monitoring station closest to the K-65 Silos; therefore a dose calculation based on the monitoring data does not yield significant results.
3. An additional Curie Release also occurs from the Ra-226 and Uranium Particulates (See Appendix A).

Under 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, there are established dose guidelines. Specifically 40 CFR Part 191.03b states that "Management and Storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities for the disposal of such fuel or waste that are operated by the Department and are not regulated by the Commissioner Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from discharges of radioactive material and direct radiation from such management and storage shall not exceed 25 mrem to the whole body and 75 mrem to any critical organ."

The K-65 residues currently stored at the FMPC do not contain in excess of 100 nanocuries per gram of an alpha emitting transuranic isotope (i.e., elements with an atomic number greater than 92) and therefore the provisions of 40 CFR Part 191 are not directly applicable to the management or storage of the residues. It is, however, the goal of the FMPC to meet the dose standards in 40 CFR Part 191. Based upon the actual environmental monitoring data for radon, the existing condition of the K-65 Silos does not exceed the limits of 40 CFR 191. The radon concentrations at the FMPC site boundary are within background levels, and therefore do not contribute to an increased offsite radiation dose. However, based upon the certain probability of advanced cracking of the K-65 Silo domes, the radon concentration levels could exceed

background levels at the FMPC site boundary and cause radiation doses exceeding the limits set by 40 CFR 191. Therefore, based upon the probability of advanced cracking and the estimated radiation doses that may result, the FMPC should implement additional controls to ensure that the requirements are met.

5.0 TEMPERATURE AND PRESSURE MONITORING OF THE K-65 SILOS

5.1 Monitoring System Description

The K-65 temperature and pressure monitoring system consists of an instrumented flange assembly that mounts onto one of the existing manholes flanges that are located at four equal, radially spaced distances on top of each of the K-65 Silo domes. Each instrumented flange assembly consists of two thermocouples and a differential pressure transmitter. The thermocouples were designed to measure the gas temperature inside a K-65 Silo at the inside top surface and at an approximate distance of 7 feet into a silo. The differential pressure transmitter was designed to measure the difference in pressure between the K-65 Silo internal tank pressure and the surrounding atmospheric pressure. In addition, a surface thermocouple was installed on each silo to provide a temperature measurement of the external concrete silo dome surface. All of the data from the thermocouples and differential pressure transmitters were recorded by a continuous monitoring data logger located adjacent to the K-65 Silos.

5.2 Temperature and Pressure Monitoring Data

5.2.1 Monitoring Period

The K-65 monitoring system was installed onto the K-65 Silos on March 13, 1987. Continuous monitoring from the installation

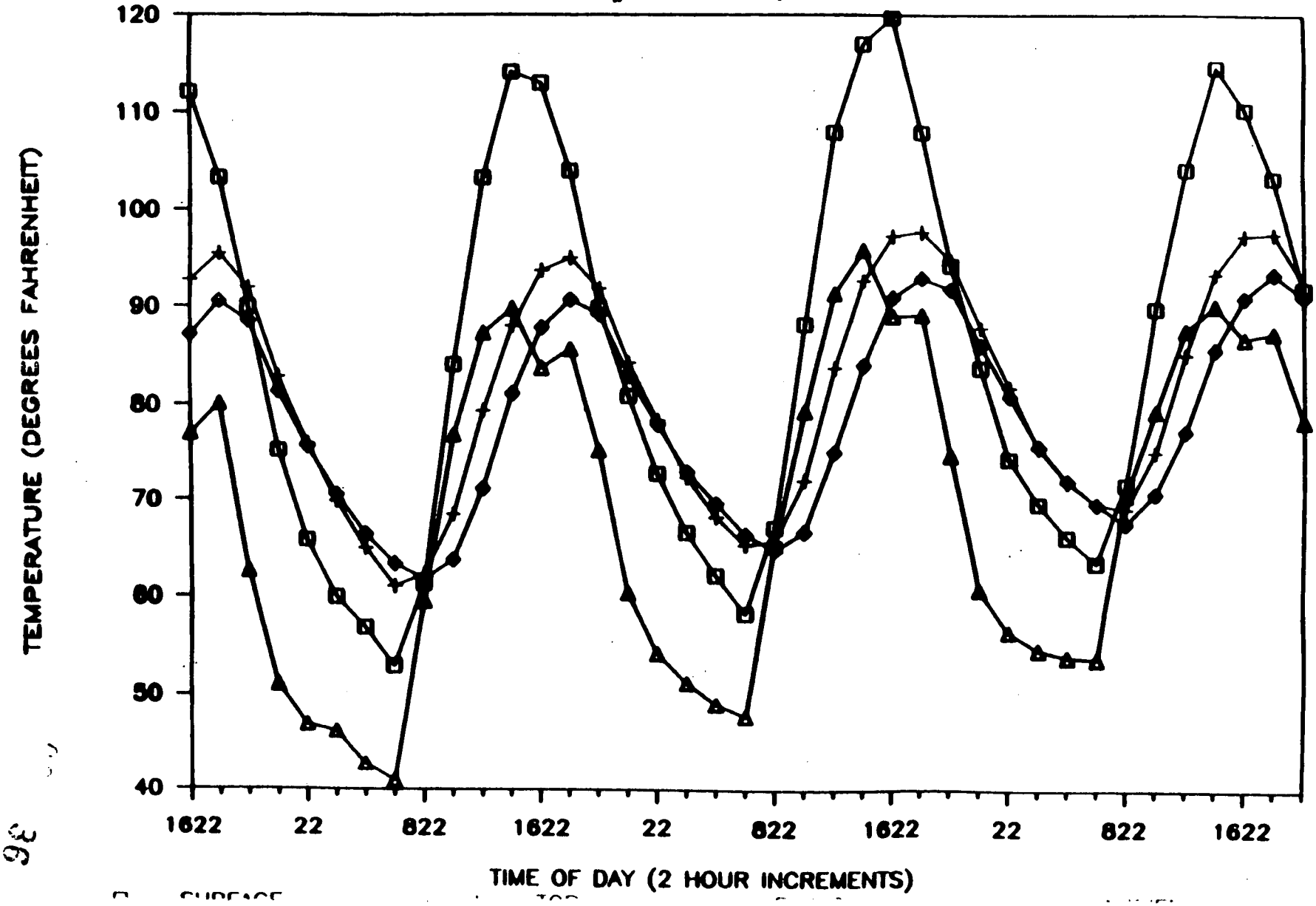
date (March 13, 1987) to the time the monitoring system was taken off line (May 15, 1987) is not applicable, due to in line calibration difficulties and data logger malfunctions. Continuous data was collected, however, during the period of May 8-11, 1987, during which time large ambient temperature variations occurred in the Fernald area. Large ambient temperature variations have the greatest potential of producing significant pressure fluctuations within the K-65 Silos. Since negligible pressure variations occurred during this period of large temperature variations, the collected monitoring data was judged as representing the worst case and the need for additional monitoring deemed unnecessary.

5.2.2 Data Results

The temperature monitoring data results from K-65 Silos 1 and 2 for the period of May 8-11, 1987 are shown in Figures 5.2.2-1 and 5.2.2-2 respectively. The x-axis on the figures represents the actual time of day in two hour increments and the y-axis represents the temperature recorded in degrees Fahrenheit. Four temperature curves are plotted in the Figures: the dome concrete surface temperature indicated in the legend as "surface"; the internal gas temperature of the silo near the top dome surface indicated in the legend as "top"; the internal gas temperature of the silo near the surface of the waste residues indicated in the legend as "bottom"; and the ambient temperature in the vicinity of the K-65 Silos indicated in the legend as "ambient". As can

