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REMOVAL SITE EVALUATION THORIUM STORAGE BUILDINGS VOLUME 1

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REPORT

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2019

Removal Site Evaluation

Thorium Storage Buildings

Volume 1

(See Volume 2 for AIRDOS Data)

Fernald Site Office (FSO)
Fernald, Ohio

July 1991

U. S. DEPARTMENT OF ENERGY

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1.0 INTRODUCTION AND PURPOSE

The Fernald Site (FS) is the Department of Energy's (DOE) interim storage site for thorium and thorium compounds. There are approximately 15,000 55 gallon drum equivalents stored in Buildings 60, 64, 65, 67, and 68 (See Figure 1). The thorium compounds at the FS were produced at various locations between 1953 and 1986 and have been stored at the site since that time. The physical form of the thorium varies from metal to powder to liquids and represents 61 streams or sources of material (See Table 1). In addition, the specific process knowledge of these streams appears in Appendix A.

This Removal Site Evaluation (RSE) has been performed to consider mechanisms that would cause a release of the stored thorium from the buildings, the potential for these identified releases to occur, and the exposures to radioactive material that would occur if there was a release. In addition, the projected exposures from the release and/or the projected air concentration were determined by the use of the EPA program - AIRDOS, are used to calculate the risk to off-site and on-site occupants. The exposures to the specific radioactive material involved in the different thorium storage warehouses are calculated individually and combined. Through both dose calculations and comparison to EPA Health Effects Assessment Summary Tables, a risk assessment is made. These can be compared to the acceptable range of 1E-04 to 1E-06 lifetime risk for the potential development of cancer.

This Removal Site Evaluation is developed in accordance with the approach given in 40 CFR 300.410. Section 2.0 of this RSE presents current site conditions which are supplemented by Appendix A, Process Knowledge, and Appendix B, Thorium Inventory. Section 3.0 summarizes the Site Radiological Considerations at the Thorium Warehouses including the specific radionuclides and their forms relative to the possible release mechanisms. Section 4.0 develops the Source Term, or radioactive inventory. Appendix C further describes warehouse conditions including the Gamma Exposure Rates Within Buildings. Appendix D provides air sample data to support the significance of current airborne releases. Section 5.0, Evaluation of Potential Threat, presents current release conditions and potential release scenarios. Appendix E provides the Tornado Probability which could lead to maximum releases from the warehouses. Appendix F summarizes atmospheric diffusion calculations, using the EPA AIRDOS model, for existing and potential releases. Tables are provided for each building and for each radionuclide. In addition, the impact of releases from all buildings, simultaneously, is provided.

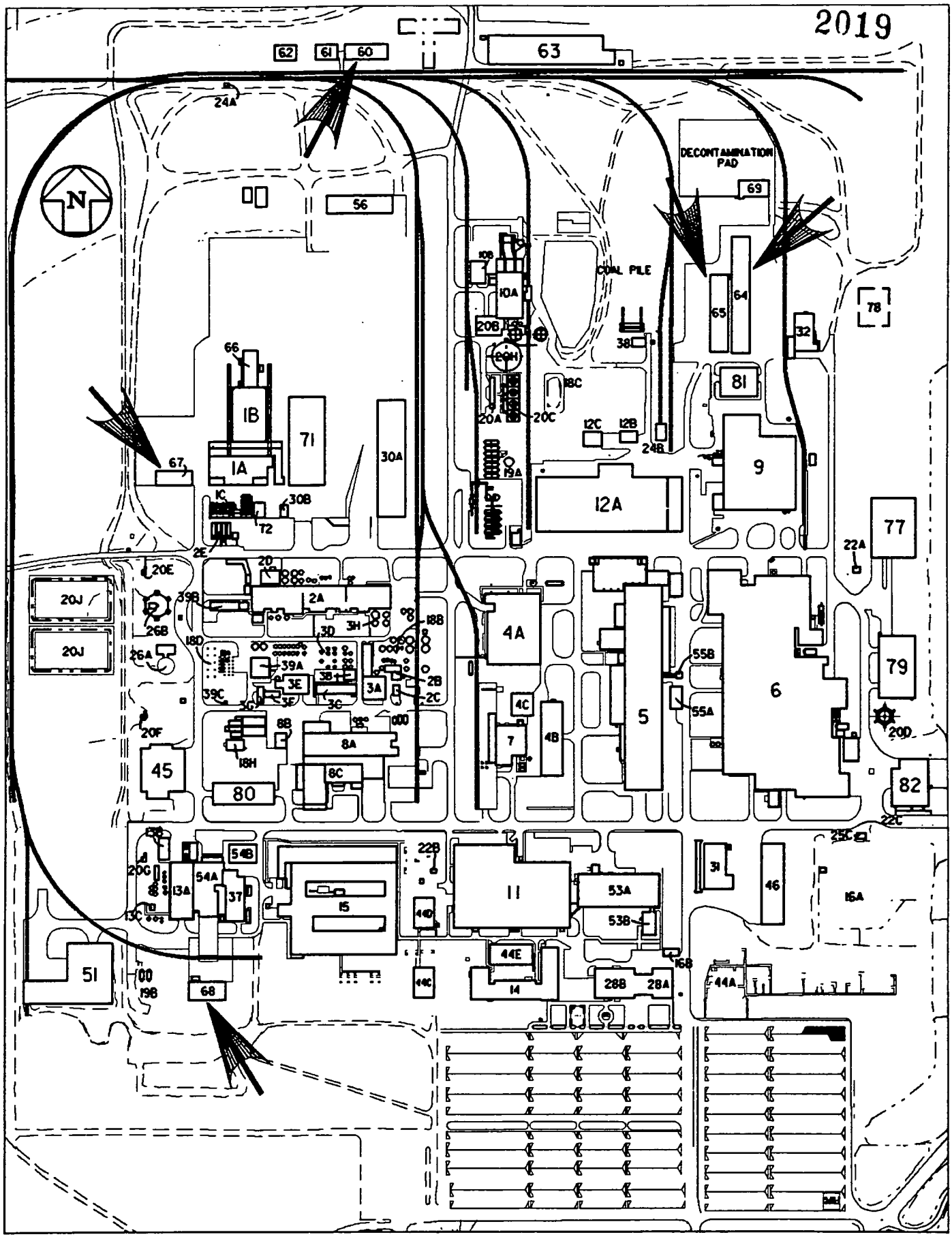


FIGURE 1

THORIUM STORAGE WAREHOUSES

TABLE 1

THORIUM STORAGE

BUILDING NUMBER	NUMBER OF CONTAINERS	CONDITION OF CONTAINERS	CONDITION OF WAREHOUSE	OTHER COMMENTS
64	420	Good	Good	35-gallon drums on pallets, various sizes of wooden crates. 6 individual streams of materials.
65	5,599	Poor	Fair	Various sizes of drums (35, 55, tall 55-gallon containers) stacked 3 high, most not palletized. Integrity of drums sitting on concrete floor is deteriorated. 5 individual streams of materials --3 streams comprised of only 4 containers . . . mostly from 2 streams.
67	6,004	Good	Good	Various sizes of containers (mostly cans) in baskets or palletized. 1 container obviously damaged (5-gallon pail). Some wooded crates and flat pieces of metal. 44 individual streams of materials.
68	1,317	Good	Good	55-gallon drums stored similar to those in Bldg. 65 but their condition is much better. Other materials in the building may need to be relocated to provide access. 2 individual streams of materials.
60	1,788	Good	Good	Individually overpacked drums. 4 individual streams of materials.

2.0 FERNALD SITE CONDITIONS

As indicated above, the stored thorium is from 61 different process streams. It is presently stored in five site Buildings, 60, 64, 65, 67, and 68. All of these buildings are about 35 years old. The oldest Building, 60, is 40 years old. As detailed in Table 1, four of the five warehouses are assessed to be in good condition. Building 65 has been determined to be in poor condition. All of the buildings are metal frame and metal sided Butler type buildings and are all located on cement slabs. Thus, the buildings have a rigid structure and are not dilapidated or deemed to be in danger of collapse; in addition, the doors and windows are intact, and an active maintenance program is in place to ensure the continued integrity of the structure.

The thorium materials are stored in drums of varying sizes and various other containers such as pails and wooden crates. In addition, some of the thorium is in the form of flat pieces of metal. A container specific listing is provided in Appendix B.

Inspection notes indicate that most containers are intact in all of the buildings except for Building 65. The containers in Building 65 are stacked three-high; most are not on pallets and many are in a severe state of deterioration or have been breeched, releasing the contents. Although no longer confined in a drum, the contents are still contained within the building. A significant release to the environment is postulated only if building integrity is lost.

There are drums stored in Building 64 which contain potentially pyrophoric thorium.

Some drums in Building 68 are stacked three-high. These drums are in good condition but the storage configuration does not minimize possible damage from the catastrophic hazards considered.

A small fraction of the containers are known to contain Resource Conservation Recovery Act (RCRA) listed materials, and a few drums remain to be sampled for RCRA related analyses. Appendix A summarizes Process Knowledge, and the Appendix B Thorium Inventory includes the RCRA status of the containers.

Chemicals used in the refining of the thorium compounds, and other chemicals present as intermediates, included: oxalic acid, nitric acid, thorium nitrate, thorium oxalate, thorium oxide, and thorium hydroxide solid. Calcium oxide was used to enhance sintering and other chemicals that may have been used include diamyl amyl phosphonate, ammonia, and ammonium sulfate. None of the above are listed in the 40 CFR 261 Subpart D.

From the mid 1960's to the mid 1970's, thorium was provided to facilities for test irradiations for potential breeder reactor applications[1]. In preparation, thorium oxalate was precipitated from a thorium nitrate solution and then calcined to thorium oxide. This material was then used

for the test irradiations. Following irradiation, uranium was separated from the thorium through an efficient solvent extraction process. The returned thorium contained only a minor fraction of the uranium-232 and 233. Most of this material is stored in Building 68.

The thorium has been consolidated from other production areas, including material from the Plant 8 silo and bins, and is now stored in appropriate containers in Building 60. Building 60 is one of the oldest buildings on the site; but the drums stored in it are only two years old and consist of individually overpacked drums (a filled drum placed inside a larger drum).

Overpacked drums are also currently stored in Building 64. These drums had been previously stored outside of Building 65.

3.0 SITE RADIOLOGIC CONSIDERATIONS

Most of the thorium stored in Building 65 has not been separated from its natural daughters. It is Brazilian sludge which has had some rare earths removed. The balance of thorium at the FS has been separated from the original ore. Both thorium-232 and thorium-228 are chemically separated and recovered together in the production purification process. The separated product initially contains only trace amounts of the non-thorium isotopes present in the ore; chemical partitioning is somewhat less than 100 percent. Since some of the thorium was processed as long as 36 years ago, it is assumed that sufficient time has passed for in-growth of radium-228 (6.7 yr) and actinium-228 (6.13 hr) from the parent thorium-232. The thorium-228 daughters are all short half-lived and in-growth to secular equilibrium occurs within several weeks after separation. Therefore, 36 year old thorium will contain all of the following principle radionuclides:

Thorium-232	Polonium-216
Thorium-228	Lead-212
Radium-228	Bismuth-212
Radium-224	Polonium-212 (64%)
Radon-220	Thallium-208 (36%)

Much of the thorium is less than 36 years old; thus, daughter equilibrium is a conservative assumption. Under current conditions, some of the thoron is released and the significance of that release is analyzed in Section 5.0. A conservative assumption for assessment of the release of solid particulates is that no thoron is lost and that all daughters are present in equal activity concentrations.

Because the uranium-238 series frequently co-exists with the thorium-232 series in nature, a fraction of the thorium recovered through chemical separation of the ore includes thorium-230. Radium-226, the thorium-230 daughter, will grow in very slowly because of its relatively long half-life (1602 yr). Significant airborne concentrations of radon-222 require a significant quantity of radium-226.

Some of the thorium-232 stored at the FS has been irradiated with neutrons for production of fissile uranium-233. A portion of the thorium inventory includes the latter isotope.

4.0 RADIOLOGICAL SOURCE TERM

The current FS inventory of thorium materials consists of approximately 1,300 metric tons of various thorium materials in approximately 15,000 containers. The inventory of thorium and compounds is presented in Appendix B.

4.1 Source Term by Building

The following summarizes the inventory by building, including the radiological source term that is necessary for input to the AIRDOS program:

Building 60 — 1788 containers: oxides and other forms

Thorium-232	19 Curies
Radium-228	19 Curies
Thorium-228	19 Curies
Thorium-230	2 Curies

Building 64 — 420 containers: metal, oxides, and other forms

Thorium-232	11 Curies
Radium-228	11 Curies
Thorium-228	11 Curies
Thorium-230	1 Curie

Building 65 — 5599 containers: hydroxide and oxalate

Thorium-232	35 Curies
Radium-228	35 Curies
Thorium-228	35 Curies
Thorium-230	3 Curies

Building 67 — 6004 containers: oxides and other forms

Thorium-232	16 Curies
Radium-228	16 Curies
Thorium-228	16 Curies
Thorium-230	2 Curies
Uranium-233	0.2 Curies

Building 68 — 1317 containers: oxides and other forms

Thorium-232	36 Curies
Radium-228	36 Curies
Thorium-228	36 Curies
Thorium-230	4 Curies
Uranium-233	41 Curies

Passive radon (radon-222) and thoron (radon-220) daughter monitoring has been carried on in the storage warehouse buildings since 1988. The inventory within Building 65 may include significant radium-226 based upon the apparently high concentrations of radon. It is possible that a high ratio of thoron to radon could cause incorrect results through use of the algorithm to distinguish the two gases based upon the response of the two types of track etch cups. Additional sampling is planned to determine if a significant quantity of radium-226 is present in Building 65.

Table 2 below presents the three year average concentrations of radon (Rn-222) and thoron (Rn-220) from the track etch cup measurements.

Table 2. Average Radon and Thoron Concentrations (1988-90) (pCi/L)

Thorium Storage Warehouse	Radon-222	Radon-220
Building 64		
1988	1.90	2.53
1989	0.94	16.90
1990	1.79	50.18
Building 65		
1988	100.13	(-12.29)
1989	69.98	18.61
1990	62.18	20.28
Building 67		
1988	6.47	9.17
1989	6.65	19.13
1990	6.74	26.09
Building 68		
1988	13.87	(-3.77)
1989	7.71	(-0.27)
1990	11.26	5.46

(Negative values were computed as shown. There appears to be a weakness in the algorithm that does not allow accurate segregation of radon and thoron.)

In all buildings, the average thoron concentrations are increasing which indicates a progressive loss of confinement of the thoron gas being produced in the storage containers. Also, because the thoron continues to increase, the most recent year's data was used for the AIRDOS run.

Gamma ray exposure rate surveys are presented in Appendix C with isodose contours (mr/hr) and accompanying representations of the storage configurations within each building. The exposure rates are of concern for occupational controls; however, there is insignificant off-site exposure through this path. Also, a number of actions which contribute to shielding of the gamma radiation has reduced occupational exposure in the vicinity of the buildings.

5.0 EVALUATION OF POTENTIAL THREAT

5.1 Current Conditions

5.1.1 Radioactive Airborne Particulate Releases

There are some unconfined thorium compounds in the storage warehouses (e.g. Building 65), and there is evidence of localized contamination adjacent to the buildings. The impact of any ongoing entrainment can be assessed through review of air particulate sample results from the FS Environmental Monitoring Program. Figure 2 shows the EMP air sampling locations. Appendix D provides a summary of the 1989 air particulate sample results.

Review of the air particulate sample concentrations shows that there is minimal impact from airborne radionuclides that can be related to the thorium inventory. The AMS 6 average for radium-228 was 9.5E-06 pCi/m3 and thorium-228 averaged 1.1E-05 pCi/m3. By using the dose calculations provided in DOE Order 5400.5[2], the annual committed effective dose equivalent calculated from AMS 6 does not exceed 0.03 mRem/yr which is much less than the National Emission Standards for Hazardous Air Pollutants (NESHAPs) limit of 10 mRem/yr. In addition, the combined risk calculated by the Environmental Protection Agency (EPA) HEAST methods for these two isotopic concentrations would be 6E-09.