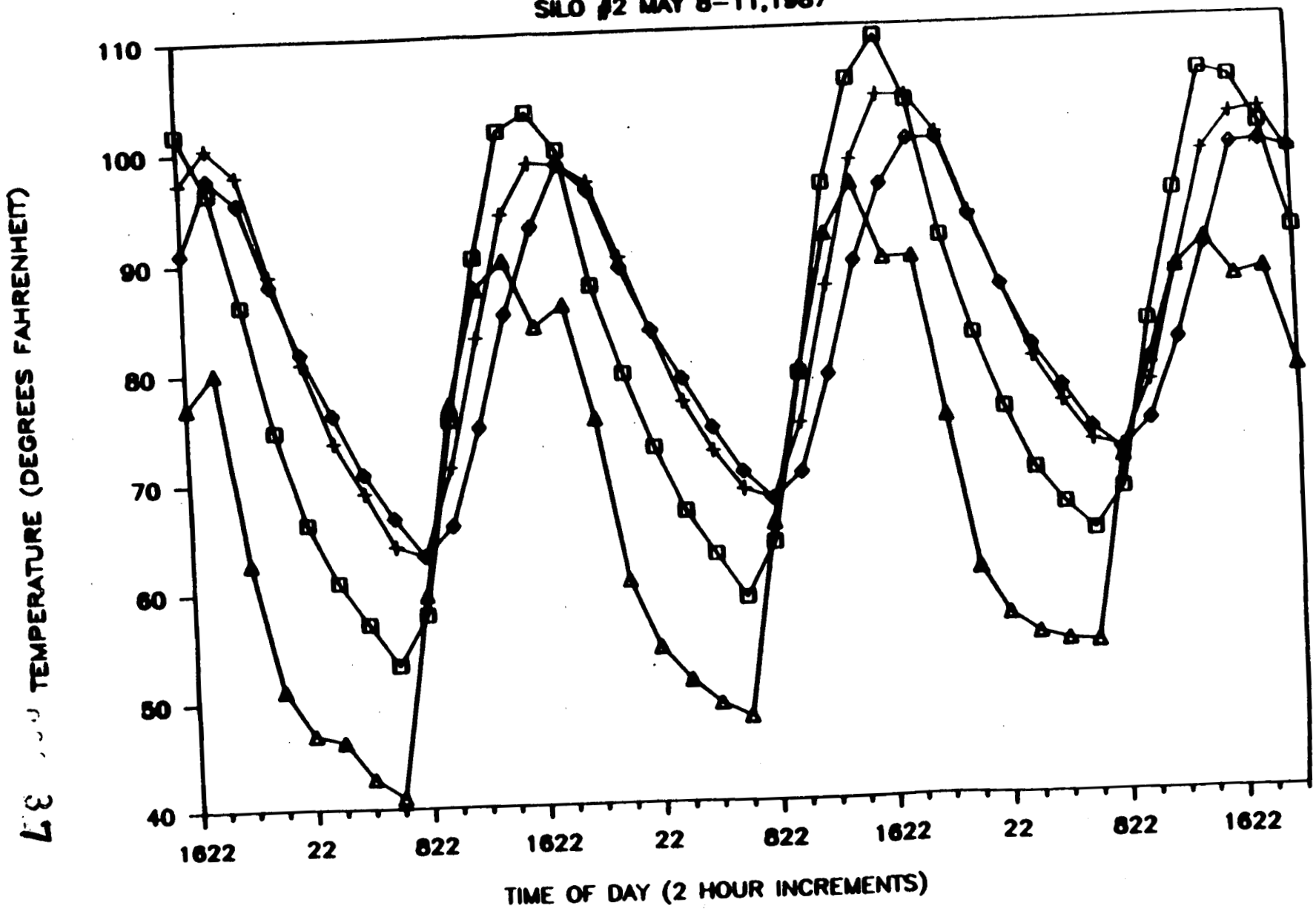
TEMPERATURE VS. TIME

SILO #1 MAY 8–11, 1987



TEMPERATURE VS. TIME

SILO #2 MAY 8–11,1987



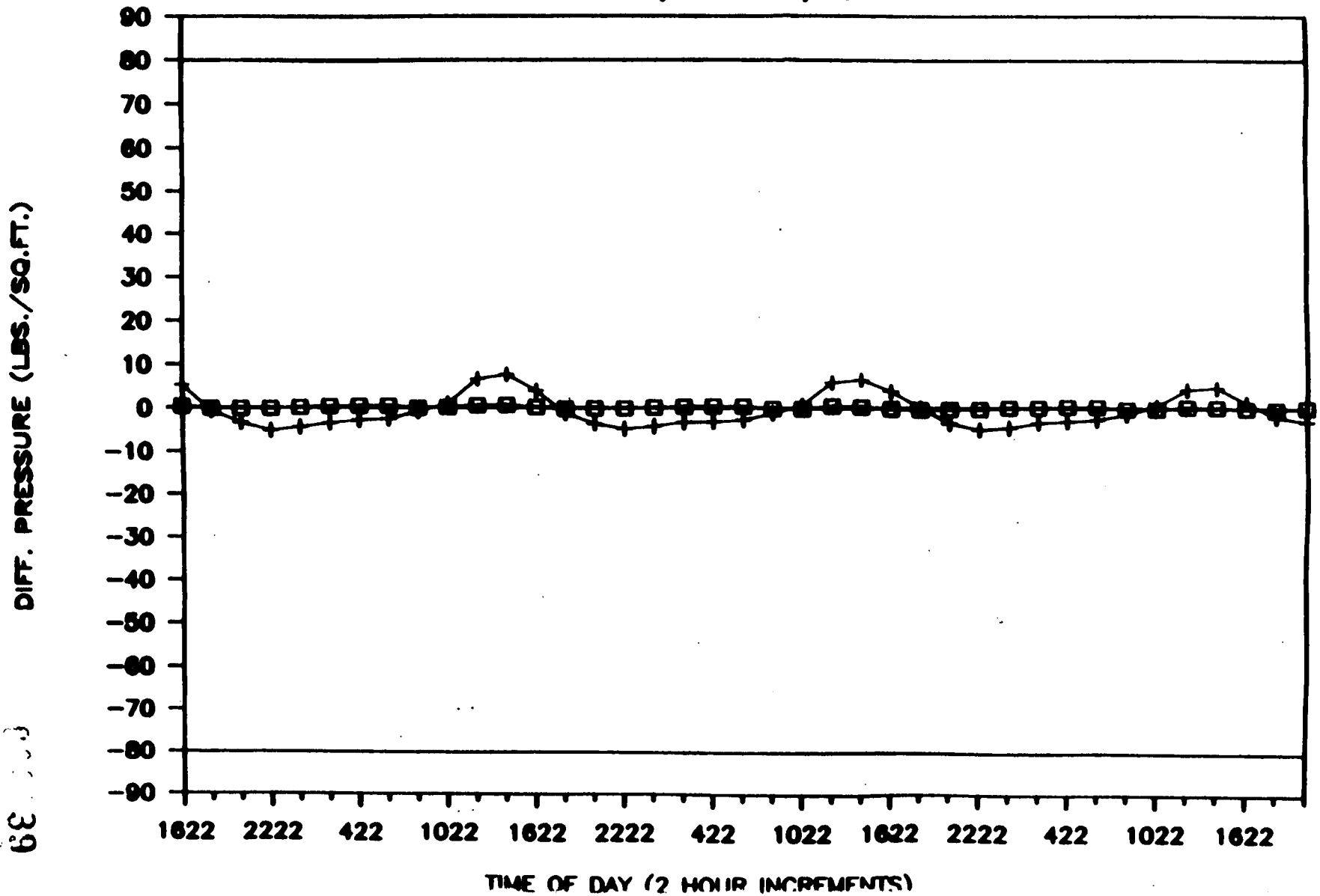
be observed from both Figures 5.2.2-1 and 5.2.2-2 the ambient temperature during the monitoring period varied a maximum of a approximately 42°F in a 12 hour period. Correspondingly, the internal gas temperature measurements (Bottom) for both K-65 Silos show an approximate 35°F differential during the same time period as the ambient temperature variation. The temperature data shows that the K-65 Silos have negligible insulating properities and that the gas phase contained within the top of the silos fluctuates to nearly the same amplitude as the ambient temperature.

Notice also that the surface temperatures of the K-65 Silos exceed the ambient temperature due to radiant heating from the sun. In addition, Silo 1 surface temperature readings are higher then Silo 2 surface temperature readings for the same period due to a difference in radiant heating. Recall that Silo 2 is essentially weatherproofed with a light grey membrane coating while Silo 1 is a dark grey color and t efore does not reflect the sun's radiant energy as well as Silo 2. Temperature data other than the periods illustrated in Figures 5.2.2-1 and 5.2.2-2 look similar, however, the magnitude of the variations are not as great.

The pressure monitoring data results from K-65 Silos 1 and 2 for the same period as the temperature data (May 8-11, 1987) are shown in Figure 5.2.2-3. The x-axis again represents the actual time of day in two hour increments and the y-axis represents the differential pressure (internal silo gas pressure - atmospheric pressure) in pounds per square feet (PSF). The "square" symbols

DIFFERENTIAL PRESSURE VS. TIME

K-65 SILOS, MAY 8-11, 1987



represent the differential pressure data measured from Silo 1 and the "plus" symbols represent the differential pressure data measured from Silo 2. The continuous horizontal lines at plus and minus 80 PSF represent the buckling limit as determined by Camargo Associates, Ltd during their structural analysis of the K-65 Silos (Reference 2). As can be observed from Figure 5.2.2-3 neither of the K-65 Silos are capable of holding a significant differential pressure with respect to the buckling limit of the silo domes. K-65 Silo 1 shows negligible pressure variations as the internal gas temperature varies due to ambient temperature fluctuations. K-65 Silo 2 shows a slight capability of holding a maximum differential pressure of approximately plus 7.6 PSF and minus 4.9 PSF during the monitoring period. In comparison, using the ideal gas equation, a closed tank of air initially at 2117 PSF (14.7 psi) and 63°F would experience a pressure increase of approximately 142 PSF if the internal temperature was increased 35°F. If, however, the tank was maintained at atmospheric pressure i.e., allowed to leak the expanding air to the atmosphere during the temperature increase of 35°F, and the tank initially contained 25,000 cubic feet of air (approximate gas volume of a K-65 Silo), then the volumetric air release would be approximately 1,750 cubic feet.

In summary, the pressure data indicates that both of the K-65 Silos exchange gas freely with the surrounding atmosphere, otherwise much higher pressure differentials would have been recorded during the temperature variations. The suspected reason that K-65 Silo 2 shows some pressure differential as compared to K-65 Silo 1 is that the weatherproofing membrane may act as a weak pressure seal.

6.0 OPTIONS EVALUATED FOR CONTROL OF RADON EMISSIONS FROM THE K-65 SILOS

6.1 Overall Design Considerations

In order to effectively control radon emissions from the K-65 Silos, the following assumptions were utilized to develop the alternatives:

- Approximately 60 Ci/year of Radon 222 is released from the K-65 Silos by diffusion through the concrete dome, (Appendix A);

- Under current structural conditions, approximately 600 Ci/year of Radon 222 is released by expansion of the gas within the K-65 Silo domes (Appendix A);

- The K-65 Silo domes are not capable of holding any significant pressure above or below the atmospheric pressure (Section 5.2.2);

- The K-65 Silos gas phase experiences temperature fluctuations very similar to those of ambient temperature (Section 5.2.2);

- The control of radon emissions is considered as an interim solution (3-5 years) until final remediation plans are developed and implemented; and

- The K-65 Silo domes are structurally weakened and have limited capacity to support any additional loading (Reference 2).

- Any material that would be placed in the silos to cover the residues and attenuate the radon emissions may have to be removed in the near future if final remediation plans so dictated.

6.2 Alternatives for Radon Emission Control From the K-65 Silos

Based upon the criteria listed in Section 6.1, feasible alternatives were considered for control of radon emissions from the K-65 Silos. Due to the fact that the silos are not capable of holding any significant pressure, (i.e., the silos readily exchange gas with the surrounding atmosphere), and the K-65 materials may have to be removed from the silos in the near future (3-5 years) the alternatives for radon emission control are limited. Since the silos were not designed to function as pressure vessels, even the weatherproofing of one of the K-65 Silos did not appreciably improve its pressure holding capabilities (Figure 5.2.2-3). Therefore, the radon emission control alternatives that are defined in Sections 6.2.1 through 6.2.3 are intended to operate without further attempts to seal the silo dome surfaces.

6.2.1 Water Column Absorption

Water column absorption is used in many applications to control the emission of gaseous pollutants by allowing the effluent gas to interface the water and be absorbed by the water. Success of the water column absorption is dependent upon the solubility of radon gas in water as compared to the other gases present. It is

of the carbon beds occurred, as determined by downstream gas sampling, valves could be activated to isolate the saturated carbon bed and circulate the gas to a fresh carbon bed. Some of the important factors that would need to be considered in the design of such a system would be the adsorption efficiency of the activated carbon beds, the total adsorption capacity of a given carbon bed before saturation occurs, flow rate requirements and shielding requirements.

6.2.3 Void Space Filling

Filling the void space above the residues in the K-65 Silos with a rigid polyurethane foam material would serve to remove the existing reservoir that the radon gas currently accumulates above the residues. In addition, the foam material would act as a diffusion barrier to trap the radon gas that diffuses from the residues and hold up the radon gas until it decayed into its respective, particulate daughter products; thus never allowing the radon gas to escape into the environment. In order to accomplish the silo void space filling, the foam material would have to be pumped into the silos through the four existing manholes on the silo domes. A temporary treatment system for the radon gas that would be initially displaced by the foam material would be required to reduce the release of radon to the environment during filling of the silos. A temporary system such as the water column absorption (Section 6.2.1) or the solid media adsorption system (Section 6.2.2) could be utilized to treat the initial volume of

7.0 EVALUATION OF THE ALTERNATIVES

The evaluation of the four radon emission control alternatives (Sections 6.2.1 - 6.2.4) is based on a numerical ranking from 1 (least acceptable) to 5 (most acceptable) concerning the following criteria:

- Environmental Acceptability
- Reliability/Operability
- Implementation Time
- Cost

The results from the ranking are presented in Table 7.0. A definition of each of the ranking criteria and justification for the ranking assignments is explained in Sections
7.1 through 7.4.

7.1 Environmental Acceptability

The environmental acceptability of an alternative was determined by estimating the ability of an alternative to reduce radon emissions with the least environmental impact. Factors such as expected treatment efficiency and waste generation from the treatment systems were considered. The goal in implementation of the radon emission control

TABLE 7.0

RANKING OF RADON EMISSION CONTROL ALTERNATIVES*

ALTERNATIVE	ENVIRONMENTAL ACCEPTABILITY	RELIABILITY/ OPERABILITY	IMPLEMENTATION TIME	COST	TOTAL
Water Column Absorbtion	4	2	2	3	11
Solid Media Adsorbtion	4	2	4	3	13
Void Space Filling	4	5	4	2	15
Temperature Control	2	2	4	3	11

* 1 = least acceptable
5 = most acceptable

systems. The water column absorption alternative was ranked well below the other alternatives due to the estimated longer design time (12 months) caused by the lack of "off the shelf" systems for the particular application.

7.4 Cost

The cost of an alternative is an order of magnitude estimate of the total cost for the alternative considered. Overall, all of the alternatives are considered approximately equal as far as total cost is concerned. The void space filling alternative was estimated to have a higher cost than the other three alternatives due to the added up front cost of the fill material and the potential removal costs of the fill material. An estimate of $300,000 was made to implement and maintain radon emission controls for a period of three to five years on the K-65 Silos. This cost does not include any waste disposal that may be included during or after the life of the system.

8.0 RECOMMENDATIONS

Based upon the analysis presented in this FI, the FMPC is within all applicable DOE and EPA guidelines and regulations for the emission of radon from the K-65 Silos. However, it is the goal of the FMPC to continue to meet the dose requirements listed in 40 CFR 191. Therefore, the FMPC recommends that additional interim controls be implemented to reduce the radon emissions from the K-65 Silos. The recommendations with regard to the additional controls are as follows:

1) Initiate and expedite final detailed design for the system to fill the void space in the K-65 Silos with foam, including a temporary solid media adsorption system to treat the initial displaced radon gas;

2) Complete the operation of filling the K-65 Silos by November of 1987; and

3) Complete the weatherproofing of the K-65 Silos after the silos are filled; as soon as the weather permits.

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1) NLO Analysis, 1972.

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3) G. R. Hagee, P. H. Jenkins, P. J. Gephart, C. R. Rudy, "Radon and Radon Flux Measurements at the Feed Materials Production Center, Fernald, Ohio," Monsanto Research Corporation, Miamisburg, Ohio, MLM-MU-85-68-001, August 6, 1985.

4) Letter, J. A. Sample (Camargo Associates, Ltd.) to J. T. Grumski (Westinghouse Materials Company of Ohio) "Estimated Remaining Service Life of K-65 Silos," dated February 2, 1987.

5) Gibeau, R., The Cincinnati Post, November 21, 1986.

6) Westinghouse Materials Company of Ohio, "Feed Materials Production Center Environmental Monitoring Annual Report for 1986," FMPC-2076, Special UC-41, April 30, 1987.

APPENDIX A

ANALYSIS OF POTENTIAL AND PROBABLE ACCIDENTS OCCURRING AT THE K-65 STORAGE SILOS

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Introduction

This report is being prepared to analyze the radiological health concerns associated with the existing conditions of the K-65 Silos and the potential accidents and incidents associated with these silos. The results of this analysis will be used to determine if interim remedial controls are required to maintain the K-65 domes within acceptable safe limits.

1.0 K-65 Silo Physical Description

On the west side of the FMPC at Fernald, Ohio are the two K-65 Silos. These Silos were constructed in 1951 and 1952 and are used for the storage of radium bearing residues that are a byproduct of uranium ore processing. The location of these silos is shown on the Plant Map Figure 1-1.

The silos are concrete cylinders 80 feet in diameter and 27 feet high. They have a concrete floor and footing and a domed concrete roof. The silos were bermed with earth in 1964 at a 1.5:1 horizontal to vertical slope to reduce tension on the walls from internal loading. The earthen embankment has the added benefit of reducing radon emissions from the walls and providing additional weather protection. In 1983 the embankment slope was increased to 3:1 ratio.

1.0.1 Description of Structural Components

The two K-65 Silos are cylinders constructed of reinforced concrete, are 80 feet in diameter by 27 feet in height, and are filled to a 23-foot depth with a solid radium bearing residue.

1.0.1.1 History

The silos were originally built in 1951 and 1952 and were filled with a metal oxide water slurry at a rate of 8000 gallons per day. The radioactive slurry sludge was allowed to settle and the water was decanted. The residue sludge has a density of approximately 100 lbs. per cubic foot and an angle of repose of 0 degrees. The maximum allowable depth of the solid material in the silos was 23 feet.