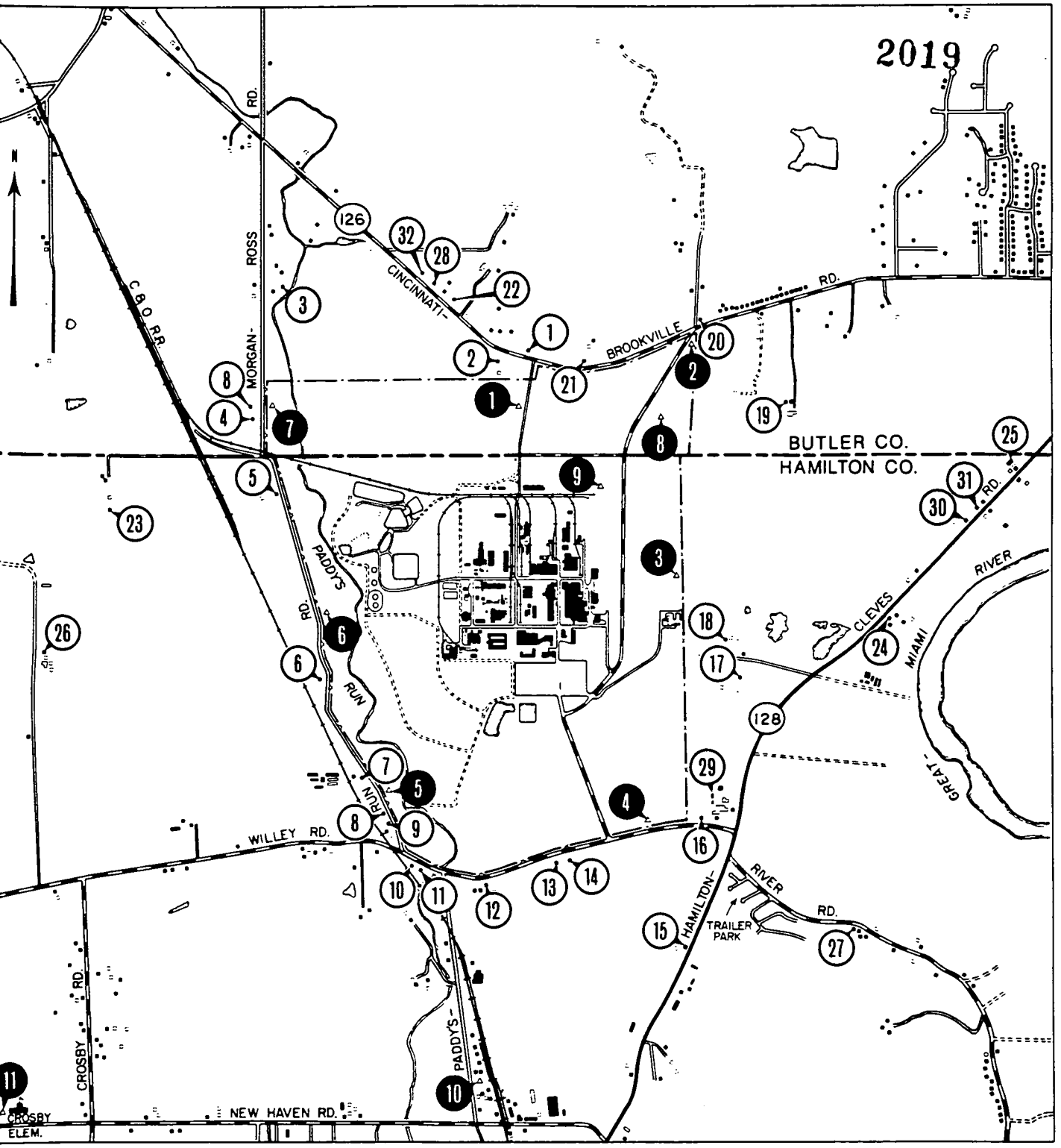
5.1.2 Radioactive Gas Releases

Airborne radon-222 (radon) is expected due to releases from radium-226. Radon-220 (thoron) is released from radium-224 in the thorium decay series. A principal concern at the FS is the radon-222 from radium-226 in the K-65 Silos 1 and 2 which are not associated with the thorium storage locations. Passive and active radon monitoring is focused on Silos 1 and 2. In addition, each of the air particulate EMP sampling locations has passive radon monitors. There is no attempt to discriminate thoron contribution at these locations because of the 55 second half-life and typical downwind transport time. The radon-222 concentrations at the EMP locations are not statistically distinct from expected ambient or background concentrations.

However, there are passive monitors in the thorium storage buildings which are designed to provide distinct concentrations of radon and thoron. These concentrations were provided in Table 2 of Section 4.0. Those concentrations were multiplied by the respective building

FMPC ENVIRONMENTAL RESIDENTIAL CENSUS, 1989

FIGURE 2



0 1/2 1 2

SCALE OF MILES

LEGEND

- Heavy Duty Roads
- Medium Duty Roads
- Light Duty Roads
- Fixed Air Monitoring Stations
- Numbered Residence
- FMPC Boundary

volumes to provide total quantities present in the buildings. Those data are provided in Table 3.

Table 3. Airborne Radon and Thoron Within Building Based Upon 1990 Average Concentrations

	Building Volume (liters)	Radon (uCi)	Thoron (uCi)
Building 64	5.15E5	0.92	25.8
Building 65	5.74E6	356.9	116.4
Building 67	1.72E6	11.6	44.9
Building 68	2.88E6	32.4	15.7
	TOTAL	401.8	202.8

There are too many unknown factors bearing on the rate of release of radon and thoron from the thorium storage buildings to propose a defensible estimate. To establish some reference, an analysis was made based upon the assumption that each of the buildings has one air exchange per day. The daily releases are then equal to the totals given in Table 3. On an annual basis, the quantities released are:

Radon-222	0.15 Ci/yr
Radon-220	0.074 Ci/yr

These source terms were then input to the EPA AIRDOS code to calculate downwind concentrations. These results are included as a part of Appendix F and the significance of those results are discussed below.

An AIRDOS run was made using the total source term described above. The release point is the geometric center among the buildings, and the nearest receptor is located 1625 meters in the east-southeast direction. The AIRDOS model calculates a working level (WL) for Rn-222 (based on 70 percent equilibrium), but it does not calculate a WL for Rn-220 (thoron). However, a manual calculation of the radon daughter WL was made using the airborne concentration provided by AIRDOS results. As shown in Table 4, the combined WL calculated for the nearest resident is 1.15E-06 WL.

Table 4. Results of the Estimated Current Continuous Release of Radon, Thoron and Daughters at the Nearest Receptor

	Radon-222	Radon-220
Air Concentration (pCi/L) (AIRDOS Run)	3.53E-05	1.60E-08
Daughter Working Levels (1) (AIRDOS Run)	2.47E-07	
Daughter Working Levels (2) (Calculated)	3.57E-07	8.00E-07
Inhalation (pCi/yr)	2.84E+02	1.29E-01
HEAST Slope Factor (3)	1.10E-11	1.94E-08
Calculated Risk	3.12E-09	2.50E-09

(1) Calculated through AIRDOS which assumes 70% daughter equilibrium with radon-222. AIRDOS does not calculate thoron daughter Working Levels.

(2) Calculated from the AIRDOS radon-222 and radon-220 concentrations and assuming 100% daughter equilibrium.

(3) Calculated for all radon-222 daughters. Calculated for four radon-220 daughters; transport time on the order of 15-30 minutes results in nearly complete decay of radon-220 (55 sec) and polonium-216 (0.15 sec).

The calculated risk is relatively low in comparison to the range of 1E-04 to 1E-06. Calculated concentrations of radon and thoron at the nearest receptor are very low in comparison to expected ambient background levels. For reference, the combined daughter concentration of 1.15E-06 Working Levels is nearly 10,000 times less than one EPA guidance of 0.02 Working Levels (40 CFR 192.12).

5.1.3 Summary of Existing

In summary, the current off-site conditions include:

Airborne particulate release:

Annual dose	<0.03 mRem/yr
Risk	6E-9

Airborne radon and thoron release:

Annual dose	5.9E-05 WLM
Risk	2E-10

5.2 Potential Release Scenarios

In addition to the current releases, assessed above, an assessment of potential release scenarios has been made. Potential release mechanisms include the effects of high winds, tornadoes, earthquakes, fires, and floods.

The condition of the containers within each building is variable. Containers within Building 60 are in good condition and are least likely to cause a significant release with loss of building integrity. Some containers in Building 65 have deteriorated, and there is loose material on the floor and other surfaces. Conditions in Building 68 are flawed, and some of the stacking could topple either with further deterioration or with some other force such as a tremor or earthquake. These conditions motivate an assessment of a maximum or "catastrophic" release.

5.2.1 High Velocity Winds

Buildings 64, 65, 67, and 68 were designed to withstand direct winds of 100 mph. Although Building 60 is a different type of structure, it was built with these same specifications. Winds of this velocity have only been observed in micro-scale situations such as thunderstorms, tornadoes, and micro-burst. The highest velocity wind ever recorded at the Greater Cincinnati Airport (17 miles south) was 64 mph in March of 1986. The highest sustained wind was 44 mph for three minutes during the same weather event. Thus, the high wind experience suggests that it is unlikely that these forces would cause building damage to the extent that there is a significant release.

5.2.2 Tornadoes

During 1990, the University of Cincinnati performed a Probabilistic Risk Assessment for the K-65 Silos at the FMPC[3]. This study included a review of tornado probabilities for both incidence and severity. Considerable National Oceanic and Atmospheric Administration (NOAA) data were reviewed covering a time frame from January, 1916 to April, 1989. More recently, a series of funnel clouds were reported during June, 1990 and one tornado was reported to have touched down within a mile of the FS.

For focus, the University of Cincinnati analyzed a data set for Ohio, Indiana and Kentucky for the most recent 9 1/4 year period. They utilized the Fujita Tornado Scale which is summarized in Table 5.

Table 5. Fujita and Pearson Tornado Scale[3]

Scale	Maximum Windspeed (mph)	Path Length (Miles)	Path Width (Miles)
F0	40-72	0.4-0.9	0.0034-0.0097
F1	73-112	1.0-3.1	0.0102-0.0312
F2	113-157	3.2-9.9	0.0318-0.0994
F3	158-206	10-31	0.10-0.30
F4	207-260	32-99	0.40-0.90
F5	261-318	100-315	1.0-3.1

The University of Cincinnati statistical assessment covered approximately 41,000 square miles of the tri-state area with 117 documented tornadoes from 1980 through 1989. Table 6 summarizes the data including the resultant probabilities.

Table 6. University of Cincinnati Tornado Data Summary
Ohio, Kentucky, and Indiana, 1980-1989

Intensity	Affected Area (sq. mi.)	Number of Occurrences	Probability/yr per Square Mile
F0	0.74	18	1.91E-06
F1	14.23	68	3.65E-05
F2	11.02	23	2.83E-05
F3	7.59	5	1.95E-05
F4	4.77	2	1.22E-05
F5	10.25	1	2.63E-05
	48.62	117	1.25E-04

Further statistical analysis, summarized in Appendix E, provides the following:

Total probability for a tornado	1.2E-03/sq.mi.
Five year probability for >F2	4.3E-04/sq.mi.

Since the buildings were constructed to withstand 100 mph winds, it is assumed that force F2, and higher, would result in the destruction of the buildings. A significant release of material from the buildings would be expected.

5.2.3 Earthquakes

The FS is located in a seismically quiet region that has experienced ground motion principally due to the events in adjacent regions. The low level of seismic activity has resulted in the lack of interest in regional seismicity, and a rather small number of instrument recorded events. An earthquake analysis was performed by Camargo[4] for the K-65 silos. An earthquake with a peak ground motion acceleration of 0.05g, and the ground motion duration of 10 seconds, has a 90% probability of occurrence within a fifty year period. The seismic analysis showed that the silos would not fail under these stresses. Other structural damage on the FS would also be expected to be minimal and with no significant release of thorium from the storage buildings.

5.2.4 Fire

Arson and equipment fires are the leading causes of fires in the United States[5]. Security at the FS reduces the arson threat. Items listed below show a reduced probability for equipment and electrical fires in the thorium storage buildings.

1. All pallets and wood used for stacking drums aretreated for fire retardation.

2. All the "Butler Type" buildings have cement-asbestos siding on the walls.

3. All warehouses only have lighting circuits that are locked off. These lights are used only during inspections.

4. All of the over-packing equipment in the North end of Building 64 is disconnected.

An electrical fire could occur while the lighting circuits are on, but this would not lead to loss of building integrity. A pyrophoric fire is possible with materials stored in Building 64, but release from the Building would be minimal since there would be no appreciable loss of integrity.

Approximately half of all building fires are as a result of outside brush fires. Control of grass and weeds adjacent to the thorium storage buildings prevent a fire of this nature.

In the event of a fire, water from fire hoses could result in the runoff which would be controlled for clean-up.

5.2.5 Flood

Since the Fernald production area and thorium warehouses are above the 100 year flood plain, there is virtually no probability of a flood capable of entraining contaminants to any distance from the buildings. Building 65 experienced flooding during an earlier construction project, but this was only due to temporary grading at that time. This condition was corrected and no further flooding has been experienced.

5.2.6 Potential Airborne Release

The maximum potential threat appears to be the loss of building integrity, through high velocity or tornadic winds, with an airborne release of a fraction of the inventory. In addition to the entrainment of loose materials, it is likely that deteriorated containers would also lose integrity with contents contributing to the airborne effluent. It is apparent from Section 5.2 that the probability for such an event is low.

There are too many possible variables to accurately predict the fraction of the source term that could be released through such an event. In order to establish some reference, an assessment was made based upon a reasonably conservative ten percent release estimate. These quantities were input to the EPA AIRDOS code to assess the consequence of such a release.

As in the earlier case, for existing radon and thoron releases, AIRDOS was used to calculate downwind concentrations due to atmospheric diffusion. More features of the code were used for this larger potential release.

AIRDOS accepts radionuclide source terms, along with local meteorological data, and utilizes a modified Gaussian plume

diffusion model to compute horizontal and vertical dispersion of the radionuclides. Downwind airborne concentrations and ground deposition is calculated. The code then uses this information to calculate radiation doses to the public through inhalation of airborne activity, external exposure from activity deposited on the ground, and through a number of ingestion pathways. The ingestion pathways used in the dose calculations include ingestion of locally produced meat, milk, and produce. For this RSE, the location of specific residences (receptors) closest to each of the thorium warehouses was input to the code to calculate information for those locations. In addition, airborne concentrations were calculated for 22.5 degree sectors (16 compass directions) at distances of 1700, 1800, 2000, 2200, 2500 and 5000 meters from each of the warehouses.

A large array of input parameters are required for the AIRDOS code. Those that are readily available for this locale were used. The developers of the code recognized that it may be unreasonable to mount an extensive set of studies to determine each value. There are a number of supported default values that are described in the short bibliography provided in Appendix F.

Through this assessment, it is obvious that nearly all the dose is due to the inhalation pathway. The significance of any differences between site specific parameters and AIRDOS default values affecting the ingestion pathway is reduced.

One assumption was made in this particular use of AIRDOS. The program is designed to handle annual average releases. The accident scenario, with the ten percent release of the source term, is most likely to occur in a short period of time. The doses that are calculated are very nearly the same, but one recognizes that the same dose is likely to be experienced in a short period of time instead of gradually over a period of one year. Similarly, the airborne concentrations will be proportionately higher in the shortened time frame. Any continuing releases, following an accidental release, will be much lower for the balance of the year.

There is one kind of event would result in higher radiation doses than those calculated here. Annual average site meteorological data were input to the code and the wind speeds are representative of normal conditions. If an accidental release is accompanied by high winds, it is possible that a more focused and higher concentration plume could be directed to an off site receptor. While the dose distribution would be less wide spread, it is possible that significantly higher doses could be experienced in a

narrower down wind path. It is not reasonable to pursue all possible conditions.

Appendix F provides a relatively complete summary of the AIRDOS results. In addition, there is supplemental information in the Appendix which further clarifies the parameters used and permits a better understanding of the code results. In addition, four key reference citations are given.

Table 7 summarizes the age-averaged lifetime excess total cancer risk for the nearest receptor to each building based upon the calculated airborne concentration for the principle isotopes shown. Figure 2 (Sec. 5.1) shows the receptor locations. At the bottom of Table 7, the ALL case constitutes the simultaneous release from all buildings from a point which is the geometric center among the buildings. While only thorium-232 is shown, the Slope Factor used to calculate risk is a summation which includes the risk from each of the thorium-232 daughters. The single Slope Factors for thorium-230 and uranium-233 were used because insufficient time has passed for significant daughter in-growth. The Slope Factors used to calculate the risk were taken from the December, 1990 update of the Health Effects Assessment Summary Tables.

The AIRDOS code provides radiation dose results and these are summarized for the nearest receptors in Table 8. The committed effective dose equivalent from release from all buildings is 28.6 Rem to the nearest residence. Over 99% of the radiation dose is due to inhalation for all isotopes except radium-228. Dose through inhalation of the latter is approximately 70%. Radium-228 is expected to be more soluble and contributes to foodstuffs through the various pathways. Approximately 30% of the dose from radium-228 occurs through ingestion; primarily ingestion of vegetation (crops).

The risk was calculated using the risk coefficient for effective dose equivalent promulgated by the National Council on Radiation Protection and Measurements. For comparison, the lifetime risk previously calculated through HEAST Slope Factors is also provided. There is relatively good agreement. In any case, the risk is above the acceptable range of 1E-04 to 1E-06.