Figure 1-1 Plant Map Showing Location of the K-65 Silos

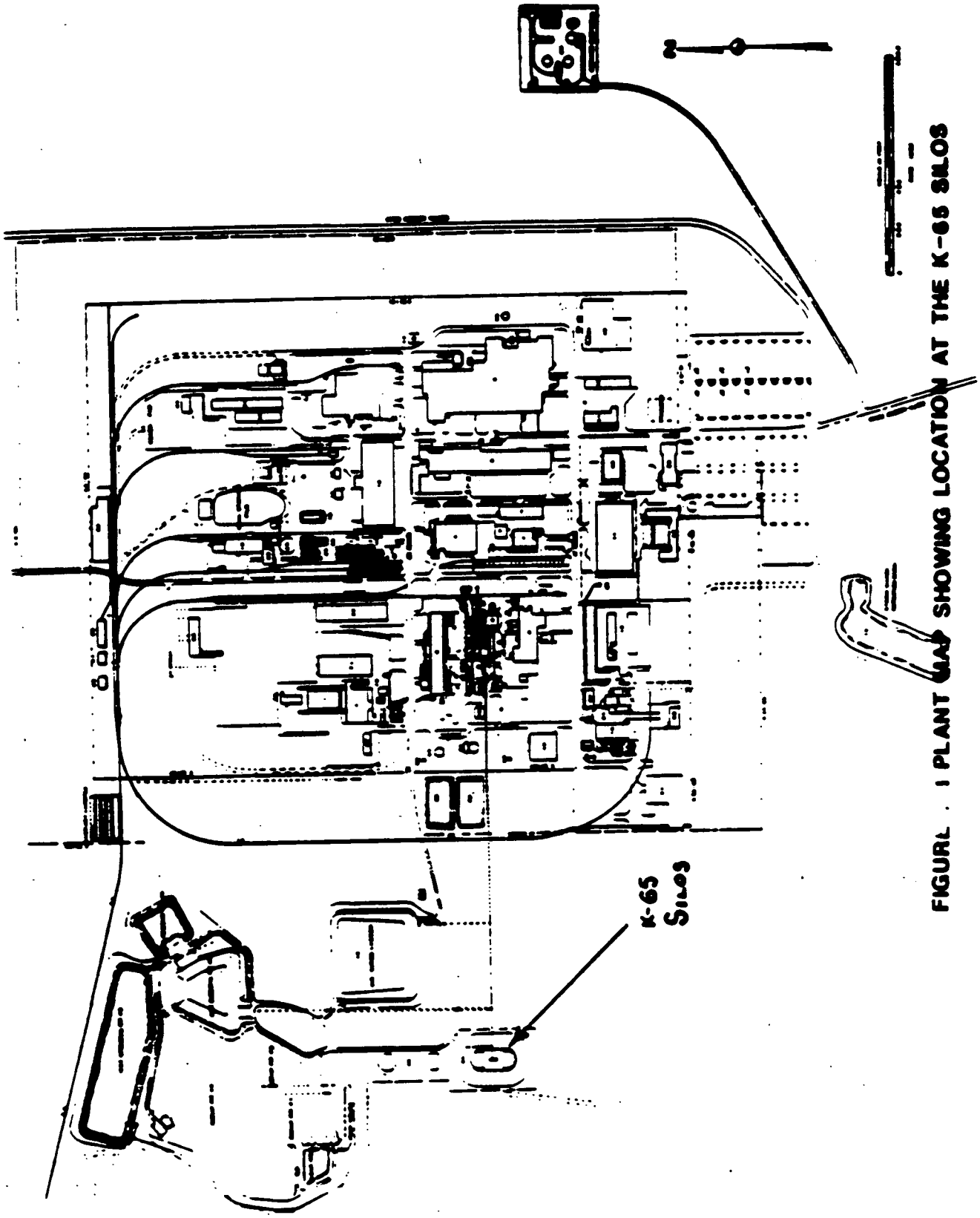


FIGURE . 1 PLANT MAP SHOWING LOCATION AT THE K-65 SILOS

In 1963 the silos showed signs of exterior surface deterioration. Large areas of spalling occurred on the exterior gunnite coating leaving post tension wires exposed to the weather. The walls were repaired and waterproofed in 1964. After the repair the silos were earth embanked to the top of the silo wall to relieve tensile stresses in the wall from internal loading. In 1983 the earth embankment was reinforced by decreasing the embankment slope. In 1985, Camargo Associates, Ltd. was subcontracted to perform a nondestructive analysis using non-destructive testing and computer modeling techniques. Figure 1-2 is a typical section of a K-65 Silo.

1.0.1.2 Floor and Drainage

The K-65 silo floors are made of reinforced concrete and were sealed prior to filling with the residue material. The minimum 28-day compressive strength of the floor and footings was 3000 pounds per square inch (PSI). The maximum allowable uniform soil loading pressure is 4000 pounds per square foot (PSF). There has been no direct observation of the silo floor or footing since the silos were filled in 1953; however, the 1983 Camargo investigation indicated that the floor and footing was structurally stable under the existing static load and should remain stable for approximately five to ten years.

1.0.1.3 Walls and Berms

The silo walls were constructed of reinforced concrete with 0.162 inch diameter wires post-stressed to 140,000 PSI. The post-tensioned wires were covered with a 3/4 inch layer of gunnite. The minimum 28-day compressive strength of the concrete was 4500 PSI and the wires were assumed to have a 30% strength loss for a design stress of 100,000 PSI. In 1963, the silo walls were showing signs of surface deterioration of the gunnite coating which left patches of the tensioning wires exposed.

Figure 1-2 Typical Section of a K-65 Silo

Subsequently, sections of the wires became severely corroded and broken. Repairs performed in 1964 consisted of chipping away all of the loose gunnite coating and replacing it with a 3/4-inch layer of mortar. After completion of the gunnite/mortar repair a waterproof sealant was applied to the exterior wall surfaces. An earthen embankment was then built to the top of the wall with a 1.5:1 slope (horizontal:vertical) to relieve tensile stress inside the silos due to the internal loading since the internal tension wires were not replaced.

In subsequent years during heavy rainfall periods, soil erosion occurred. The eroded areas were repaired but the problem recurred. In 1983, the earthen embankment was enlarged to a 3:1 slope and no further soil erosion has occurred

The Camargo investigations reported that the K-65 silo berms and walls were structurally stable and would remain so for approximately five to ten years under existing static loads, however if the silo contents or embankment are to be removed they are to be removed simultaneously else failure of the walls or base structure could result.

1.0.1.4 Domed Roof

The domed roofs of the K-65 Silos are concrete originally designed to be 8 inches thick at the wall and tapering to 4 inches thick at the center. There has been no remedial repair to the silo dome since construction in 1951/52. The 1985 Camargo report identified the domes as the most critical single component of the entire silo support system. The critical buckling load of the dome was calculated to be 284 PSF for the existing concrete outside the center 20 foot diameter critical dome area. Using a safety factor of four, an additional allowable load of 71 PSF is permissible. Inside the critical 20-foot diameter critical area, the buckling load was calculated to be 104 PSF for 2 inches of concrete. Using a safety factor of four, the allowable load would be 26 PSF which is nearly the same as the dead weight of the center section of the dome. Therefore the single component of the silos most likely to fail is the center section of the dome, and that section has no further life expectancy.

Table 1-1 Elemental (Inorganic) Constituents of the K-65 Silos
Data Obtained in September 1970

Constituent Element	Weight Percent	Total Met tons
Silver (Ag)	<0.002	0.176
Aluminum (Al)	0.875	77.0
Arsenic (As)	<0.3	<2.64
Gold (Au)	<0.005	0.44
Boron (B)	0.015	1.32
Barium (Ba)	0.07	6.16
Berillium (Be)	ND*	-----
Bismuth (Bi)	ND*	-----
Calcium (Ca)	3.89	342.0
Cadmium (Cd)	ND*	-----
Chlorine (Cl)	ND**	-----
Cobalt (Co)	0.175	15.4
Chrome (Cr)	0.012	1.06
Copper (Cu)	0.05	4.4
Fluorine (F)	ND**	-----
Iron (Fe)	1.2	105.6
Mercury (Hg)	ND*	----
Lanthanum (La)	0.089	7.83
Magnesium (Mg)	1.25	110.0
Manganese (Mn)	0.02	1.76
Molybdenum (Mo)	0.02	1.76
Sodium (Na)	0.7	61.6
Nickel (Ni)	0.225	19.8
Lead (Pb)	5.1	448.8
Phospate $(PO_4)^{-3}$	ND*	-----
Antimony (Sb)	ND*	-----
Selenium (Se)	ND**	-----
Silicate (SiO_4)	40.06	3587.0
Tin (Sn)	0.008	0.7
Sulfate $(SO_4)^{=}$	ND**	-----
Titanium (Ti)	0.07	6.16
Vanadium (V)	0.021	1.85
Zinc (Zn)	ND*	-----
Zirconium (Zr)	0.02	1.76
Yttrium (Y)	0.004	0.35
Rare Earth Metals		
Dysprosium (Dy)	0.003	0.26
Erbium (Er)	ND*	-----
Europium (Eu)	ND*	-----
Gadolinium (Gd)	0.004	0.35
Holmium (Ho)	<0.0015	0.13
Lutetium (Lu)	ND*	-----
Samarium (Sm)	0.0048	0.42
Terbium (Tb)	ND*	-----
Thulium (Tm)	<0.0008	0.07
Ytterbium (Yb)	0.0006	0.05

ND* None Detected ND** No Data

1.0.2.2 Elemental Quantities

A list of the inorganic constituents of the contents of the K-65 silos is given on Table 1-1. Silicates comprise approximately 40% of the total amount by weight. Other elemental constituents greater than 1% by weight are calcium, iron, magnesium, and lead. No data on organic constituents are available.

1.0.2.3 Physical State

The contents of the silos was added as a slurry. After decanting the water the sludge had a density of approximately 100 pounds per cubic foot. The present state of the materials in the silos is unknown, but is assumed to be a solid with a slight increase in density toward the bottom of the silo.

1.0.2.4 Identified Hazardous and Radiological Contained Materials

There are no identified organic hazardous materials contained in the K-65 Silos; however, there has not been an organic chemical analysis of the silo contents. There are some metallic hazardous materials in the silos. These are given in the elemental inventory list of Table 1-1.

Radiological constituents of the K-65 residue have been estimated to be 11,200 Kg of natural assay uranium (0.711% ^{235}U) and 1,652 Curies of radium (1.652 Kg ^{226}Ra). The radium concentration seems to be uniform with an average concentration of 2.0×10^5 pCi per gram. Radon daughter flux measurements made in October 1984 at 24 locations on each silo range from 13pCi per square meter per second to greater than 3×10^7 pCi per square meter per second. The highest flux values for radon were obtained at silo surfaces which contain obvious cracks.

1.1 K-65 Engineering Studies

There have been at least three engineering studies of the K-65 Silos. The first was the original design of the silo structures prior to and during construction in 1951 and 1952. The second engineering study was during the silo repair performed in 1963/64 when the silo walls were repaired and the original earthen berm was installed. The third engineering study was the Camargo Associates Ltd. study begun in July 1985.

1.1.1 Earthen Berm Installation

The earthen berm installed in 1964 was designed to support the silo walls and to provide some weather protection. An

added benefit of this berm was the radiation shielding provided by the dirt. The berm, however, was not adequate as originally installed else there would have been no soil erosion of the berm during heavy rain fall. This deficiency was rectified in 1983 when the earthen berm was increased.

1.1.2 Camargo Study

In July of 1985, Camargo Associates, Ltd. (Camargo) was subcontracted to perform a nondestructive testing and structural analysis on the K-65 Silos (Silos 1 and 2) using state-of-the-art testing equipment and computer modeling techniques.

The K-65 Silo investigation was performed in three phases. The first phase was a computer analysis of the storage silos based on the original construction specifications and drawings without any material degradation.

The second phase of the engineering study involved three types of nondestructive field tests and studies to determine the characteristics of the silos as they existed at that time. The three types of tests were the soil exploration test, the "Echo Pulse" system of testing the silo domes, walls, and base slab, and the "Ground-Radar Survey" of the earthen embankment around the K-65 Silos. The field work was subcontracted by Camargo to Muenow and Associates and, Soil and Materials Engineering.

The third phase of the enginnering study employed a detailed computer analysis of the K-65 Silos utilizing the results of the initial "designed" computer analysis from the first phase and the condition of the silos as determined by nondestructive testing in the second phase.

1.1.2.1 Floor and Drainage

The base slab drainage is adequate especially considering the earthen berms tendency to direct rainwater away from the silos.

1.1.2.2 Walls and Berm

The static load combinations of the dome contents and the earthen berm indicate the following:

Under dead load, the contents, and the earthen berm, the stress levels indicate that the wall is under compression and as such is in a stable condition. This represents the present condition of the silos;

Under dead load and the contents, the stress levels indicate that the remaining post-tensioning wires would be in tension greater than 150,000 PSI which

is greater than the original design tension of the post-tensioning wires. This case represents the condition of the silos if the earthen berm were removed.

Under dead load and considering the effects of the earthen berm, the silo wall stress levels are at 1000 PSI of compression. Due to the magnitude of this compression, especially considering the age of the domes, removal of the silo contents without removing the earthen berm should not be employed.

Therefore, the base slab and walls of the K-65 Silos are structurally stable under the existing static loads (dead load, tank contents, and earthen embankment). This stable condition is expected to continue for some time into the future. Removal of the tank contents, however, must be accompanied with simultaneous removal of the earthen embankment to prevent wall collapse. The contrapositive of this situation should also be avoided.

1.1.2.3 Domed Roof

The Silo dome is the most critical part of the entire system. Under the static loads as they exist at the present time, the maximum hoop stress is 41 PSI tension near the center of the dome and 190 PSI compression near the edge.

Another loading consideration is the buckling stability of the dome. The center dome uniform critical buckling load is approximately 104 PSF. Using a safety factor of four, this indicates that the center section of the dome is not capable of supporting much more than its own dead weight (25 PSF). The allowable uniform total load of the center section of the dome is about 26 PSF. Outside the critical center section the critical buckling load of the domes has been reduced to 284 PSF due to thinning of the concrete. Using a safety factor of four, the allowable laod is 71 PSF.

A proposal was made to reduce the radon emissions and direct radiation from the K-65 Silos by covering the domes with three feet of soil. This load calculation results in a stress of 1000 PSI tension near the dome center and 300 PSI compression at the edge. Based on the low buckling load capacity, covering the silo dome with three feet of earth is not possible without some reinforcement to the dome.

1.1.2.3.1 Existing Failure of the Dome Roof

The center 20-foot diameter portion of the dome top is structurally unsound for existing static loads and no life expectancy can be assigned to this section of the dome.

The 30-foot diameter dome cap designed by Camargo and installed by WMCO in January, 1986 will not prevent the collapse of the center 20-foot diameter section of the silo domes. However these dome caps do not mitigate the release of ^{222}Rn for the present situation nor will they in the event of partial dome collapse. Therefore the K-65 Silo failure analysis does not recognize the existance of these dome covers.

An additional data input was the historical 30-year wind rose (1948-78) for the FMPC site. This wind rose was included to predict the time fraction that the K-65 silo plume would be directed toward the nearest offsite individual (5%). This wind rose is given as Figure 2-1. The secular isotope equilibrium used in the AIRDOSE computer model was specified as 30% to account for stagnant deposition of the radon daughters along the plume path. This was a specified constant assumption for all releases.

The AIRDOSE computer model was used to determine the plume code and the uptake of radionuclides released from the K-65 Silos for existing and proposed silo dome failure. The AIRDOSE data was interperted for three cases. The first case was for total body doses to the nearest off-site resident from the K-65 Silos (approximate distance 500 m South-West of the silos). The second case was for total body doses to a typical individual at the center of the plantsite population (approximate distance 730 m due East of the silos). The final case was the total body does to the nearest off-site resident in the most propable wind direction (approximate distance 1300 m North-North-East of the silos). The location of the first two of these three cases is shown in the partial plant map, Figure 2-2. All of the AIRDOSE calculations were conservatively assuming that each individual was on the plume centerline where ^{222}Rn concentrations are maximized.

2.0.3.1 Existing Silo Condition

The existing condition of the silos was analyzed using the following data from the Borak Report. The annual ^{222}Rn emission due to diffusion through the concrete dome is estimated at 60 Ci/yr. The free volume of each silo is about 25000 cubic feet and the silos are capable of free air exchange with the surrounding atmosphere (the silos are not pressure or gas containment vessels). Given that the average dinural temperature fluctuation in the area of the FMPC is approximately 20°F, each silo exchanges, on an average, 1000 cubic feet of gas with the surrounding atmosphere based upon the daily temperature fluctuation and the silo volume. The gas in the silo contains approximately 850 uCi per cubic foot of ^{222}Rn; therefore, an average of 850 mCi of ^{222}Rn is released from the silos daily resulting in an additional ^{222}Rn release of about 600 Ci per year.

2.0.3.1.1 Causes and Probability

This condition is an existing situation.

2.0.3.1.2 Release Rate and Duration

The approximate release of ^{222}Rn from the domes is presently 650 Ci per year.

2.0.3.1.3 Consequence

2.0.3.1.3.1 Plantsite

At an average onsite distance of 730 m from the source the ^{222}Rn air exposure as calculated by AIRDOSE is 3.7×10^{-4} Working Levels (WL). This value represents the average onsite concentration for an unprotected individual.

The annual total body dose for the onsite individual within the 730 m limit as calculated by the AIRDOSE computer code is 5.72 mRem (corrected for 40 hr per week and 50 week per year). The uptake pathway is entirely by inhalation.

2.0.3.1.3.2 Public

At a minimum offsite residence distance of 500 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is 2.36×10^{-4} WL for an unprotected individual.

The annual total body dose for the nearest offsite residence for an offsite individual as calculated by the AIRDOSE computer code is 19.9 mRem (24 hour days, 7 day weeks, 52 week years, and wind blowing to this direction 5% of the total time). The uptake pathway is entirely by inhalation.

At the most probable wind direction and a residence distance of 1300 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is 4.3×10^{-4} WL for an unprotected individual.

The annual total body dose for the offsite residence in the most probable wind direction as calculated by the AIRDOSE computer code is 36.5 mRem (24 hour days, 7 day weeks, 52 week years, and wind blowing to this direction 12.3% of the total time). The uptake pathway is entirely by inhalation.

2.0.3.2 Advanced Cracking

Cracking of the silo dome center section (Advanced Cracking) will certainly occur due to the advanced state of deterioration as stated in the Camargo report. The existance of the dome cover is expected to have little effect on the release of ^{222}Rn in this event, and, for this failure analysis, is assumed not to be installed.