Table 7. Cancer Risk from Airborne Concentrations through HEAST Ten Percent Release Scenario

BLDG	Nearest Receptor (meters)	Isotope	Air Conc. (pCi/m3)	Slope * Factor	Lifetime Risk
60	750	Th-232	1.48E+00	1.1E-07	1.3E-03
		Th-230	1.57E-01	3.1E-08	3.9E-05
					1.3E-03
64	1200	Th-232	3.62E-01	1.1E-07	3.19E-04
		Th-230	3.29E-02	3.1E-08	2.46E-05
					3.40E-04
65	1200	Th-232	1.15E+00	1.1E-07	1.02E-03
		Th-230	9.88E-02	3.1E-08	8.20E-06
					1.00E-03
67	1700	Th-232	2.86E-01	1.1E-07	2.53E-04
		Th-230	3.57E-02	3.1E-08	8.90E-06
		U-233	3.57E-03	2.7E-08	7.75E-07
					2.60E-04
68	1300	Th-232	1.03E+00	1.1E-07	9.02E-04
		Th-230	1.15E-01	3.1E-08	2.85E-05
		U-233	1.17E+00	2.7E-08	2.55E-04
					1.20E-03
ALL	1625	Th-232	2.26E+00	1.1E-07	2.00E-03
		Th-230	2.32E-01	3.1E-08	5.77E-05
		U-233	7.96E-01	2.7E-08	1.73E-04
					2.20E-03

* Factor per pCi inhaled.

Table 8. Whole Body Dose Equivalent and Lifetime Risk to the Nearest Receptor
Ten Percent Release Scenario

BLDG	Isotope	Dose Equivalent (Rem)	Percent due to Inhalation	NCRP Risk*	HEAST Risk**
60	Th-232	1.38E+01	99.7		
	Ra-228	8.20E-02	70.2		
	Th-228	4.11E+00	99.9		
	Th-230	3.32E-01	99.7		
		1.84E+01		2.3E-03	1.3E-03
64	Th-232	3.35E+00	99.7		
	Ra-228	2.00E-02	69.6		
	Th-228	9.95E-01	99.9		
	Th-230	6.95E-02	99.7		
		4.43E+00		5.5E-04	3.4E-04
65	Th-232	1.07E+01	99.7		
	Ra-228	6.35E-02	69.6		
	Th-228	3.17E+00	99.9		
	Th-230	2.09E-01	99.7		
		1.41E+01		1.8E-03	1.0E-03
67	Th-232	2.65E+00	99.7		
	Ra-228	1.58E-02	69.1		
	Th-228	7.86E-01	99.9		
	Th-230	7.54E-02	99.7		
	U-233	3.90E-03	99.9		
		3.53E+00		4.4E-04	2.6E-04
68	Th-232	9.55E+00	99.7		
	Ra-228	5.69E-02	69.5		
	Th-228	2.89E+00	99.9		
	Th-230	2.42E-01	99.7		
	U-233	1.27E+00	99.9		
		1.40E+01		1.7E-03	1.2E-03
ALL	Th-232	2.10E+01	99.7		
	Ra-228	1.25E-01	69.2		
	Th-228	6.22E+00	99.9		
	Th-230	4.89E-01	99.7		
	U-233	8.64E-01	99.9		
		2.86E+01		3.6E-03	2.2E-03

* Based upon the NCRP risk coefficient of 1.25E-04 per Rem whole body committed effective dose equivalent.

6.0 ASSESSMENT OF THE NEED FOR A REMOVAL ACTION

Consistent with Section 40 CFR 300.410 of the National Contingency Plan, the DOE shall determine the appropriateness of a removal action. The eight factors to be considered in this determination are listed in 40 CFR 300.415 (b) (2). The following apply specifically to the thorium stored in Buildings 60, 64, 65, 67, and 68:

Sub-paragraph (i)
Actual or potential exposure to nearby human populations, animals, or the food chain from hazardous substances or pollutants or contaminants.

Sub-paragraph (iii)
Hazardous substances or pollutants or contaminants in drums, barrels, tanks, or other bulk storage containers, that may pose a threat of release.

Sub-paragraph (v)
Weather conditions that may cause hazardous substances or pollutants or contaminants to migrate or be released.

These factors are considered appropriate because of the relatively large inventory of thorium and related materials in approximately 15,000 containers in the five storage buildings at the FS. Of the scenarios reviewed, only the low probability tornado would clearly result in loss of building integrity with spread of contaminants.

Deterioration of containers and the current storage conditions, particularly in Buildings 65 and 68, would enhance release of contaminants with loss of building integrity. Although the probability for a tornado to destroy the buildings is quite low, the estimated resultant radiation dose and attendant risk would be above the acceptable range. Improvement of current storage conditions would diminish the potential threat to the public and to site workers, and would further be an application of best management practices.

7.0 APPROPRIATENESS OF A RESPONSE

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If it is determined that response actions are appropriate due to current storage conditions and the potential for release of contaminants, a number of actions may be required to address the existing situation.

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(s) and provide supporting documentation for the decision(s).

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

At present, the following actions would be desired based on the conclusions of this RSE:

1. Clean up and overpack the material stored in Building 65 to correct the present conditions that would minimize any release if a catastrophic tornado occurred. In addition, this action will reduce occupational exposure.

2. Modify the storage configuration of drums in to reduce the potential for collapse and spillage.

3. Plan for the ultimate storage or disposal of the stored thorium.

REFERENCES

1 Cavendish, J.H., and White, J.F., Production of Thorium for the Light Water Breeder Reactor, Program Phases I and II, NCLO-1088, National Lead Co., November, 1971.

2 DOE Order 5400.5, Radiation Protection of the Public and the Environment, U.S. Dept. of Energy, February 8, 1990.

3 Janke, R.C., and R.J., and Ijaz, T., A Probabilistic Risk Assessment for the K-65 Silos at the FMPC, (Univ. of Cincinnati), FMPC/SUB-029, UC-702, Westinghouse Materials Co. of Ohio, November, 1990.

4 K-65 Silos Study and Evaluation Report, Camargo Associates Ltd., February, 1986.

5 Fire in the United States: 1983-1987 and Highlights for 1988, FA-94, U.S. Fire Administration, Federal Emergency Management Agency, August, 1990.

APPENDIX A

PROCESS KNOWLEDGE

B. F. Brush/D. C. Bonfer

Steve Brown

2019

From: B. F. Brush/D. C. Bonfer

WMCO:EMT(TD):90-435

Date: December 10, 1990

Subject: PROCESS KNOWLEDGE DOCKET FOR THORIUM METAL STREAMS

To : Solid Waste Compliance

The Proposed Amended Consent Decree (PACD) with Ohio EPA (OEPA) requires that by November 1990, process knowledge be evaluated to support RCRA determinations for thorium streams stored at the Feed Material Production Center (FMPC). The process knowledge evaluated is contained in the Thorium Streams Process Knowledge Docket. Thorium streams were divided for review into three categories: 1) thorium metal streams; 2) oxides, hydroxides, and oxalates; and 3) white salt (ThF_4) and thorium nitrate, and miscellaneous streams. This memo summarizes process knowledge for thorium metal streams, including background, process knowledge, stream specific information, and references.

The information summarized herein is based on review of open literature, FMPC documents, and through personal discussions with FMPC operations personnel identified in the references section. This memo does not constitute a RCRA determination, but serves as a support document for the determination process.

Background:

Thorium metals were produced at the FMPC in the early fifties (1953 - 1956) and again in the late sixties/early seventies (1969 - 1972). These production periods are referred to as early and late metal production, respectively. Most of the metal from early production was sent to Hanford and/or Savannah river as metal rods as target material for irradiation and subsequent recovery of fissionable materials. The bulk of the metal from late production was sent to Oak Ridge (Y-12) as derbies to be cut up and arc melted to form ingots (presumably for eventual fabrication into breeder reactor target elements).

During both production periods small quantities of materials were sent off-site to special projects or laboratories for testing or analysis. Many of these materials were returned to the FMPC (DOE's thorium repository) following the test program. Similarly, some off-spec and leftover materials were returned from the Oak Ridge and Hanford/Savannah River projects.

Process Knowledge:

Early metals production used both a wet and a dry method for conversion of ThO_2 to ThF_4. The wet method was the Ames process involving precipitation of ThF_4 from a thorium

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nitrate solution using aqueous HF. The dry method used the hydrofluorination equipment in Plant 4 (i.e., the screw type reactors). The production processes for early metals production are documented in FMPC standard operating procedures (SOPs) and manufacturing specifications (MS) listed in the reference section. Later metals production was carried out using a wet method for ThF_4 production that relied on a modified Ames ThF_4 reduction process. Again, the SOPs and MSs in the reference section document this process. Further documentation is provided in the report Thorium Metal Production (NLCO-1080).

Product requirements for metal purity required extremely low levels of allowable trace materials. Data were reviewed to determine the common trace contaminants that caused metal streams to be off-spec. These contaminants included carbon, nitrogen, magnesium, iron, aluminum, and zinc. None of the most common materials are included on the TC constituent list. Lead and chromium were included in the material analyses. In the records reviewed, lead was always below the detection limit of 1 ppm, while chromium was always within the specification limit of 75 ppm, with average chromium concentrations generally less than 20 ppm. Thorium metals, like the thorium oxides, hydroxides and oxalates, are not soluble to any extent unless they are acid digested at extremely low pH (dissolved in nitric acid @ pH < 0). Thus, the metals streams are not expected to fail the Toxicity Characteristic.

Metals streams may have undergone some oxidation over time, generating some thorium oxide (ThO_2) on the metal surface. However, surface oxidation for thorium does not progress nearly as fast as it does for uranium metals. Other metals streams may have undergone some oxidation when removed from a furnace operation at a temperature sufficiently high to cause the metal to oxidize ("burn"). In any case, oxidation residues do not contain any constituents or exhibit any characteristics that present any of concern for RCRA determinations.

Some of the thorium metal shapes produced at the FMPC were clad at off-site facilities with aluminum, stainless steel, or zirconium. Cladding processes require high temperature and pressure to fuse the surface layers of the cladding material with the surface layers of the substrate thorium metal. Based on a review of the Kirk-Othmer Encyclopedia of Chemical Technologies, cladding operations do not use any materials that are of potential RCRA concern with the exception of surface cleaning agents. However, any residues of surface cleaning agents would be destroyed or driven off during the high temperature cladding process. Clad materials were returned to the FMPC for decladding and dissolution when the clad materials were not within spec (e.g., due to size or shape), when there were leftover materials from a program, or when a lab was through testing a material.

Most of the metals streams on-site that were not product streams were destined for reprocessing via dissolution in nitric acid or through metals reprocessing (e.g., arc melting operations). These streams were stored on-site prior to reprocessing. The thorium metals streams in inventory at the FMPC (i.e., those included in this review) were either being stored

prior to reprocessing or were returned by off-site sources when thorium projects were terminated (during both early and late metals production).

Stream Specific information

Stream #2 - Clad Metal for HNO_3 Dissolution

Material: 075
Source: DZA (DuPont, Aiken, SC - received small amounts of thorium materials for testing)

This stream consists of two drums with a net weight of 50 lbs each.

Stream #3 - Partially Oxidized Metal, no METL-X

Material: 081
Source: 341 (Remelt furnace, Pilot plant)
This material was generated during later metals production. Oxidation may have resulted when a charge was removed from the furnace at too high a temperature, contacted the ambient air, and "burned" (oxidized). This stream consists of three drums with a net weight of 342 lbs.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #6 - Top Crops from Primary Ingots

Material: 103
Source: FZB (Y-12, Oak Ridge, TN - Processed thorium metal)

Y-12 received thorium derbies (Y-12 derbies) from the FMPC and arc melted them to form the thorium metal shapes required for their program. Top crops from this arc melting were returned to the FMPC for reprocessing (e.g., dissolved in nitric acid, precipitated as thorium tetra fluoride, and blended with other thorium tetra fluoride for subsequent metal production). This material is from later metals production. There are 16 drums of this material, with a net weight of 13,937 lbs.

Stream #7 - Metal Spills and Extrusion Ends

Material: 104
Source: 340 (Pilot plant remelt and casting)
FZC, FXB, AIC, 340, NLA, FAX, MBN, FZB, HYA (see Thorium Off-Site Source Function List)

Metal spills and extrusion ends were materials destined for reprocessing. Metal spills are frequently partially oxidized, and are often associated with a blow-out of the reduction pot. Extrusion ends are the ends of extruded pieces (first or last part out of the extruder) which may not have the desired geometrical or metallurgical characteristics. Both of these metal streams were to be reprocessed either through remelt or dissolution.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream # 11 - Metal Declad by Machining or Chemical Treatment

Material: 128
Source: 300, 323 (FMPC Pilot plant - general and Rockwell furnace)
HXA, HYA, ZXH, MBN, FZC, DYA, DZA, AVA, CAF (see Off-site Thorium Source Function List)

Metals are generally declad by either physical or chemical processes. Off-site testing labs were used to evaluate various decladding processes. The metal content of these waste streams is either 100% or very close to 100%. At the FMPC sodium hydroxide solution (NaOH) was used to declad aluminum clad thorium metals, stainless steel was declad using a physical process, and zirconium was declad using the Zirn-Lo process (see SOPs and material specs).

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #12 - Partially Oxidized Metal

Material: 128
Source: 323, 365 (FMPC Pilot plant - Rockwell furnace and oxidizing furnace)
MBN, CAF, MIO, PZA (See Off-site Thorium Source Function List)

Partially oxidized metals for reprocessing.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #14 - Metals to be Oxidized

Material: 136
Source: 345 (FMPC - Pilot plant)
AIC, FZB, MBN, ASA, FAX, CBH, FZA, PZA (See Off-site Thorium Source Function List)

Metal pieces small enough to be oxidized in a furnace for subsequent dissolution and reprocessing.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #17 - Clad Metal for Acid Dissolution

Material: 141
Source: MBN (Nuclear Metals - West Concord, MA)

Nuclear Metals did materials testing and evaluation.

Stream #19 - Solid Metal for Pickling

Material: 136
Source: 750, 300, 320, 731 (FMPC operations)
LAB, BBA, HVA, FAX, FZB, PZA, CAF, FTA, FBA, DVA, DZA, AVA, LAE
(See Off-site Thorium Source Function List)

This material was to pickled to remove oxides prior to remelt.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #20 - Solid Metal for Remelt

Material: 223
Source: CAK, FZC, DZA, PZA (See Off-site Thorium Source Function List)

Solid thorium metal to be reprocessed through remelt.

Stream #21 - Metal for Double Melting

Material: 227
Source: 320, 345, 732 (FMPC - Pilot plant and lab)
FBA, LZB, CYT, DZA (See Off-site Thorium Source Function List)

This material was to be reprocessed by double melting. Double melting refers to the process of remelting a cropped ingot to achieve higher purity.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #22 - Product Top Crops for Remelt

Material: 229
Source: FBA (General Electric, Evendale, OH)

Product top crops for reprocessing via remelt.

Stream #23 - Derbies, Code 1 or 3

Material: 300
Source: 732 (FMPC Operations - Analytical Lab)
MIO (Nuclear Metals, West Concord, MA)

Code 1 indicates a "prime" derby, while code 3 indicates a derby with some CaF_2 slag. These derbies were destined for reprocessing.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #24 - Thorium Briquettes

Material: 302
Source: 300, 955 (FMPC - Pilot plant and Plant 9)

Identified as 99% thorium. Review of the SOP indicates no RCRA materials used in the process. Briquettes were formed from compressed thorium metal turnings.

No RCRA listed materials were intoduced or created during on-site production of this material.

Stream #25 - Thorium metal, archive samples

Material: 098
Source: 100 (FMPC Operation - Plant 1 general)

This material was used for archive purposes, i.e., archived as a specific shape for reference.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #29 - Solid Metal for Remelt

Material: 222
Source: CAF (Battelle Labs, Columbus, OH)

Solid metal returned from Battelle Labs (for testing and evaluation) to be reprocessed via remelt.

Stream #35 - Thorium Metal to be Pickled

Material: 228
Source: CZA, DZA (Argonne Labs, Argonne, IL; Dupont, Aiken, SC)

Thorium metal for pickling to remove oxides prior to remelt.

Stream #58 - Partially Oxidized Metal

Material: 130
Source: 732 (FMPC Operations - Analytical Laboratory)

Thorium metal from the analytical lab destined for reprocessing.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream # 60 - Code 4 Derbies

Material: 254
Source: 732, 320 (FMPC Operations - Analytical Labs; Pilot Plant)

Code 4 indicates that the derbies from dezincing were physically off-spec. These derbies were destined for reprocessing.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #61 - Thorium Material for Recovery

Material: 137
Source: CZA, PZA (Argonne Labs, Argonne, IL; Bettis Labs, W. Mifflin, PA)

Some of this material is identified as having 100% thorium content (i.e., it is thorium metal). This material was destined for reprocessing.