2.0.3.2.1 Causes and Probability

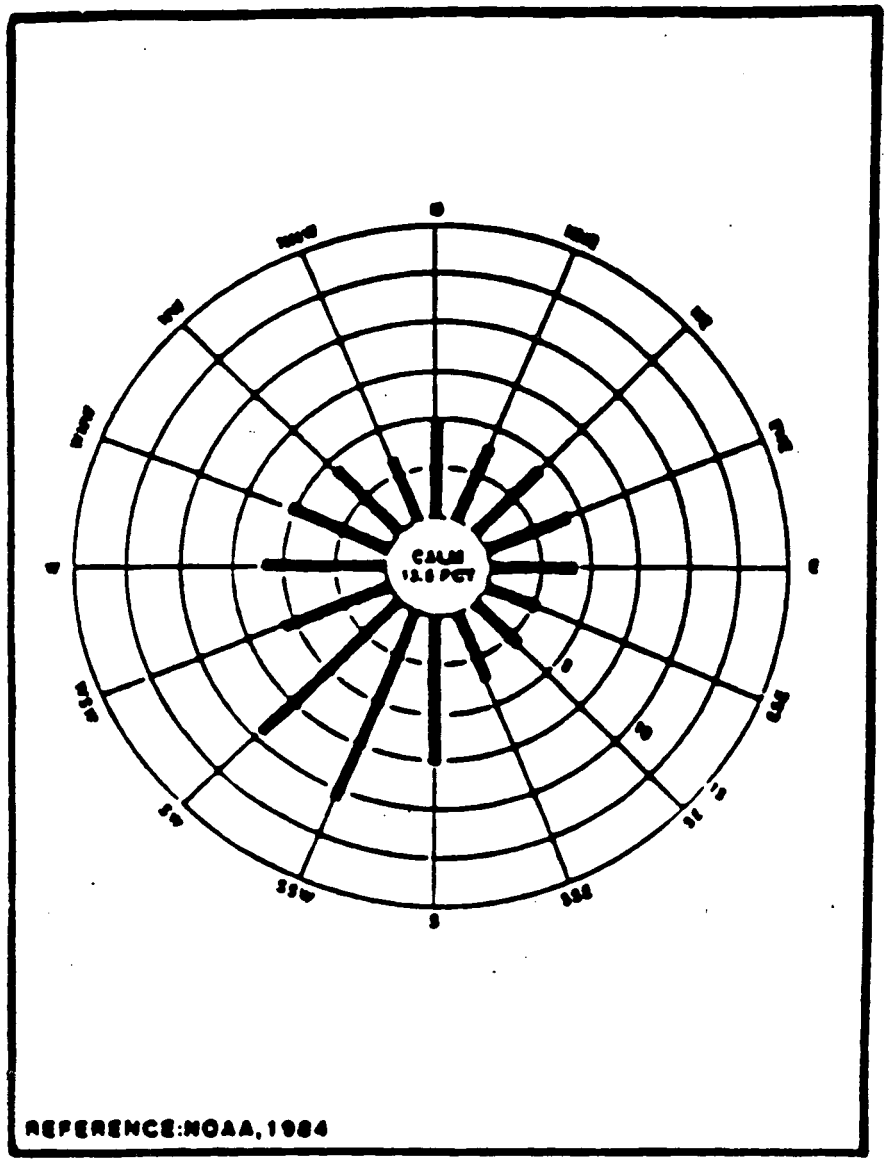
Severe dome cracks have a near certainty of occurrence according to the Camargo report, due to the environmental weathering of the silo domes.

2.0.3.2.2 Release Rate and Duration

Severe cracks in the K-65 Silo dome can increase radon releases within the tanks. The amount of the release is bounded on the lower end by the radon release rate through 4 inches of concrete. There is no particulate source term for this case and the only radionuclide release considered is ^{222}Rn.

The release rates as reported in the Borak report are 2.0×10^5 $pCi/m^2/s$ for bare residue and 2.0×10^4 $pCi/m^2/s$ for residue blanketed by 4" of concrete. The existing release rate of radon is the same as the latter case. Using a surface area of 930 m^2 for both domes (no angle of repose, silo diameter 80 feet) the radon source term becomes 37.2 uCi/s (1300 Ci/yr) for advanced dome cracking.

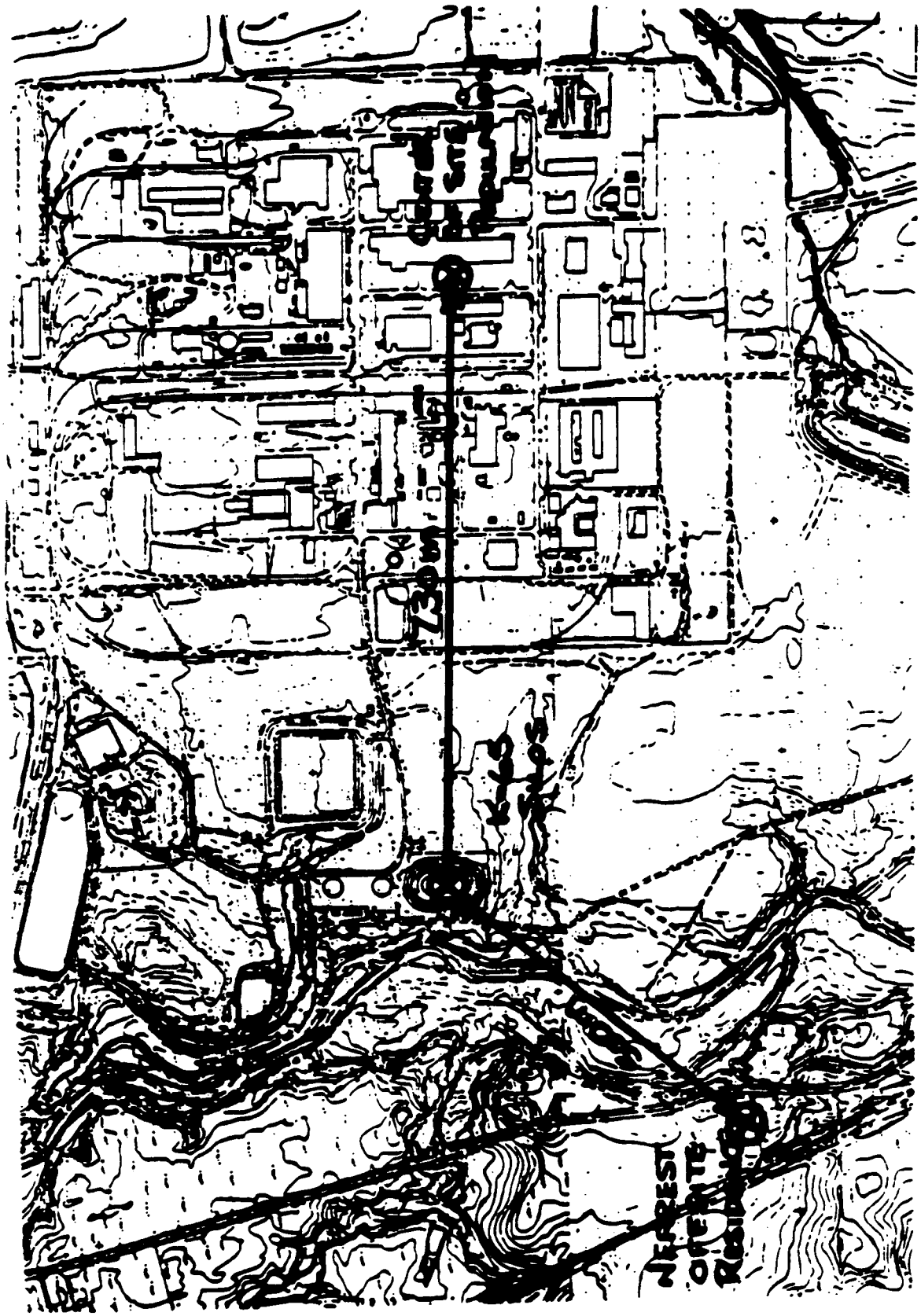
Figure 2-1 Historical Wind Rose for the FMPC Site



PERCENT FREQUENCY OF WIND DIRECTION FOR THE PERIOD 1948 THROUGH 1978 AT THE GREATER CINCINNATI METROPOLITAN AIRPORT.

FIGURE 2-1 WIND ROSE FOR THE FMPC SITE

Figure 2-2 Partial Site Map Showing Location of the Nearest Off-Site Resident and the Center of Plantsite Population



2.0.3.2.3 Consequence

2.0.3.2.3.1 Plantsite

At an average onsite distance of 730 m from the source the ^{222}Rn air exposure as calculated by AIRDOSE is 9.75×10^{-4} Working Levels (WL). This value represents the average onsite concentration for an unprotected individual.

The annual total body dose for the onsite individual within the 730 m limit as calculated by the AIRDOSE computer code is 18.9 mRem (corrected for 40 hr per week and 50 week per year). The uptake pathway is entirely by inhalation.

2.0.3.2.3.2 Public

At a minimum offsite residence distance of 500 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is 6.35×10^{-4} WL for an unprotected individual.

The annual total body dose for the nearest offsite residence for an offsite individual as calculated by the AIRDOSE computer code is 53.7 mRem (24 hour days, 7 day weeks, 52 week years, and wind blowing to this direction 5% of the total time). The uptake pathway is entirely by inhalation.

At the most probable wind direction and a residence distance of 1300 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is 1.08×10^{-3} WL for an unprotected individual.

The annual total body dose for the offsite residence in the most probable wind direction as calculated by the AIRDOSE computer code is 91.8 mRem (24 hour days, 7 day weeks, 52 week years, and wind blowing to this direction 12.3% of the total time). The uptake pathway is entirely by inhalation.

2.0.3.3 Partial Dome Collapse

As with the advanced cracking, partial dome collapse (center 20-foot diameter section of one dome) has a near certainty of occurrence according to the Camargo report.

2.0.3.3.1 Causes and Probability

The cause of the partial domes collapse is deterioration, and the probability of occurrence is one.

2.0.3.3.2 Release Rate and Duration

In the event of partial dome collapse a quarter of the residue area is uncovered by the partial dome collapse. The ^{222}Rn release rate is determined from the product of the uncovered area and the bare radon emission rate ($2x10^{5}$ $pCi/m^{2}/s$). This results in the same Rn emission rate of the advanced cracking, or 37.2 uCi/s. In addition to the radon release, partial dome collapse will also be accompanied by a ^{226}Ra and uranium particulate release.

2.0.3.3.3 Consequence

2.0.3.3.3.1 Plantsite

At an average onsite distance of 730 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is $9.75x10^{-4}$ Working Levels (WL). This value represents the average onsite exposure for an unprotected individual.

The annual total body dose for the onsite individual within the 730 m limit as calculated by the AIRDOSE computer code is 18.9 mRem (corrected for 40 hr per week and 50 week per year). The uptake pathway is entirely by inhalation.

2.0.3.3.3.2 Public

At a minimum offsite residence distance of 500 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is $6.35x10^{-4}$ WL for an unprotected individual.

The annual total body dose for the nearest offsite residence for an offsite individual as calculated by the AIRDOSE computer code is 53.7 mRem (24 hour days, 7 day weeks, 52 week years, and wind blowing to this direction 5% of the total time). The uptake pathway is entirely by inhalation.

At the most probable wind direction and a residence distance of 1300 m from the source

the ^{222}Rn air concentration as calculated by AIRDOSE is 1.08×10^{-3} WL for an unprotected individual.

The annual total body dose for the offsite residence in the most probable wind direction as calculated by the AIRDOSE computer code is 91.8 mRem (24 hour days, 7 day weeks, 52 week years, and wind blowing to this direction 12.3% of the total time). The uptake pathway is entirely by inhalation.

2.0.3.4 Complete Dome Collapse

Complete dome collapse is the failure of both dome structures. This is not a recognized failure identified in the Camargo report, however complete dome collapse could occur as a consequence of some external energy source such as tornados or earthquakes.

2.0.3.4.1 Causes and Probability

The Camargo report does not addressed complete silo dome failure as credible as a result of degradation. Therefore dome failure due it degredation is not considered a credible event.

2.0.3.4.2 Release Rate and Duration

In the event of complete dome collapse all of the residue area is uncovered. The ^{222}Ra release rate is determined from the product of the uncovered area and the bare radon emission rate (2×10^5 $pCi/m^2/s$). This product is roughly ten times the emission rate of the advanced cracking or 186 uCi/s (6000 Ci/yr). In addition to the radon release, complete dome collapse will also be accompanied by a ^{226}Ra and uranium particulate release.

The source term for the radium from the partially-collapsed dome is determined assuming an average wind velocity of 9.1 mph (4.07 m/s). This wind velocity is associated with a particulate resuspension factor of 9×10^{-7} $g/m^2/s$. Using an exposed area of $460 m^2$ (roughly the surface area of two domes) the radium emission rate is 8.1 pCi/s. In addition to the radium emission is the polonium decay daughter (^{218}Po). The release of this material is assumed to equal that of the radium (8.1 pCi/s).

2.0.3.4.3 Consequence

2.0.3.4.3.1 Plantsite

At an average onsite distance of 730 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is 3.42×10^{-3} Working Levels (WL). This value represents the average onsite exposure for an unprotected individual.

The annual total body dose for the onsite individual within the 730 m limit as calculated by the AIRDOSE computer code is 66.4 mRem (corrected for 40 hr per week and 50 week per year). The uptake pathway is entirely by inhalation.

2.0.3.4.3.2 Public

At a minimum offsite residence distance of 500 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is 1.5×10^{-3} WL for an unprotected individual.

The annual total body dose for the nearest offsite residence for an offsite individual as calculated by the AIRDOSE computer code is 127 mRem (24 hour days, 7 day weeks, 52 week years, and wind blowing to this direction 5% of the total time). The uptake pathway is entirely by inhalation.

At the most probable wind direction and a residence distance of 1300 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is 3.9×10^{-3} WL for an unprotected individual.

The annual total body dose for the offsite residence in the most probable wind direction as calculated by the AIRDOSE computer code is 331 mRem (24 hour days, 7 day weeks, 52 week years, and wind blowing to this direction 12.3% of the total time). The uptake pathway is entirely by inhalation.

2.0.3.5 Airplane Crashes

An airplane crash into the K-65 Silos would result in an extreme bounding worst case release. Not only would the crash remove the domed roofs (complete dome collapse), the force of the collision would cause an immediate puff release of material contained in the silos.

2.0.3.5.1 Probability of occurrence

Airplane crashes are known to occur most frequently within a few miles of an airport. This is an obvious conclusion when the manuvers at most risk in any normal flight are takeoff and landing, which are most likely to occur at an airport.

The K-65 Silos occupy 1.79×10^{-4} square miles, therefore, the probability of an aircraft crash into the silos is 6.44×10^{-8} per year.

2.0.3.5.2 Release Rate and Duration

An airplane crash into the K-65 Silos would result in complete dome collapse of both silo domes along with the immediate suspension of significant quantities of the silo inventory. The consequence of this accident would be a two minute puff release of 22 Ci of ^{222}Rn and 22 Ci of ^{218}Po. The amount of ^{226}Ra released in the puff is negligible. These quantities are the amount of radioactive materials in the ullage (head space) above the silo inventory. In addition to the puff release, there would be a continuous residual release of material. The continuing release is modeled by complete dome collapse (Section 2.0.3.4.3).

2.0.3.5.3 Consequence

2.0.3.5.3.1 Plantsite

Puff Release

At a distance of 500 m from the source the air exposure as calculated by AIRDOSE is negligable. This is due to the plume lofting to high to affect onsite individuals. Therefore, there is no exposure to radiation in the puff release in the event of total dome collapse.

Continuous Release

At an average onsite distance of 730 m from the source the air concentration as calculated by AIRDOSE is 3.42×10^{-3} Working Levels (WL). This value represents the average onsite exposure for an unprotected individual.

The annual total body dose for the onsite individual within the 730 m limit as calculated by the AIRDOSE computer code is 66.4 mRem (corrected for 40 hr per week and 50 week per year). The uptake pathway is entirely by inhalation.

Combined Puff and Continuous Exposure

The only individual exposure in the event of dome collapse is attributed to the continuous release.

2.0.3.5.3.2 Public

Puff Release

At a distance of 500 m from the source the air exposure as calculated by AIRDOSE is negligable. This is due to the plume lofting to high to affect onsite individuals. Therefore, there is no exposure to radiation in the puff release in the event of total dome collapse.

Continuous Release

At a minimum offsite residence distance of 500 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is 1.5×10^{-3} WL for an unprotected individual.

The annual total body dose for the nearest offsite residence for an offsite individual as calculated by the AIRDOSE computer code is 127 mRem (24 hour days, 7 day weeks, 52 week years, and wind blowing to this direction 5% of the total time). The uptake pathway is entirely by inhalation.

At the most probable wind direction and a residence distance of 1300 m from the source the ^{222}Rn air concentration as calculated by AIRDOSE is 3.9×10^{-3} WL for an unprotected individual.

The annual total body dose for the offsite residence in the most probable wind direction as calculated by the AIRDOSE computer code is 331 mRem (24 hour days, 7 day weeks, 52 week years, and wind blowing to this direction 12.3% of the total time). The uptake pathway is entirely by inhalation.

Combined Puff and Continuous Exposure

The all individual exposure in the event of dome collapse is attributed to the continuous release.

2.0.3.6 Tornados

A tornado is an event that can credibly lead to complete dome collapse. The consequence of this event is given in section 2.0.3.4.3.

2.0.3.6.1 Probability of occurrence

The probability of a tornado striking a particular location during one year is the product of the annual tornado frequency and the ratio of the affected area to the area in which the annual tornado frequency is known. Given that Hamilton County has been hit by an average of 15 tornados per year for the past 80 years, the area of the K-65 Silos is 1/10th of an acre, and the area of Hamilton County is 264,960 acres, the probability of a tornado striking the K-65 Silos is about 5.7×10^{-6} per year.

During the period years 1960-1976, FMPC wind records list gusts in excess of 50 mph on eleven occassions and 60 mph on two occasions. Due to the configuration of the K-65 Silos and earthen embankment the extreme wind effects on the silos is negligible; therefore this is not a silo dome failure mechanism.