B.F. Brush/D.C. Bonfer

2019

From: B. F. Brush/D. C. Bonfer

WMCO:EMT(TD):90-434

Date: December 10, 1990

Subject: PROCESS KNOWLEDGE DOCKET FOR THORIUM OXIDE, OXALATE, AND HYDROXIDE STREAMS

Solid Waste Compliance

To : The Proposed Amended Consent Decree (PACD) with Ohio EPA (OEPA) requires that by November 1990, process knowledge be evaluated to support RCRA determinations for thorium streams stored at the Feed Material Production Center (FMPC). The process knowledge evaluated is contained in the Thorium Streams Process Knowledge Docket. Thorium streams were divided for review into three categories: 1) thorium metal streams; 2) oxides, hydroxides, and oxalates; and 3) white salt (ThF_4) and thorium nitrate, and miscellaneous streams.

This memo summarizes process knowledge for thorium oxide, hydroxide, and oxalate streams, including process knowledge overview, stream specific information, and references. The information summarized herein is based on review of open literature, FMPC documents, and through personal discussions with FMPC operations personnel identified in the references section. This memo does not constitute a RCRA determination, but serves as a support document for the determination process.

PROCESS KNOWLEDGE OVERVIEW

The FMPC produced thorium oxide for use in various experimental projects during the mid-1950's and from the mid-1960's through the mid-1970's. The majority of the materials were made for the Light Water Breeder Reactor (LWBR) Program (reference NLCO-1088) conducted in the mid-1960's to the mid-1970's. In the process the FMPC precipitated thorium oxalate from a thorium nitrate solution. This thorium oxalate was then sent to General Electric in Evendale, Ohio where the material was calcined to thorium oxide or thoria. The calcining process involved heating the thorium oxalate at high temperature ranging from 600-1650 degrees F, thus producing thorium oxide. This project was also known as the Bettis program due to the bulk of the material being sent to Bettis Labs in West Mifflin, Pennsylvania. At Bettis the material was used to produce clad (canned) target elements for the LWBR. Process knowledge for this material is documented in FMPC SOP's, FMPC reports, manufacturing specifications, and from

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discussions with FMPC operations personnel.

Throughout the on-site process by which the thorium oxalate was precipitated and the thorium oxide was calcined, no RCRA listed materials were introduced or created (reference SOP's 11-C-227, 11-C-228, FMPC-482 Special). Chemicals used in the reaction and intermediates within the reaction included: oxalic acid (see manufacturing specs), nitric acid (neutralized to a pH greater than 3 in the reaction chamber), thorium nitrate (precipitated to thorium oxalate), thorium oxalate, thorium oxide, and thorium hydroxide solid. Calcium oxide was used to enhance sintering. Other chemicals that may have been used include diamyl amyl phosphonate (used as an extractant for impurities), ammonia (used to precipitate thorium nitrate to thorium hydroxide), and ammonium sulfate (used to enhance solubility)(please reference SOP 11-C-237). None of the chemicals above are listed in the 40 CFR Subpart D. Any materials that may exhibit a hazardous characteristic (40 CFR Subpart C) such as nitric acid for corrosivity, were either neutralized or depleted in the process.

An inventory of the thorium drums on-site provides a listing of the percent thorium by weight of each drum lot. By using the theoretical values of the percent thorium content by weight of the drum lots, conclusions may be drawn that verify a stream is only thorium oxide, thorium oxalate or any other thorium compound.

The following table list thorium compounds and the theoretical value of thorium (% by weight).

THORIUM COMPOUND	% THORIUM BY WEIGHT
thorium oxalate [$Th(C_2O_4)_2*6H_2O$]	45.0%
thorium oxide [ThO_2]	87.9%
thorium nitrate tetrahydrate [$Th(NO_3)_4*4H_2O$]	42.0%
thorium hydroxide [$Th(OH)_2$]	77.3%
thorium tetra fluoride [ThF_4]	75.3%

Materials from off-site sources were generally received from facilities that had previously obtained their supply of thorium from the FMPC. The material was returned to the FMPC (the DOE thorium repository) when the materials were no longer required for the off-site operation. These materials were generally excess materials, byproduct materials for reprocessing, or off-spec process materials. The material code and the percent thorium are evidence that may be used to support a position on the composition of the waste. Off-site sources can be grouped into three different categories: laboratories that received small quantities, manufacturing facilities that received larger quantities for processing, and

storage facilities.

Some thorium oxide materials were sent off-site to be canned. The thorium was canned in several metals, those most commonly used included aluminum(Al) and zirconium(Zr). The canning process involved encasing the thorium in a metal. The canning process did not involve any RCRA materials.

Materials may be off-spec for trace impurities (e.g., a common concern was rare earth metals - lanthanide series, which do not include any TC metals); ability to pelletize; and particle size, shape, or other physical characteristics.

STREAM SPECIFIC INFORMATION

#4 ThO2, Off-Spec. (085)

Off-site source:
(LAB) 45.4% Thorium
-Thorium was used at Livermore Labs(LAB) in small quantity for experimental purposes.
-This material only contains about half of the theoretical thorium.

#5 Scrap ThO2, high fluoride (101)

Off-site sources:
(FBA) 86.5% Th
-General Electric(FBA) performed calcining to convert the thorium oxalate cake to thorium oxide, this process did not use any materials that could be considered RCRA hazardous in any form(refer to NLCO-1088).
-Percent thorium approaches theoretical.
(HYA) 85.4-87.1% Th
-Battelle NW(HYA) performed laboratory analysis and/or processing tests.
-Percent thorium approaches theoretical.

#10 Wet Th Oxalate Cake (115)

On-site sources:
Pilot Plant(300) & Laboratory(732) 34.9-36.7% Th
-Thorium production was performed in the Pilot Plant and analyses were performed in the Lab. Values are all within a small range and would suggest that sampling was performed at a certain point in production as specified in the SOP's. In addition the material is wet which supports the lower than theoretical value for the Th.
-See on-site Process Knowledge Overview(PKO).

No RCRA listed materials were introduced or created during on-site production of this material.

#13 Oxides Clad/Mixed with Aluminum (133)

Off-site source:
(HXA) 87.8% Th
-UNC, Richland, WA - canned thorium oxide pellets and clad thorium
metal.
(HYA) 87% Th
-Battelle NW Labs, Richland, WA - test and evaluation laboratory
(DZA) 74.9, 85, 87.9% Th
-Dupont, Aiken, SC - test and evaluation laboratory
(MBR) 87.8 and 88.0% Th
-Babcock and Wilcox, Lynchburg, VA - canned thorium oxide pellets

#15 Oxides, Clad with other than Al, Zr, SS (138)

Off-site source:
(PZA) 43.5,54.0,75.0% Th
-Materials processed at Bettis Labs(PZA) were used for reactor fuel. The actual and theoretical value differences may be explained by the presence of the canning material. Upon review of the 741 receiving reports this material was clad with plastic. The percent of plastic used in the cladding varies.

#16 Oxides Clad with Zr (140)

Off-site sources:
(PZA) 20-80% Th
-Note knowledge in #15, Oxides clad with other than Al, Zr, SS, for Bettis Labs(PZA) and for clad thorium material.

(CZA) 72.0% Th
-Argonne Labs(CZA) performed analysis and/or processing tests.
-Note cladding information in PKO.

#18 ThO2 pellets-refinery feed (166)

On-site source:
Plant 8(800) 87.8% Th
-Value is almost equal to the theoretical value for ThO2.
-Please see on-site information in the PKO.

No RCRA listed materials were introduced or created during on-site production of this material.

Off-site sources:
(HYA) 90.0% Th
-Battelle NW(HYA) performed analysis and/or processing tests.
(CCS) 87.8% Th
-Babcock & Wilcox(CCS) canned thorium pellets.
(JSG) 87.5% Th
-EG & G, Idaho Falls, Idaho
(FAX) 87.7% Th
-Nuclear Fuels Services(FAX) produced pure ThO_2 from thorium nitrate received from the FMPC and also produced thorium metal ingots that were sent to Bridgeport Brass (now RMI) for extrusion.
(FZG) 87.2% Th
-ORNL(FZG) performed analysis and/or processing tests.
(YUD) 88.5% Th
-Exxon Nuclear(YUD) performed analysis and/or processing tests.
(CZA) 88.2% Th
-Argonne Labs(CZA) performed analysis and/or processing tests.
(PZA) 83.6, 86.2-88.6% Th
-Bettis Labs(PZA) pelletized Th oxide powder.

#31 ThO2 powder-refinery feed (167)

Off-site sources:
(CCS) 87.8% Th
-Babcock & Wilcox(CCS) performed analysis and/or processing tests.

(DZA) 87.6-88.0% Th
-DuPont(DZA) performed analysis and/or processing tests.

(FAX) 87.1-87.7% Th
-Nuclear Fuel Services(FAX) produced pure Th oxide from Th nitrate received from the FMPC and also produced thorium ingots sent to Bridgeport Brass (now RMI) for extrusion.

(FVA) 87.7% Th
-National Lead of Ohio(FVA) or the FMPC. See on-site information in the PKO.

(HYA) 87.8% Th
-Battelle NW(HYA) performed analysis and/or processing tests.

(JSG) 87.8% Th
-EG&G(JSG) performed analysis and/or processing tests.

(PZA) 83.2-87.8% Th
-Bettis Labs(PZA) pelletized thorium oxide powder.

(YUD) 88.1% Th
-Exxon Nuclear(YUD) performed analysis and/or processing tests.

#46 Off-spec. Th oxalate, French src. (078)

On-site sources:
Lab(732) and Pilot Plant(300) 25-35% Th
-Off-spec may be attributed to non-hazardous impurities. The material was probably analyzed before drying. Item #10, wet thorium oxalate, had Th weights of approximately 35% which are comparable to these values for thorium.

No RCRA listed materials were introduced or created during on-site production of this material.

Off-site sources:
(FBA) 27.9% Th
-General Electric(FBA), see item #5, Scrap ThO_2, high fluoride, and PKO for process knowledge of this material. Material is probably wet, causing a lower than theoretical % Th.

(FCZ) 46.0% Th
-Tennessee Nuclear(FCZ). Thorium content for this stream approaches theoretical.

#50 Thorium Oxide, archive samples (098)

Off-site source:
(FBA) 88.0% Th
-General Electric see item #5, Scrap ThO_2, high fluoride and PKO for process knowledge.

#51 Scrap ThO2-low F (100)

Off-site sources:
(CZA) 87.6-93.5% Th
-Argonne Labs(CZA) performed analysis and/or processing tests.
(FAX) 87.6% Th
-Nuclear Fuel Services(FAX) produced thorium oxide from

thorium nitrate received from the FMPC and also produced thorium ingots that were sent to Bridgeport Brass (no RMI) for extrusion.

(FBA) 87.1-87.8% Th
-General Electric(FBA) see item #5, Scrap ThO_2, high fluoride and PKO for process knowledge.

(FCZ) 86.8% Th
-Tennessee Nuclear(FCZ)

(FZG) 88.4% Th
-ORNL(FZG) performed analysis and/or processing tests.

(LAE) 83.3% Th
-Rockwell International(LAE) performed analysis and/or processing tests.

(PZA) 85-87.9% Th
-Bettis Labs(PZA) pelletized thorium oxide powder; also see PKO.

(YUD) 88.1% Th
-Exxon Nuclear(YUD) performed analysis and/or processing tests.

#52 Scrap ThO2-high F (101)

On-site sources:
Lab(732) 68.8% Th
Plt 8(836) 56.1% Th
-Please see on-site information in the Process Knowledge Overview.
-The wide range of thorium content is due to variable drying conditions giving variable moisture content and the possibility of the presence of thorium oxalate in the drums. The thorium oxalate may have been placed in the drums when the project was finished and labeled thorium oxide.
Pilot Plt(362) 19.8% Th

#53 Scrap ThO2 (102)

Off-site sources:
(DZA) 88.6% Th
-Dupont(DZA) performed analysis and/or processing tests.

(FBA) 87.8% Th

-General Electric(FBA) see item #5, Scrap ThO_2, high fluoride and PKO for process knowledge.

(PZA) 85.0-87.7% Th
-Bettis Labs(PZA) pelletized thorium oxide powder, also see PKO.

#54 ThO2 product (202)

On-site sources:

Pilot Plt(372) 87.5% Th
Lab(732) 86.6-87.5% Th
-Please see on-site information in the Process Knowledge Overview

No RCRA listed materials were introduced or created during on-site production of this material.

Off-site sources:

(PZA) 87.8-88.0% Th
-Bettis Labs(PZA) pelletized thorium oxide powder, also see PKO.

(CZA) 88.0% Th
-Argonne Labs(CZA) performed analysis and/or processing tests.

(FYC) 87.8% Th
-MMES(FYC) performed analysis and/or processing tests.

(FBA) 87.8% Th
-General Electric(FBA) see item #5, Scrap ThO_2, high fluoride and PKO for process knowledge.

(HYA) 86.1% Th
-Battelle NW(HYA) performed analysis and/or processing tests.

#55 ThO2 from impure thorium nitrate (105)

On-site sources:
Pilot Plt(364) 63.3, 66.2, 71.8-79.9% Th
Lab(732) 76.5% Th
-This material is Th hydroxide produced from unpurified

thorium nitrate via the thoria gel process(please see SOP 11-C-237). The lot code identifies the material as ThO2 but it is Th hydroxide (there is no material code for Th hydroxide). According to the SOP, no RCRA materials were used in the process. Differences in the percent of thorium present in each material is due to differing lengths of drying times for the hydroxide causing variable moisture content.

No RCRA listed materials were introduced or created during on-site production of this material.

#56 ThO2 from Sol-Gel proc.(205)

On-site sources:
Lab(732) 86.6% Th
-Materials from General Electric analyzed in the FMPC laboratory.

No RCRA listed materials were introduced or created during on-site production of this material.

Off-site source:
(FBA) 84.5-87.3% Th
-General Electric(FBA) see item #5, Scrap ThO_2, high fluoride and PKO for process knowledge.

#66 Off-spec. ThO2 (French src.) (151)

On-site source:
Pilot Plt(333) 72.1% Th
-Generated from the East Wheelabrator dust collector that serviced the packaging station for dried thorium hydroxide (to be sent to General Electric for sintering).
-The lower thorium content is due to high moisture.

No RCRA listed materials were introduced or created during on-site production of this material.

Off-site source:
(FBA) 87.8% Th
-General Electric(FBA) see item #5, Scrap ThO_2, high fluoride and
PKO for process knowledge.

#68 Thorium Oxide - refinery feed (166)

(PZA) 73.9%, and 52.9% Th
-Bettis Labs(PZA) pelletized Th oxide powder, also note information from item #15, Oxides clad with other than Al, Zr, SS.
-All Bettis ThO_2 material was made from purified thorium nitrate. Any impurities in less than theoretical lots are most probably due to water or clad materials.

#69 ThO_2 Refinery feed (167)

On-site source:
Plant 8(800) 82.6-84.5% and 43.6-61.4% Th
-See on-site information in the Process Knowledge Overview.
-This stream was generated from the removal of the thorium handling facilities, bins and silos. the system was located on the east side of Plant 8. See Thorium handling system removal docket.

No RCRA listed materials were introduced or created during on-site production of this material.

#70 ThO_2 powder - Refinery feed

Off-site sources:
(CBH) 59.0% Th
-Brookhaven Labs(CBH) performed analysis and/or processing tests.

(CZA) 54.9% Th
-Argonne Labs(CZA) performed analysis and/or processing tests.

(FCZ) 20.6-39.6% Th
-Tennessee Nuclear(FCZ)

#71 Scrap ThO_2 -low F (100)

On-site sources:
Pilot Plt(300) 65.3%, (361) 57.8-69.6% Th

Lab(732) 75.0% Th

-Please see on-site information in the Process Knowledge Overview

-The wide range of thorium content is due to variable drying conditions giving variable moisture content and the possibility of the presence of thorium oxalate in the drums. The thorium oxalate may have been placed in the drums when the project was finished and labeled thorium oxide.

Plt 8(800) 46-55% Th

-This 800 source material was generated from the removal of the thorium handling facilities, bins and silos. The system was located on the east end of Plant 8. See Thorium handling system removal process knowledge docket.

Off-site source:

(LAW) 53.2% Th

-General Atomic Technologies performed analysis and/or processing tests.

<u>#72 ThO2 product (202)</u>

(FCZ) 54.8% Th

-Tennessee Nuclear(FCZ)

<u>#73 Wet Th Oxalate Cake (115)</u>

Off-site sources:

(FAV) 17.0% Th

-Kerr-McGee(FAV) performed laboratory analysis and/or processing test.

REFERENCES

Briggs, G. G., and J. H. Cavendish, Thorium Metal Production, National Lead Company of Ohio (NLCO-1080), prepared for the U.S. Atomic Energy Commission, January, 1971.

FMPC Standard Operating Procedures (SOP), Manufacturing Specifications (MS), and Production Supply Specifications (PS).

SOP - Purification of Th Feed Materials by Solvent Extraction (11-C-216)
SOP - Preparation of Thorium Oxalate, Calcium Added (11-C-227)
SOP - Preparation of Thorium Oxalate, No Calcium Added-Binary Material(11- C-228)
SOP - Preparation of Thoria Gel for Storage (11-C-237)
SOP - Thorium Production Operations (FMPC - 149 rev., special)
SOP - Production of White Oxide (ThO_2) in the Thorium Plant (FMPC-482 Special)

Cavendish, J. H.(NLO), White, J. F., Production of Thoria for Light Water Breeder Reactor(LWBR) Program Phase I & II, National Lead Company of Ohio, (NLCO-1088) prepared for the U.S. Atomic Energy Commission, November 1971.

Burkhardt, W., Briggs, G. G., Clavel, A. L., White, J. F., Production of Dense Thoria, National Lead Company of Ohio, (NLCO-1029), prepared for the U. S. Atomic Energy Commission, July 1969.

WMCO:PO(DCB)88-012, Memo from D. C. Bonfer to A. M. Schwartzman, THORIUM - A SEARCH FOR AVAILABLE RECORDS AT THE FMPC, dated November 15, 1988.

Kirk-Othmer, Encyclopedia of Chemical Technology, Second Edition, Volume 13, Copyright 1967.

741 Receiving Reports

B. F. Brush / D. C. Bonfer

Steve Brown

2019

From: B. F. Brush/D. C. Bonfer

WMCO:EMT(TD):90-433

Date: December 10, 1990

Subject: PROCESS KNOWLEDGE DOCKET FOR THORIUM MISCELLANEOUS STREAMS

To : Solid Waste Compliance

The Proposed Amended Consent Decree (PACD) with Ohio EPA (OEPA) requires that by November 1990, process knowledge be evaluated to support RCRA determinations for thorium streams stored at the Feed Material Production Center (FMPC). The process knowledge evaluated is contained in the Thorium Streams Process Knowledge Docket. Thorium streams were divided for review into three categories: 1) thorium metal streams; 2) oxides, hydroxides, and oxalates; and 3) white salt (ThF_4) and thorium nitrate, and miscellaneous streams. This memo summarizes process knowledge for thorium tetrafluoride and thorium nitrate streams, and miscellaneous thorium streams, including background, stream specific process knowledge, and references.

The information summarized herein is based on review of open literature, FMPC documents, and through personal discussions with FMPC operations personnel identified in the references section. This memo does not constitute a RCRA determination, but serves as a support document for the determination process.

Background:

The FMPC processed thorium materials from the early fifties through the early seventies to produce thorium metals and oxides for use in various DOE projects. In the early seventies DOE recalled all thorium materials to the FMPC, which serves as the DOE repository for thorium materials. The streams addressed in this docket represent the miscellaneous streams from processing of thorium both at the FMPC and at off-site facilities.

Stream Specific Process Knowledge:

The following entries summarize process knowledge for thorium nitrate and thorium fluoride streams, and miscellaneous thorium streams.

Stream #1 - Samples, Non-metallic, Miscellaneous

Material: 047
Source: HXA (UNC, Richland, WA - canned ThO_2 pellets and clad thorium metal)

The thorium content of this stream (87.8 % Th) indicates that the samples are pure thorium oxide.

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Stream #8 - Sawdust for Oxidation

Material: 109
Source: 345 (FMPC - Pilot plant saws)

This material is sawdust (mostly thorium metal and thorium oxide) that was generated when thorium metal derbies were cut to desired sizes (e.g., the thorium derbies were cut and welded together to form the correct size pieces for arc melting). This material is 72.5 - 95.7 % thorium.

Stream #9 - Chips and Turnings for Oxidation

Material: 110
Source: PZA, ASA, 732 (FMPC Lab and See off-site thorium source function list)

These are materials that were generated when thorium metal was worked at off-site locations to produce desired shapes. The materials contain the following % thorium: PZA - 100%; ASA - 90.0%; 732 - 90.0%. The ASA and 732 materials are believed to be lower in thorium content due to oxidation or the presence of sample jars.

Stream #26 - Contaminated Burnables: Rags, etc.

Material: 027
Source: 361 (FMPC - Pilot plant)

No information exists to evaluate the constitution of this stream.

Stream #27 - Dust Collector Bags

Material: 029
Source: FBA (General Electric, Evendale, OH)

The dust collectors were servicing either calcining/sintering operations to produce pure thorium oxides or a material handling (e.g., product packaging) station. Thus, any materials collected in the bags were thorium oxide along with some ambient dust/dirt. Thorium content for the drums was 87.8%, presumably tested on the bag residue..

Stream #28 - Dust Collector Residues - High Fluoride

Material: 062
Source: HXA (UNC, Richland, WA - Canned thorium oxide pellets and clad thorium metal)

The thorium content of this material is 87.8% thorium, which is very close to the theoretical value for thorium oxide. Based on the operations at this site and the reported thorium content, the material is thorium oxide.

Stream #30 - Off-site sump/filter cakes

Material: 162
Source: FAK (Middlesex Storage Plant, New Brunswick, NJ - Storage Depot for GSA)

The constitution of this material can't be determined based on available information.

Stream #32 - Scrap Salts - Low Fluoride

Material: 066
Source: 800 (FMPC - Plant 8)

The constitution of this material can't be determined based on available information.

Stream #33 - Non-metallic Samples

Material: 047
Source: FBA (General Electric, Evendale, OH)

The thorium content for this material is reported at 74.7, which is very close to the theoretical thorium content for (uncalcined) thorium hydroxide.

Stream #34 - Wet Thorium Oxalate Cake and Dry Thorium Hydroxide

Material: 115, 215
Source: XHP (General Atomic, Youngsville, North Carolina - stored materials from Mound Labs)

This material is known as the Brazilian sludge material. The thorium content for these materials is reported at 21.6 and 30.7%, respectively. More information on this material is forthcoming in a report being sent from Mound Labs.

Stream #36 - Thorium Waste Samples

Material: 007
Source: 732

The constitution of this material can't be determined based on available information.

Stream #37 - Contaminated Graphite Pieces

Material: 017
Source: 300 (FMPC - Pilot plant)

This stream consists of crucibles, dezincing pots, and molds used in thorium metals production. The procedures and reports indicate no uses of these materials that involve RCRA materials.

Stream #38 - Contaminated Burnables: rags, etc.

Material: 027
Source: FBA (General Electric, Evendale, OH - calcining and sintering thorium oxide and oxalate produced at FMPC)

The constitution of this material can't be determined based on available information.

Stream #39 - Dust Collector Bags

Material: 029
Source: 362 (FMPC - Pilot plant)

The constitution of this material can't be determined based on available information. It is most likely composed of ambient dust/dirt and thorium intermediates. The thorium content for this material is 13.0%.

Stream #40 - Non-metallic Samples

Material: 047
Source: 732 (FMPC Lab)

The constitution of this material can't be determined based on available information. Thorium content for this material varies from 50.0-66.2% and it is probably various thorium intermediates.

Stream #41 - Non-burnable Metal with Thorium

Material: 053
Source: PZA (Bettis Labs, West Mifflin, PA)

The constitution of this material can't be determined based on available information. Thorium content is 80.5%.

Stream #42 - Dust Collector Residues - High Fluorides

Material: 062
Source: FBA (General Electric, Evendale, OH)

The dust collectors were servicing either calcining/sintering operations producing thorium oxide product or a material handling (e.g., product packaging) station. The reported thorium content for this material is 87.1% thorium. Thus, the material is thorium oxide with some small amount of ambient dust/dirt.

Stream #43 - Scrap Salts - Low Fluoride

Material: 066
Source: CAK (Ames Labs, Ames, IA)

The constitution of this material can't be determined based on available information. Thorium content is 50.1%.

Stream #44 - Wet Sump or Filter Cake

Material: 069
Source: 362, 732 (FMPC - Analytical Lab and Pilot plant)

The constitution of this material can't be determined based on available information. Thorium content is 54.7 and 59.9%.

Stream #45 - Thorium Ore Concentrate

Material: 170
Source: CBH

The constitution of this material can't be determined based on available information. Thorium content is 59.0%.

Stream #47 - Unfired Reduction Charges

Material: 079
Source: 320 (FMPC Pilot plant metal reduction area)

An unfired reduction charge would consist of the liner material (calcium fluoride slag) and the reduction charge (zinc fluoride, calcium metal and thorium tetrafluoride). Reference the SOPs and manufacturing specs for thorium metal production. No RCRA materials were used in the process. Thorium content is 49.7%.

Stream #48 - Off Spec. ThF_4 (white salt)

Material: 082
Source: 364, 732, 826, CAK (FMPC Pilot plant operations plus Ames Lab, Ames, IA)

Thorium tetrafluoride (ThF_4) was an intermediate in the production of thorium metal at FMPC during both early and later metals production (1952 to 1954 and 1969 to 1972, respectively). Thorium tetrafluoride, zinc fluoride, and calcium metal constituted the reduction charge for thorium metals production, thus any impurities present in the thorium tetrafluoride can be directly correlated with the thorium metals assays. The material for stream #48 was off-spec. ThF_4 could be off-spec for physical parameters (e.g., density) or due to contaminants. The common contaminants which caused thorium tetrafluoride to be off-spec were water, magnesium, iron, nickel, and (rarely) zirconium. Thorium values range from 72.6-75.3%.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #49 - Reject ThF_4 (white salt)

Material: 083
Source: 300 (FMPC Pilot plant)

See narrative for stream #48. Because this material is reject thorium tetrafluoride, it was not intended for recycle. It probably comes from a bad batch (i.e., a "botched" batch) that may have been neutralized and drummed up. This stream could be a sludge like material, could have free liquids, and could have low pH. Thorium content is 25.0%.

Stream #57 - ThF_4 (white salt)

Material: 210
Source: 360, ZNX (FMPC Pilot plant and NLI, Albany, NY)

See narrative for stream #48. Note that this is not off-spec or reject white salt, but probably white salt that was just never processed. The thorium content for this stream (75.8 and 76.5) is right at the theoretical thorium content for white salt (75.8).

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #59 - Wet sump or filter cake

Material: 069
Source: 732 (FMPC laboratory)

The constitution of this material can't be determined based on available information. Thorium content is 59.9 and 54.7%.

Stream #62 - Non-recoverable Trash

Material: 003
Source: 800 (FMPC Plant 8)

The constitution of this material can't be determined based on available information.

Stream #63 - Non-recoverable Trash

Material: 003
Source: 730 (FMPC Plant 7)

The constitution of this material can't be determined based on available information.

Stream #64 - Ammonia Precipitated Thorium

Material: 147
Source: 732

This material is samples of ammonia precipitated thorium sent to the lab for analysis. The thorium content for this stream is 31% thorium. The ammonia precipitated thorium hydroxide was a sludge-like material, the pH at the end of the precipitation was pH 4.6.

No RCRA listed materials were introduced or created during on-site production of this material.

Stream #65 - Thorium Nitrate Solution

Material: 150
Source: FAK, FAX

Thorium nitrate is a strong oxidizer. In solution form, it would qualify as a RCRA corrosive liquid (pH < 2). Material specs on the thorium nitrate also show levels of chromium at 95 ppm on a thorium basis. Thorium content for (FAK) is 41.0% and for (FAX) is 27.0%.

Stream #67 - Impure Thorium Nitrate (Solid)

Material: 160
Source: CBH, FZC, HYA, PZA, YOK

Thorium nitrate tetrahydrate is a strong oxidizer. Thorium content for this material ranges from 40.0-59.1%.

Stream #74 - Off Spec. ThF_4 (white salt)
Material: 082
Source: 300, 323, 360, 362 (FMPC Pilot Plt)

See stream #48. Thorium contents range from 37.0-64.3%.

REFERENCES

Briggs, G. G., and J. H. Cavendish, Thorium Metal Production, National Lead Company of Ohio (NLCO-1080), prepared for the U.S. Atomic Energy Commission, January, 1971.

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Cavendish, J. H.(NLO), White, J. F., Production of Thoria for Light Water Breeder Reactor(LWBR) Program Phase I & II, National Lead Company of Ohio, (NLCO-1088) prepared for the U.S. Atomic Energy Commission, November 1971.

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Personal Interviews with DuWane Bonfer and Joe Patton, FMPC Engineers during thorium production periods, conducted at FMPC.

FMPC Standard Operating Procedures (SOP), Manufacturing Specifications (MS), and Production Supply Specifications (PS).

(later thorium metal production: 1969 -1972)

SOP - Dezincing thorium-zinc derbies (11-C-211)
SOP - Purification of Th Feed Materials by Solvent Extraction (11-C-216)
SOP - Precipitation of Thorium Tetrafluoride (11-C-218)
SOP - Precipitation of Zinc Fluoride (11-C-219)
SOP - Drying Wet ThF_4 and ZnF_2 Cake (11-C-220)
SOP - Dehydration of Dried ThF_4 and ZnF_2 (11-C-221)
SOP - Reduction of ThF_4 and ZnF_2 to Th-Zn Metal (11-C-222)
SOP - Preparation and Recycle of CaF_2 Liner (11-C-223)
SOP - Milling and Blending ThF_4 and ZnF_2 (11-C-224)
MS - Feed Material in Thorium Metal Production Operation (11-BE-420-17)
PS - Calcium Metal (Redistilled Grade) (20-PS-300-25)

(early thorium metal production: 1952 - 1954)

SOP - Thorium Production Operations (FMPC - 149 rev., special)
SOP - Production of White Salt (ThF_4) (FMPC - 155 rev. 1, special)
SOP - Production of a Zinc-Thorium Biscuit (FMPC - 156, special)
SOP - Survey of Analytical, Metallographic, Physical Testing, Fabrication and Machining Methods for Thorium (FMPC - 160, special)

SOP - Thorium Dezincing and Casting (FMPC - 161, special)
SOP - Thorium Chip Processing (FMPC - 164 rev. 1, special)

SOP - Zinc Chloride Processing for Use in Thorium Production (FMPC - 165 rev. 1, special)

(thorium intermediates production)

SOP - Purification of Th Feed Materials by Solvent Extraction (11-C-216)
SOP - Preparation of Thorium Oxalate, Calcium Added (11-C-227)
SOP - Preparation of Thorium Oxalate, No Calcium Added-Binary Material (11- C-228)
SOP - Preparation of Thoria Gel for Storage (11-C-237)
SOP - Thorium Production Operations (FMPC - 149 rev., special)
SOP - Production of White Oxide (ThO_2) in the Thorium Plant (FMPC-482 Special)

APPENDIX B

THORIUM INVENTORY

STREAM NUMBER	MAT. TYPE	SRC. CODE	DRUM COUNT	RCRA	Non-RCRA	MFA	EPA ID	LDR	MATERIAL DESCRIPTION	STORAGE LOCATION
1	47	HXA	1		X				Samples, Non-Met., Misc.	64
2	75	DZA	2		X				Clad Metal for HNO3 diss.	64,67
3	81	341	3		X				Part. Ox. Metal, no METL-X	64
4	85	LAB	1			X			ThO2, Off-Spec.	64
5	101	FBA	5		X				Scrap ThO2, high flouride	64
5	101	HYA	3		X				Scrap ThO2, high flouride	64
6	103	FZB	16		X				Top Crops from primary ingots	64
7	104	FZC	1		X				Metal spills & extrusion ends	64
7	104	FBX	1		X				Metal spills & extrusion ends	64
7	104	AIC	1		X				Metal spills & extrusion ends	64
7	104	340	3		X				Metal spills & extrusion ends	64
7	104	FWA	1		X				Metal spills & extrusion ends	64
7	104	NLA	2		X				Metal spills & extrusion ends	64
7	104	FAX	5		X				Metal spills & extrusion ends	64
7	104	MBN	1		X				Metal spills & extrusion ends	64
7	104	FZB	32		X				Metal spills & extrusion ends	64
7	104	HYA	1		X				Metal spills & extrusion ends	67
8	109	345	12			X			Sawdust for oxidation	64
9	110	732	2			X			Chips & Turning for oxidation	67
9	110	PZA	1			X			Chips & Turning for oxidation	64
9	110	ASA	1			X			Chips & Turning for oxidation	64
10	115	300	55		X				Wet Th Oxalate Cake	67
10	115	732	13		X				Wet Th Oxalate Cake	67
11	128	HXA	1		X				Metal decled by Mach. or Chem.	64
11	128	HYA	1		X				Metal decled by Mach. or Chem.	64
11	128	ZXH	3		X				Metal decled by Mach. or Chem.	64
11	128	MBN	1		X				Metal decled by Mach. or Chem.	64
11	128	FZC	4		X				Metal decled by Mach. or Chem.	64
11	128	DYA	5		X				Metal decled by Mach. or Chem.	64
11	128	300	1		X				Metal decled by Mach. or Chem.	64
11	128	DZA	2		X				Metal decled by Mach. or Chem.	64
11	128	AVA	1		X				Metal decled by Mach. or Chem.	64
12	131	323	1		X				Part. oxidized metal	65
12	131	365	1		X				Part. oxidized metal	64
12	131	MBN	1		X				Part. oxidized metal	64
12	131	CAF	1		X				Part. oxidized metal	64
12	131	MIO	1		X				Part. oxidized metal	64
12	131	PZA	2		X				Part. oxidized metal	64
12	131	800	1		X				Part. oxidized metal	64
13	133	HXA	55		X				Oxides clad/mixed with Al	64
13	133	HYA	1		X				Oxides clad/mixed with Al	64
13	133	DZA	5		X				Oxides clad/mixed with Al	64,67
13	133	MBR	26		X				Oxides clad/mixed with Al	64
14	136	FZC	1		X				Metals to be oxidized	64
14	136	AIC	3		X				Metals to be oxidized	64