2.0.3.6.2 Release Rate and Duration

See section 2.0.3.4.2

2.0.3.6.3 Consequence

2.0.3.6.3.1 Plantsite

See section 2.0.3.4.3.1

2.0.3.6.3.2 Public

See section 2.0.3.4.3.2

2.0.3.7 Earthquake

An earthquake is an event that can credibly lead to complete dome collapse. The consequence of this event is given in section 2.0.3.4.3.

2.0.3.7.1 Probability of occurrence

Past seismic activity in the southwestern Ohio region has been relatively minor with respect to vibration frequency and amplitude. Of the seven earthquakes that have occurred in the last 210 year period all have been of a low intensity (III on the Modified Mercalli Scale-MMS). Earthquakes with impacts great enough to crack concrete walls are designated VII on the MMS. Those large enough to cause severe structural damage and/or collapse of concrete structures are designated VIII and IX on the MMS. A study on the seismic hazard in the FMPC area reported that the return period is 1000, 100,000, and one million years for a VII, VIII, and IX MMS respectively.

2.0.3.7.2 Release Rate and Duration

See section 2.0.3.4.2

2.0.3.7.3 Consequence

2.0.3.7.3.1 Plantsite

See section 2.0.3.4.2.1

2.0.3.7.3.2 Public

See section 2.0.3.4.2.2

2.1 Risk Analysis and Consequence (Summation)

The objectives of this analysis are to: (1) examine all reasonable accident situations involved with the K-65 Silos in their present condition, (2) perform an accident analysis based upon the actual design and operating procedures, (3) make conservative evaluations of accident probabilities, and (4) make conservative assessments of both on-site and off-site impacts on the environment and personnel/public.

The following system has been used for classifying the accident probabilities (Table 2-1) and associated hazard (Table 2-2). The

TABLE 2-1
Probability Rating Scale

Probability Scale	Description	Estimated Frequency per year
E Extr High	Likely to occur at least annually	$P \geq 1.0$
D High	Likely to occur once a decade	$0.1 \leq P < 1.0$
C Medium	Likely to occur once a century	$0.01 \leq P < 0.1$
B Low	Likely to occur once a 1000 years	$0.001 \leq P < 0.01$
A Extr Low	Not likely to occur in a 1000 years	$P < 0.001$

Table 2-2 Hazard Rating and Consequence Definition

Hazard Level	Maximum Consequence
7 Catastrophic	Extremely serious impact onsite and offsite for lengthy periods of time. Large geographical area as well as large population groups affected. Large number of fatalities, both onsite and offsite.
6 Extr High	Extremely serious impact onsite, on large numbers of people and to the environment. Many fatalities onsite and possible fatalities to the public located on adjacent property. Moderate impact beyond the exclusion area.
5 High	Extremely serious impact onsite and considerable impact on the environment. Fatality, severe injury, or severe illness to operating personnel. Significant health concern to workers at nearby onsite facilities. Few people offsite seriously affected.
4 Medium	Serious onsite impact and significant impact within the exclusion area and to the environment. Fatality, severe injury, or severe illness to operating personnel. Significant health concerns to workers at nearby facilities. Few people offsite seriously affected.
3 Low	Significant onsite but only minor offsite impact. Moderate injury or creation of moderate health concerns for operating personnel. Minor health and safety concerns for nearby facility workers. Slight contamination of offsite environment.
2 Extr Low	Minor onsite but no offsite impact. Slight injury or illness to operating personnel. Local facility contamination which requires only routine procedures to control or correct. No health or safety concerns for workers at nearby facilities.
1 Negligible	Detectable onsite. No onsite or offsite impact. No identifiable safety or health concerns. Negligible contamination of the environment.

accident probabilities are classified in terms of extremely high, high, moderate, low, or extremely low probability of occurrence.

The explanation and description of these probability classes are given in Table 2-1 along with the annual probability of occurrence. The accident hazard consequence are classified as catastrophic, extremely high, high, moderate, low, extremely low, and negligible. The criteria used to assign accident consequence are given in Table 2-2. As an aid to interpreting the classifications given in Table 2-2, the following definition is given.

Exclusion Area: The area surrounding the facility in which the owner/operator has the authority to determine all activities including the exclusion or removal of personnel and property from the area.

The risk level is assigned to system/operation according to the matrix given as Figure 2-3. This matrix defines risk as being extremely high, moderate, low, and extremely low. The acceptance of the risk involved with a facility/operation is the responsibility of the facility owner (the Department of Energy).

2.1.1 Floors and Drainage

There is no identified incident that can lead to the K-65 Silo floor and drainage failure that will lead to a release of material. The earthen berm provides area drainage to preclude localized flooding and the silos are far above the Miami river floodplain to preclude general flooding. There are no springs in the silo area. Therefore there is no immediate risk associated with the Floors and Drainage.

2.1.2 Walls and Berm

There are no identified accident incidents that will only result in wall and berm failure. A direct hit of the silos by a large aircraft could result in wall and berm failure, but the domed roofs would also fail (See 2.1.3.5). Therefore there is no accident risk associated only with wall and berm failure.

2.1.3 Domed Roof

The K-65 Silo dome is the only single system component that can fail and result in a release of radioactive material. Identified dome failures are advanced cracking, partial dome failure (center 20-foot diameter section of one dome), complete dome failure (entire dome cover of both domes). Causes for silo dome failures could be degredation, airplane collisions with the silos, tornados, and earthquakes.

FIGURE 2-3

RISK MATRIX

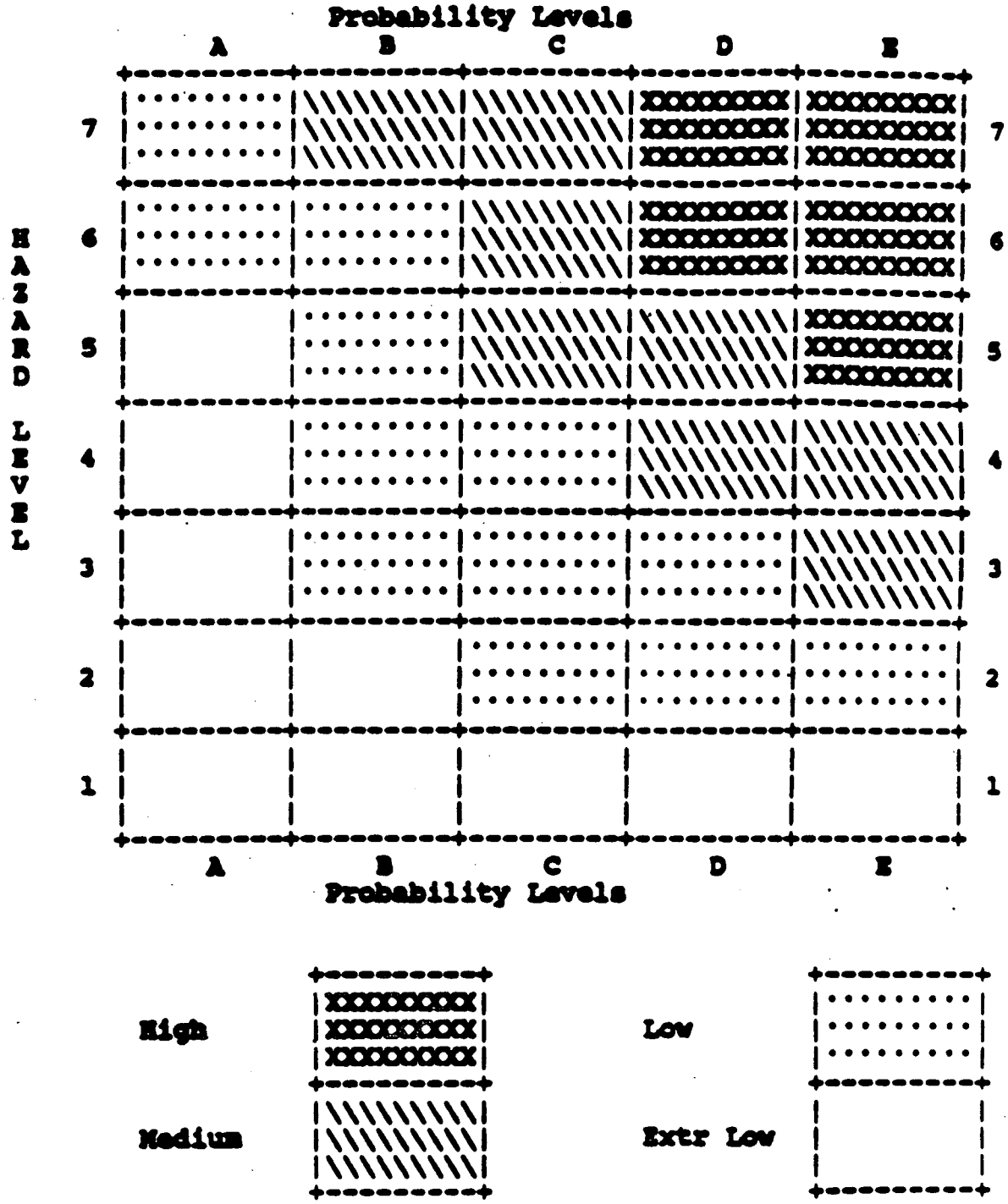


FIGURE 2-3

RISK MATRIX

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