2019

STREAM NUMBER	MAT. TYPE	SRC. CODE	DRUM COUNT	RCRA	Non-RCRA	NFA	EPA ID	LDR	MATERIAL DESCRIPTION	STORAGE LOCATION
14	136	365	2		X				Metals to be oxidized	64
14	136	FZB	19		X				Metals to be oxidized	64
14	136	MBN	1		X				Metals to be oxidized	64
14	136	ASA	2		X				Metals to be oxidized	64
14	136	FAX	1		X				Metals to be oxidized	64
14	136	CBH	1		X				Metals to be oxidized	67
14	136	FZA	1		X				Metals to be oxidized	67
14	136	PZA	1		X				Metals to be oxidized	67
15	138	PZA	4		X				Oxides, clad with other than Al, Zr,SS	64,67
16	140	PZA	23		X				Oxides, clad/mixed with Zr	64,65,67
16	140	CZA	3		X				Oxides, clad/mixed with Zr	67
17	141	MBN	1		X				Clad metal for acid dissolution	64
18	166	MYA	2		X				ThO2 pellets- refinery feed	64
18	166	800	7		X				ThO2 pellets- refinery feed	67
18	166	CCS	1		X				ThO2 pellets- refinery feed	67
18	166	JSG	1		X				ThO2 pellets- refinery feed	67
18	166	FAX	129		X				ThO2 pellets- refinery feed	67
18	166	FZG	102		X				ThO2 pellets- refinery feed	67
18	166	YUD	2		X				ThO2 pellets- refinery feed	67
18	166	CZA	2		X				ThO2 pellets- refinery feed	67
18	166	PZA	2212		X				ThO2 pellets- refinery feed	67
19	221	ASA	1		X				Solid Metal for pickling	64
19	221	FBE	1		X				Solid Metal for pickling	64
19	221	LAB	1		X				Solid Metal for pickling	64
19	221	BBA	1		X				Solid Metal for pickling	64
19	221	750	1		X				Solid Metal for pickling	64
19	221	MYA	5		X				Solid Metal for pickling	64
19	221	FAX	2		X				Solid Metal for pickling	64
19	221	300	1		X				Solid Metal for pickling	64
19	221	FZB	106		X				Solid Metal for pickling	64
19	221	320	2		X				Solid Metal for pickling	64
19	221	PZA	1		X				Solid Metal for pickling	64
19	221	CAF	1		X				Solid Metal for pickling	64
19	221	FTA	11		X				Solid Metal for pickling	64
19	221	FBA	4		X				Solid Metal for pickling	64
19	221	DYA	3		X				Solid Metal for pickling	64
19	221	DZA	1		X				Solid Metal for pickling	64
19	221	AVA	1		X				Solid Metal for pickling	64
19	221	LAE	1		X				Solid Metal for pickling	64
19	221	731	1		X				Solid Metal for pickling	67
20	223	CAK	2		X				Solid metal for remelt	64
20	223	FZC	2		X				Solid metal for remelt	64
20	223	DZA	1		X				Solid metal for remelt	64
20	223	PZA	1		X				Solid metal for remelt	64
21	227	FBA	1		X				Metal for double melting	64

STREAM NUMBER	MAT. TYPE	SRC. CODE	DRUM COUNT	RCRA	Non-RCRA	MFA	EPA ID	LDR	MATERIAL DESCRIPTION	STORAGE LOCATION
21	227	L28	1		X				Metal for double melting	64
21	227	732	4		X				Metal for double melting	64
21	227	345	1		X				Metal for double melting	64
21	227	320	1		X				Metal for double melting	64
21	227	CVT	1		X				Metal for double melting	67
21	227	DZA	1		X				Metal for double melting	
22	229	FAX	1		X				Product top-crops for remelt	64
23	300	MIO	1		X				Derblee, code 1 or 3	64
23	300	732	3		X				Derblee, code 1 or 3	67
24	302	955	1		X				Thorium briquettes	64
24	302	300	1		X				Thorium briquettes	
25	98	100	1		X				Thorium metal, archive samples	64
26	27	361	1			X			Contaminate burnable rags, etc.	64
27	29	FBA	5		X				Dust collector bags	67
28	62	HXA	18		X				Dust collector residues - high F	67
29	222	CAF	1		X				Solid metal for remelt	67
30	162	FAK	118		X*				Offsite sump/filter cakes	64
31	167	FVA	13		X				ThO2 powder - refinery feed	67
31	167	YUD	1		X				ThO2 powder - refinery feed	67
31	167	FAX	616		X				ThO2 powder - refinery feed	67
31	167	CCS	2		X				ThO2 powder - refinery feed	67
31	167	HYA	1		X				ThO2 powder - refinery feed	67
31	167	JSG	41		X				ThO2 powder - refinery feed	67
31	167	DZA	6		X				ThO2 powder - refinery feed	67
31	167	PZA	772		X				ThO2 powder - refinery feed	67
32	66	800	1			X			Scrap salts - low F	67
33	47	FBA	1		X				Non-metallic samples	67
34	215	XHP	4031		X*				Dry Thorium hydroxide	65
34	115	XHP	1564		X*				Wet Th Oxalate Cake	65
35	228	CZA	1			X			Thorium metal to be pickled	67
35	228	DZA	1			X			Thorium metal to be pickled	65
36	7	732	1			X			Thorium waste samples	67
37	17	300	2		X				Contaminated graphite pieces	67
38	27	FBA	2			X			Contaminated burnables: rags, etc.	67
39	29	362	1			X			Dust collector bags	67
40	47	732	9			X			Non-metallic samples	67
41	53	PZA	1		X*				Non-burnable metal with Th	67
42	62	FBA	1		X				Dust Collector residues - high F	67
43	66	CAK	5			X			Scrap salts, low F	67
44	69	362	19			X			Wet sump or filter cake	67
44	69	732	2			X			Wet sump or filter cake	67
45	170	CBN	1			X			Th ore concentrate	67
46	78	FBA	1		X				Off-spec. Th oxalate, French src.	67
46	78	300	150		X				Off-spec. Th oxalate, French src.	67
46	78	732	8		X				Off-spec. Th oxalate, French src.	67

SYSTEM NUMBER	ART. TYPE	SRC. CODE	DRUM COUNT	RCRA	Non-RCRA	NFA	EPA ID	LDR	MATERIAL DESCRIPTION	STORAGE LOCATION
46	78	FCZ	1		X				Off-spec. Th oxalate, French src.	67
47	79	320	1	X			D001	N (a)	Unfired reduction charges	67
48	82	364	10		X				Off-spec. ThF4 (white salt)	67
48	82	732	4		X				Off-spec. ThF4 (white salt)	67
48	82	826	21		X				Off-spec. ThF4 (white salt)	67
48	82	CAK	4		X				Off-spec. ThF4 (white salt)	67
49	83	300	1			X			Reject ThF4 (white salt)	67
50	98	FBA	4		X				Thorium oxide, archive samples	67
51	100	LAE	1		X				Scrap ThO2 - low F	67
51	100	PZA	38		X				Scrap ThO2 - low F	67
51	100	CZA	43		X				Scrap ThO2 - low F	67
51	100	FAX	42		X				Scrap ThO2 - low F	67
51	100	FBA	40		X				Scrap ThO2 - low F	67
51	100	FCZ	3		X				Scrap ThO2 - low F	67
51	100	FZQ	1		X				Scrap ThO2 - low F	67
51	100	YUD	1		X				Scrap ThO2 - low F	67
52	101	362	3			X			Scrap ThO2 - high F	67
52	101	732	2			X			Scrap ThO2 - high F	67
52	101	836	7			X			Scrap ThO2 - high F	67
53	102	DZA	1		X				Scrap ThO2	67
53	102	FBA	8		X				Scrap ThO2	67
53	102	PZA	128		X				Scrap ThO2	67
54	202	372	2		X				ThO2 product	67
54	202	732	79		X				ThO2 product	67
54	202	PZA	457		X				ThO2 product	67
54	202	CZA	94		X				ThO2 product	67
54	202	FYC	2		X				ThO2 product	67
54	202	FBA	372		X				ThO2 product	67
54	202	NYA	1		X				ThO2 from impure thorium nitrate	67
55	105	732	1		X				ThO2 from impure thorium nitrate	67
55	105	364	1275		X				ThO2 from Sol-Gel proc.	68
56	205	732	1		X				ThO2 from Sol-Gel proc.	67
56	205	FBA	27		X				ThF4 (white salt)	67
57	210	360	30		X				ThF4 (white salt)	67
57	210	ZNK	1		X				Partially oxidized metal	67
58	130	732	2		X				Wet sump or filter cake	67
59	69	732	2			X			Code 4 derbies	67
60	254	320	69		X				Code 4 derbies	67
60	254	732	2		X				Th material for recovery	67
61	137	CAK	1		X				Th material for recovery	67
61	137	CZA	1		X				Th material for recovery	67
61	137	PZA	3		X				Non-recoverable Th trash	67
62	3	800	18			X			Non-recoverable Th trash	60
63	3	730	2			X			Ammonia precipitated thorium	60
64	147	732	1		X					67

ENCLOSU

STREAM NUMBER	MAT. TYPE	SRC. CODE	DRUM COUNT	RCRA	Non-RCRA	NFA	EPA ID	LDR	MATERIAL DESCRIPTION	STORAGE LOCATION
65	150	FAK	8	X			D001,D002,D007,D008	R (b)	Thorium nitrate solution	67
65	150	FAX	1	X			D001,D002,D007,D008	R (b)	Thorium nitrate solution	67
66	151	333	1		X				Off-spec. ThO2 (French src.)	67
66	151	FBA	6		X				Off-spec.ThO2 (French src.)	67
67	160	CBN	1	X			D001,D007,D008	N (a)	Impure thorium nitrate (solid)	67
67	160	FZC	18	X			D001,D007,D008	N (a)	Impure thorium nitrate (solid)	67
67	160	NYA	1	X			D001,D007,D008	N (a)	Impure thorium nitrate (solid)	67
67	160	PZA	4	X			D001,D007,D008	N (a)	Impure thorium nitrate (solid)	67
67	160	YOK	1	X			D001,D007,D008	N (a)	Impure thorium nitrate (solid)	67
68	166	PZA	13			X			ThO2 pellets- refinery feed	67
69	167	800	1624		X				ThO2 powder - refinery feed	60
70	167	CBN	1			X			ThO2 powder - refinery feed	67
70	167	CZA	6			X			ThO2 powder - refinery feed	67
70	167	FCZ	40			X			ThO2 powder - refinery feed	67
71	100	361	42			X			Scrap ThO2 - low F	68
71	100	300	1			X			Scrap ThO2 - low F	67
71	100	732	2			X			Scrap ThO2 - low F	67
71	100	LAW	1		X*				Scrap ThO2 - low F	67
72	202	FCZ	4			X			ThO2 product	67
73	115	FAV	2			X			Wet Th Oxalate Cake	64
74	82	300	4			X			Off-spec. ThF4 (white salt)	67
74	82	323	1			X			Off-spec. ThF4 (white salt)	67
74	82	360	2			X			Off-spec. ThF4 (white salt)	67
74	82	362	1			X			Off-spec. ThF4 (white salt)	67
75	100	800	144		X				Scrap ThO2 - low F	60

Note: NFA - Needs further Action (e.g., additional process knowledge, visual inspection, or sampling and analysis)
LDR - restricted from land disposal
N (a) - not restricted, variance for "third-thirds" mixed waste through 05/08/92
R (b) - restricted from land disposal, LDRs for california list waste promulgated 07/08/87
* - revised since November 1990 notification based on additional process knowledge

OFFSITE THORIUM SOURCE FUNCTIONS

Thorium sources can be divided into three broad categories: Processing Sites, Testing Labs, and Storage Sites.

A. Processing Sites

1. FBA - General Electric, Evendale, Ohio
   - Calcining and sintering Thorium Hydroxide and Oxalate produced at the FMPC.

2. FCZ - Tennessee Nuclear, Jonesboro, Tennessee
   - Returned Thorium Oxide and Oxalate.

3. FAX - Nuclar Fuel Services, Erwin, Tennessee
   - Produced pure ThO_2 from Thorium Nitrate from Fernald.
   - Produced Thorium Metal Ingots that were sent to Bridgeport Brass (now RMI) for extrusion.

4. FZB - Y-12, Oak Ridge, Tennessee
   - Processed Thorium metal
   - Also CYT and FXB

5. FTA - RMI, Astabula, Ohio
   - Extruded Thorium metal into rods
   - Formerly BBA (Bridgeport Brass)

6. HXA - UNC, Richland, Washington
   - Canned ThO_2 pellets
   - Clad Thorium metal

7. MBR - Babcock & Wilcox, Lynchburg, Virginia
   - Canned ThO_2 pellets
   - Replaced by CCS

8. PZA - Bettis Labs, West Mifflin, Pennsylvania
   - Pelletized ThO_2 powder

9. FVA - NLO, Fernald, Ohio
   - Produced Thorium Hydroxide, Oxalate, Fluoride, and metal.

10. FWA - MCW, Walden Springs, Missouri
    - Produced Thorium Oxide, Fluoride, and metal.

11. AVA - Mound Labs, Miamisburg, Ohio
    - Processed some "Monazite Ore" and shipped all materials to XHP

B. Testing Labs

The following testing labs received small quantities of Thorium Materials for analysis and/or processing tests.

1. AIC - Atomics International, Canoga Park, California
2. ASA - Rockwell International, Golden Colorado
3. AVA - Mound Labs, Miamisburg, Ohio
4. CAF - Battelle Labs, Columbus, Ohio
5. CAK - Ames Labs, Ames, Iowa
6. CBH - Brookhaven Labs, Upton New York
7. CZA - Argonne Labs, Argonne, Illinois
8. DYA - Sylvania Electric, Hicksville, New York
9. DZA - Dupont, Aiken, South Carolina
10. FAV - Kerr-McGee, Cushing Oklahoma
11. FBE - New Brunswick Lab, New Brunswick, New Jersey
12. FBX - Vitro Chemical, Cattanooga, Tennessee
13. FYC - MMES, Padncah, Kentucky
14. FZA - K-25, Oak Ridge, Tennessee
15. FZC - ORNL, Oak Ridge, Tennessee
    - Also FZG
16. HYA - Battelle NW, Richland, Washington
17. JSG - EG & G, Idaho Falls, Idaho
18. LAB - Livermore Labs, Livermore, California
    - Also LZB
19. LAE - Rockwell International, Santa Susana, California
20. LAW - General Atomic Technologies, San Diego, California
21. MBN - Nuclear Metals, West Concord, Massachusetts

22. MIO - Nuclear Metals, West Concord, Pennsylvania

23. NLA - NLI, Incorporated, Albany, New York
    - Also ZNX

24. YUD - Exxon Nuclear, Richland, Washington

25. ZXH - Virginia Polytech, Blacksburg, Virginia

C. Storage Sites

1. FAK - Middlesex Storage Plant, New Brunswick, New Jersey
   - Probably GSA depot

2. XHP - General Atomic, Youngsville North Carolina
   - Stored material from Mound Labs

3. YQK - General Service Administration, Curtis Bay, Maryland

APPENDIX C

GAMMA EXPOSURE RATES WITHIN BUILDINGS

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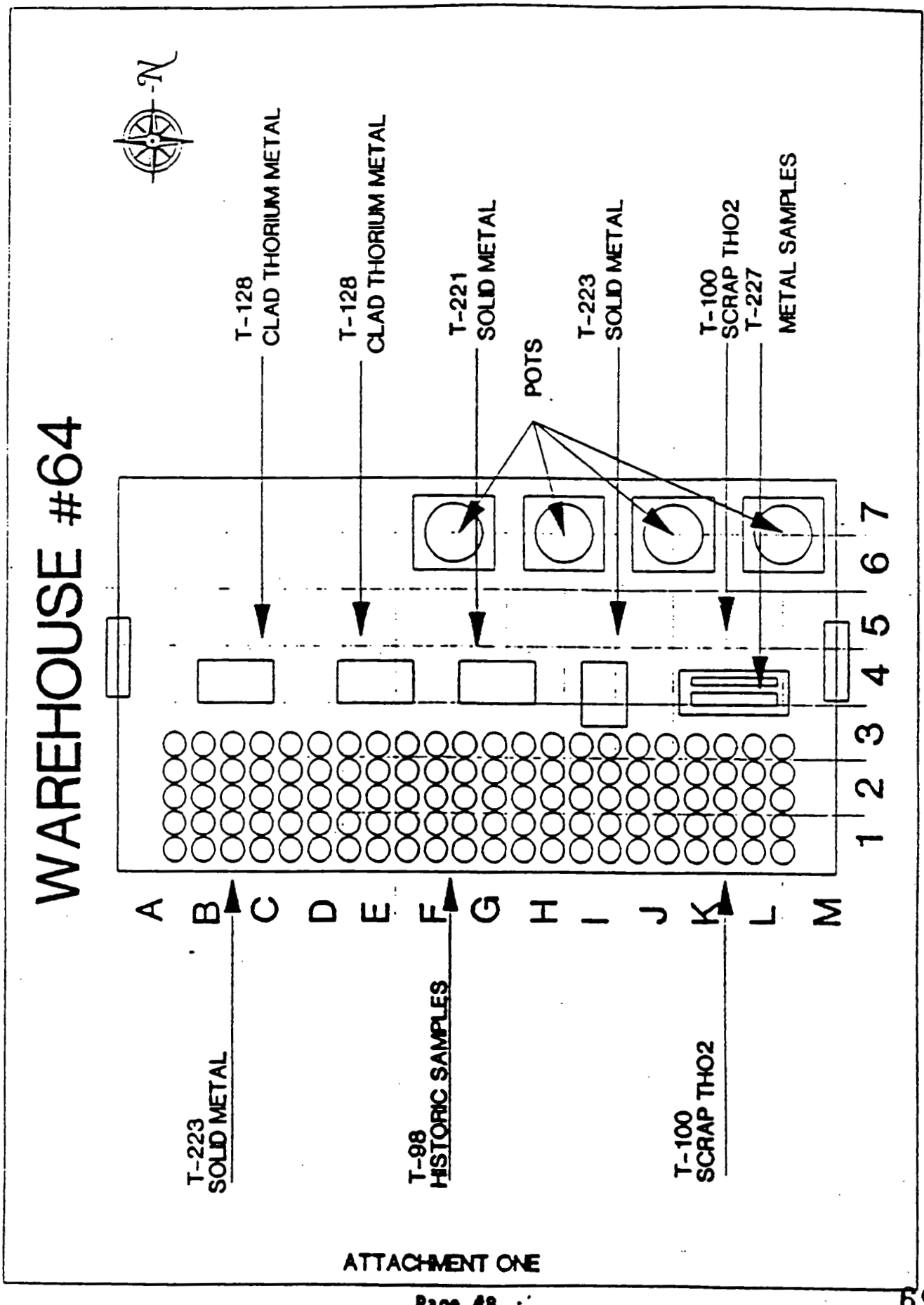
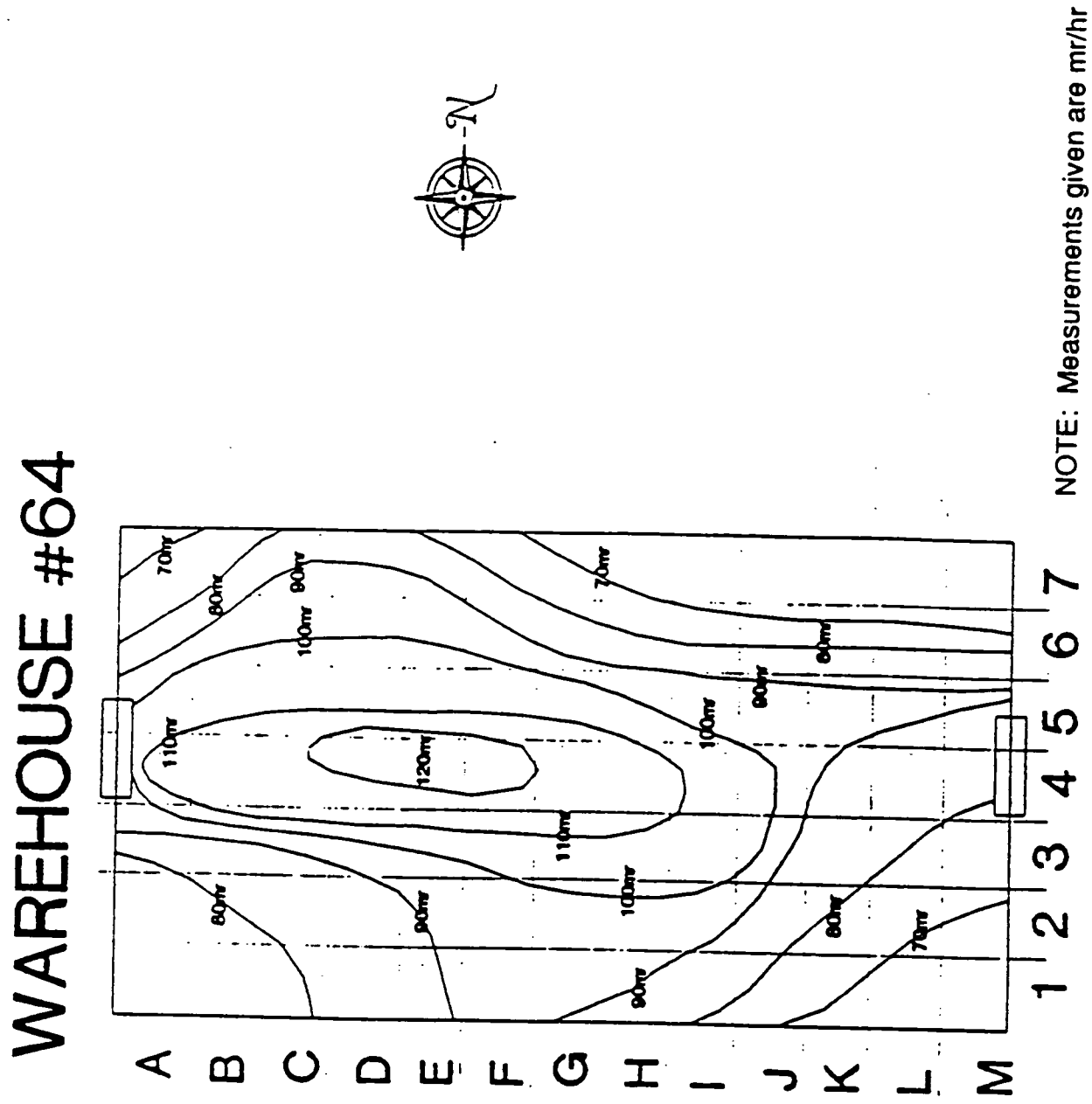
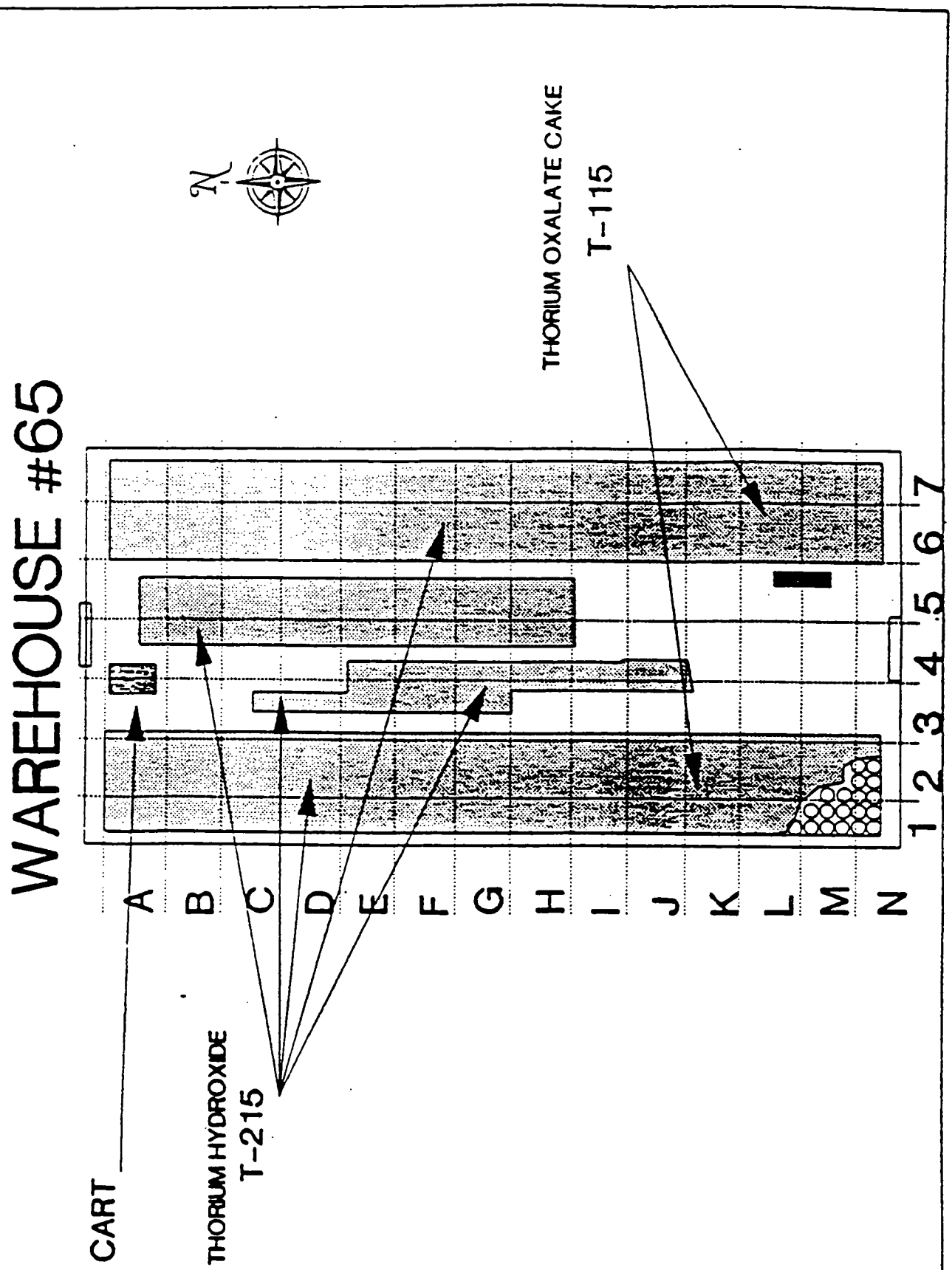


ATTACHMENT ONE



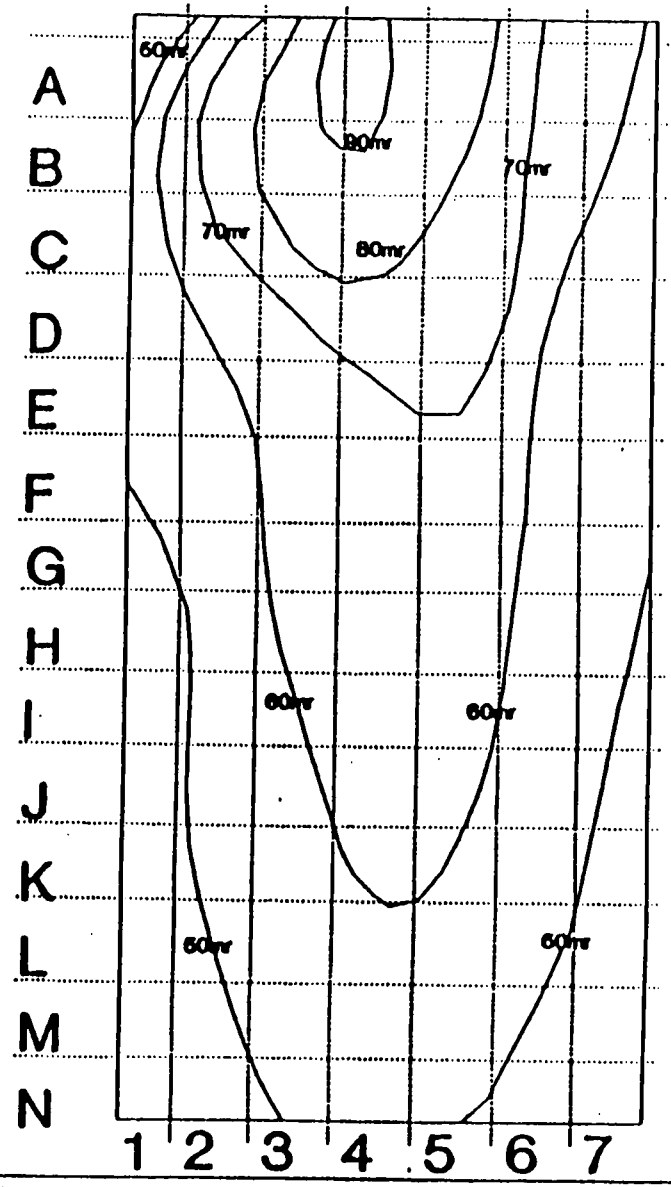
NOTE: Measurements given are mr/hr

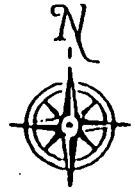
ATTACHMENT TWO



ATTACHMENT FOUR

WAREHOUSE #65





NOTE:
Measurements given are mr/hr

ATTACHMENT FIVE

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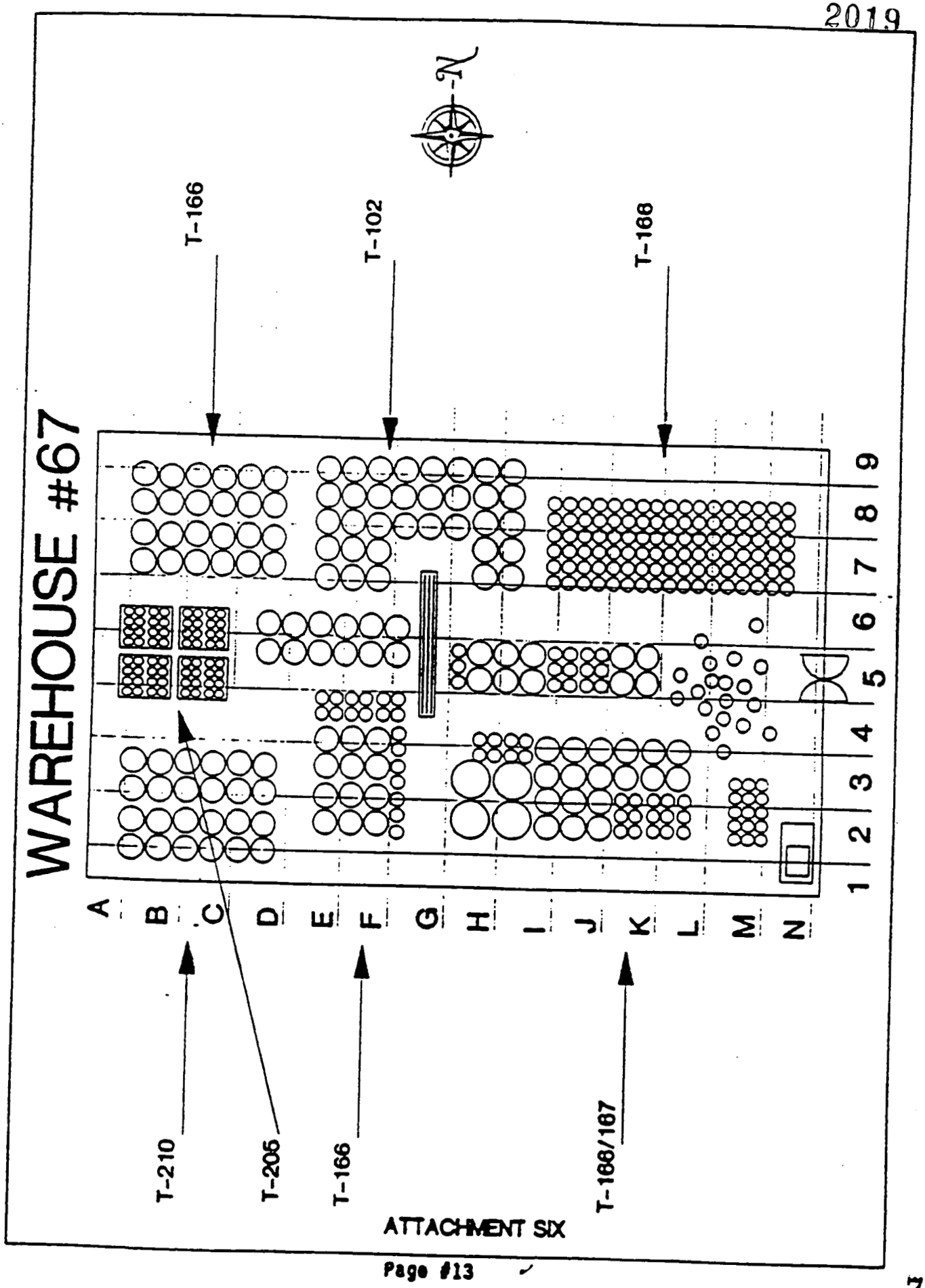

ATTACHMENT SIX

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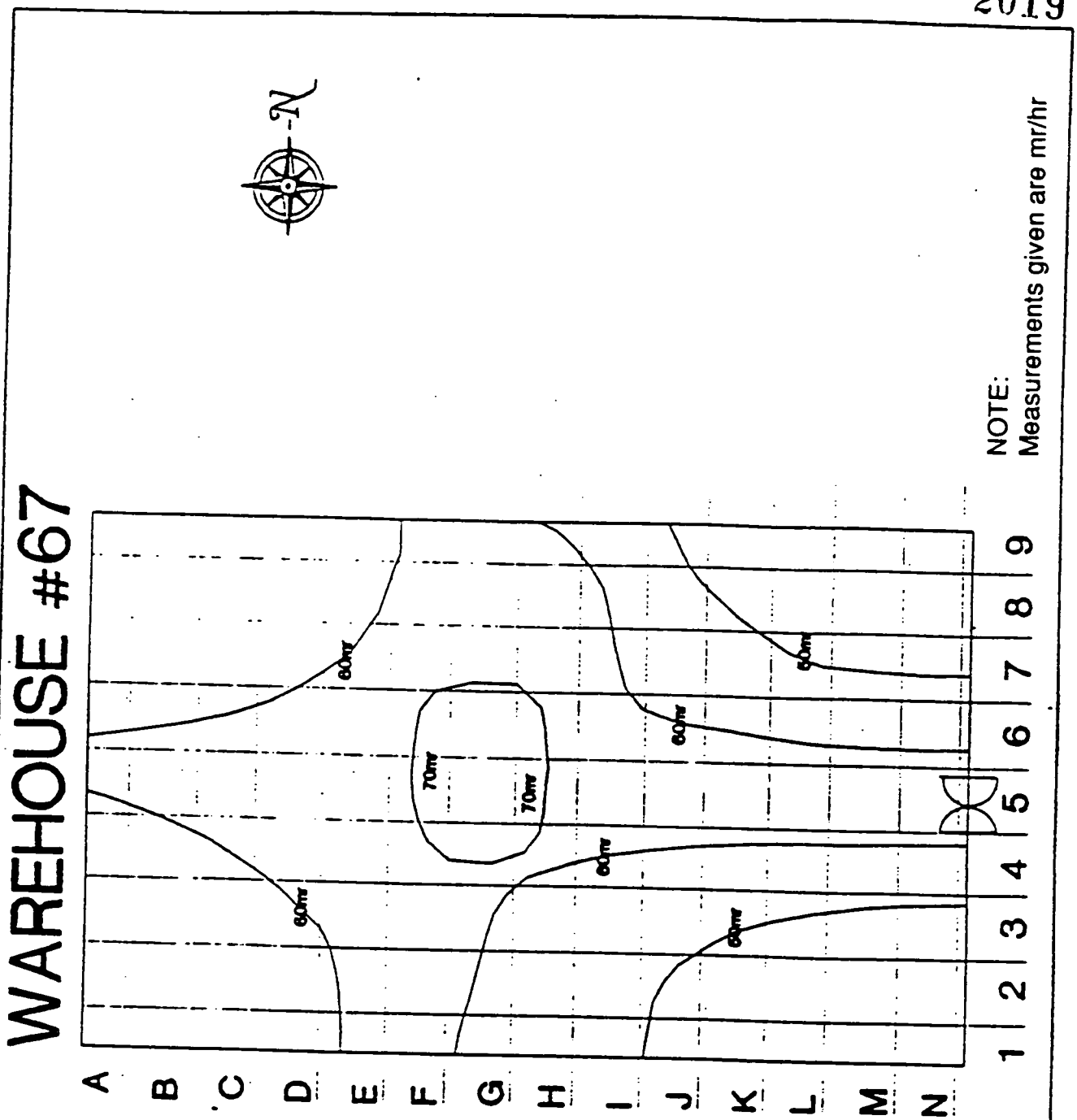
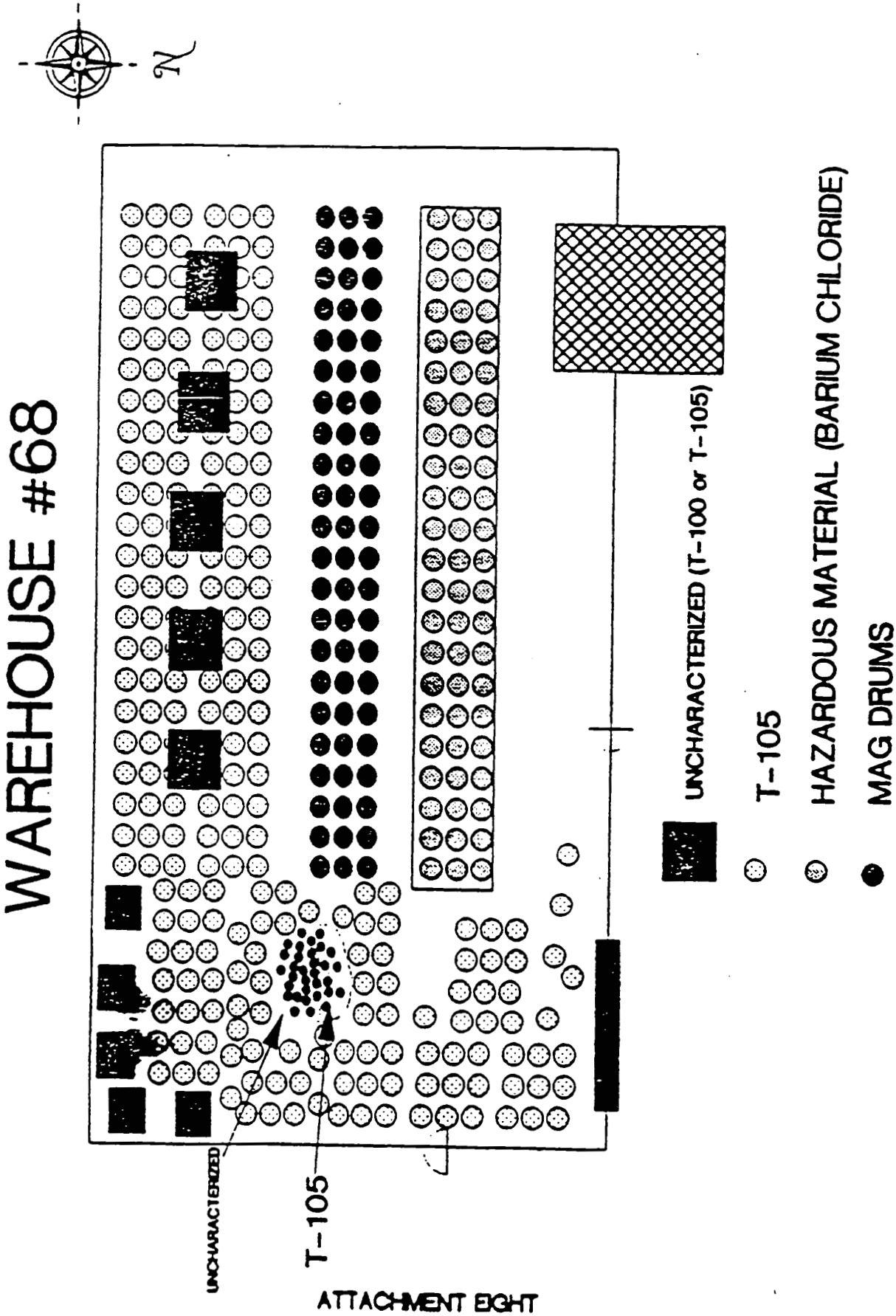
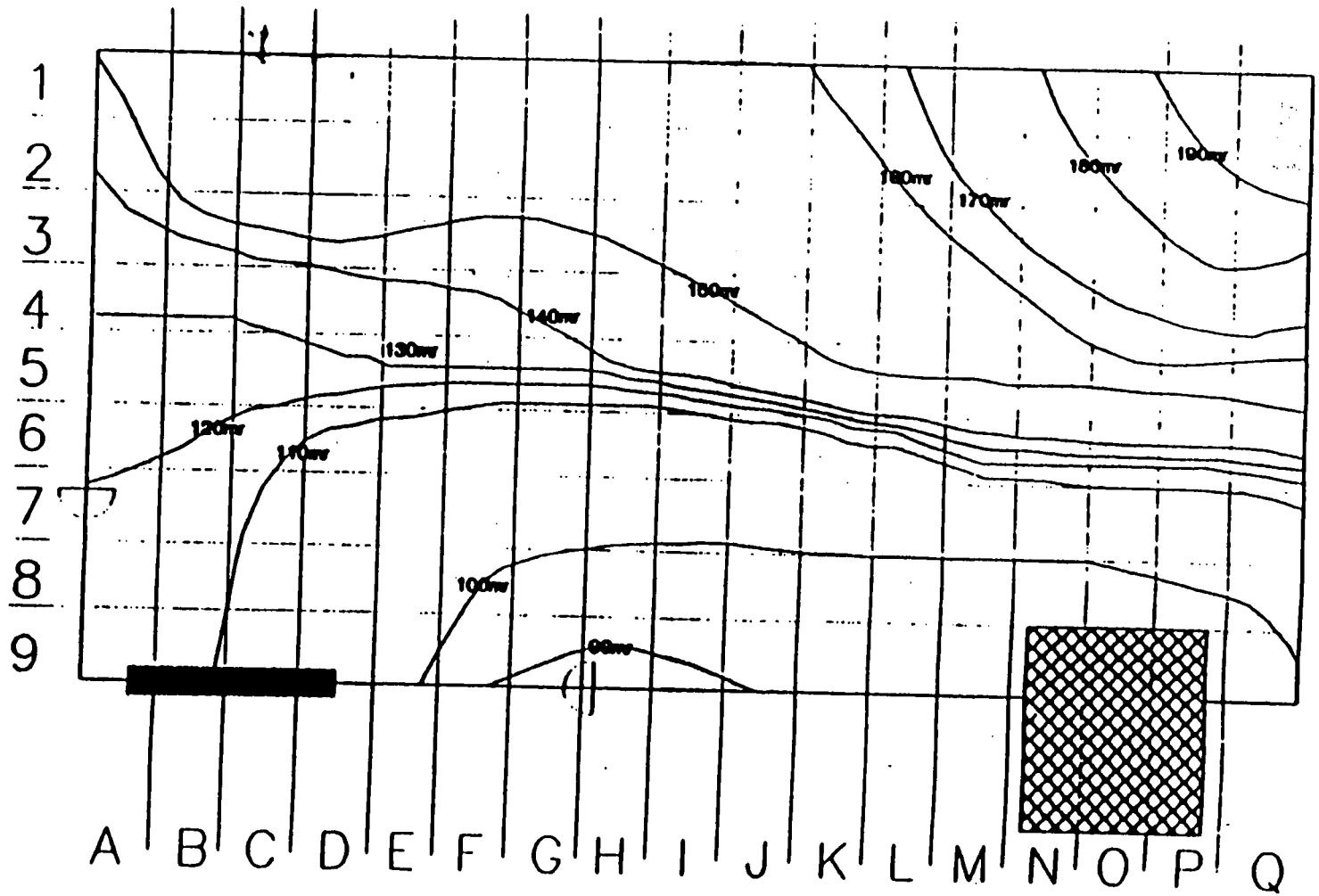


NOTE:
Measurements given are mr/hr



ATTACHMENT EIGHT

WAREHOUSE #68



NOTE: Measurements given are mr/hr

ATTACHMENT NINE

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APPENDIX D

ENVIRONMENTAL AIR SAMPLES

AVERAGE AIRBORNE CONCENTRATIONS FOR 1989
(pCi/m^3)

Radionuclide	AMS 1	AMS 2	AMS 3	AMS 4	AMS 5	AMS 6
Radium-228	< 1.0E-05	< 9.4E-06	< 1.1E-05	< 9.7E-06	< 9.4E-06	9.5±4.0E-06
Thorium-228	< 7.3E-06	< 8.0E-06	< 1.1E-05	< 9.7E-06	8.3±6.0E-06	1.1±0.8E-05
Thorium-230	8.8±5.8E-06	1.0±0.7E-05	< 1.1E-05	< 9.7E-06	< 8.0E-06	< 9.5E-06
Thorium-232	< 7.3E-06	< 8.0E-06	< 1.1E-05	< 9.7E-06	< 8.0E-06	< 9.5E-06

Radionuclide	AMS 7	AMS 8	AMS 9	AMS 10	AMS 11	AMS 12
Radium-228	1.3±0.5E-05	< 9.2E-06	< 1.0E-05	< 2.0E-05	< 2.4E-05	< 1.3E-05
Thorium-228	< 7.6E-06	< 1.9E-05	< 1.3E-05	1.3±0.4E-05	4.0±1.4E-06	1.2±0.3E-05
Thorium-230	< 7.6E-06	< 1.9E-05	< 1.3E-05	< 2.2E-06	2.6±1.2E-06	< 1.7E-06
Thorium-232	< 7.6E-06	< 1.9E-05	< 1.3E-05	< 2.2E-06	< 1.2E-06	< 1.7E-06

APPENDIX E

TORNADO OCCURRENCE PROBABILITY FROM A PROBABILISTIC RISK ASSESSMENT FOR THE K-65 SILOS AT THE FMPC

by

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Oak Ridge Operations Office

Some of the information from the University of Cincinnati report, dealing with tornado probabilities, was summarized in Section 5.2.2 of the RSE. For a better understanding of the details of the approach used, pages 2-12 through 2-19 of the report are provided in this Appendix. Part of the work was to assess tornado probabilities and the environmental impact related to potential damage to the K-65 Silos at the FS. The scope of the report extends to include the assessment of the radiation dose due to potential Silo failure. The excerpt in the Appendix deals only with the statistical analysis for tornado probabilities. The results are applicable to the tri-state area and to the thorium storage warehouses.

Probability Of Occurrence

The ranking of the tornados resulted in the tabulation of the frequency of occurrence, of each tornado class, as well as the probability per unit area and per year for a tornado of a given intensity. These results are illustrated in Table 2.3. Further analysis of the data provided a relationship between a given wind speed and the wind loading. The forces resulting from a tornado are complex and extremely difficult to model. Most of the available data has come from tests performed in wind tunnels. The direct applicability of these results is not clearly known at this time. General empirical equations have been developed from these tests and are readily used in the nuclear power industry to evaluate the response of a given structure to tornados. The NRC Regulatory Guide 1.76 delineates the maximum wind speeds and pressures drops required to be analyzed for applicability to structural response.

Approach

It is realistic to consider tornados as random phenomena in nature as are hurricanes, earthquakes and floods. Natural phenomena may be described as either deterministic or probabilistic. The probabilistic approach is by no means vague or unreliable. Probability, like other theories, should be viewed as a conceptual structure and its conclusions rely on logic.

The overall approach applied to the quantification of the frequency of a tornado and the effect of the phenomena on a specific structure was broken into two types of analyses. The first used straight forward statistical analysis of the total number of tornados, the area affected, and the time frame covered. The second involved two separate probability distributions in order to evaluate both the probability and the consequences of a single tornado event at the FMPC site.

The first approach assumes that the distribution of tornado events in time is random and that the distribution fits a Normal distribution. This allows for the estimation of the mean and variance for the occurence of tornado events per time, in a given area, and for a given intensity class. The second analysis evaluates further the relationship between the occurrence of a tornado and the effect the event will have on a given structure.

This is accomplished by utilizing two coupled distributions. The first distribution governs the discrete probability of a tornado event in time and the second distribution approximates the continuous distribution of the resulting wind velocities. The discrete distribution used is the Poisson and the continuous approximation utilizes the Gaussian distribution. This approach results in the estimation of a risk level associated with the occurrence and effect of a single tornado event in the assessment period.

Table 2.3: Summary Results Of Tornado Data From 1980 To 1989

Intensity	Area Covered (sq. mi.)	Number of Occurrences	Probability Per Year-Per Square Mile
F0	0.74	18	1.91E - 06
F1	14.23	68	3.65E - 05
F2	11.02	23	2.83E - 05
F3	7.59	5	1.95E - 05
F4	4.77	2	1.22E - 05
F5	10.25	1	2.63E - 05
	Total	Total	Total
	48.62	117	1.25E - 04
	Total Area Of Interest (sq. mi.)		
	41,004		

The risk level is defined as the probability of at least one occurrence during the life expectancy of the system considered. The risk analysis consists of collecting data on tornados with their assigned intensity classifications. A point process, Poisson, was used in modeling the tornado occurrences, thus providing the relationship between the risk level and the ratio of the return period to the life expectancy (5 years as defined in the contract). The combination of results from a best-fit density function and a best-fit point process yields the return period and thus tornado intensity (wind velocity) for the specific loads identified as critical for the K-65 silos.

Density Function

Although a discrete intensity scale is used for tornado classification, the wind speed will be the parameter ultimately used for the damage potential on the silos. Therefore, a continuous rather than a discrete density function will be used for the risk analysis. The mean wind speeds will be used to describe each intensity class. The normal or Gaussian distribution was selected to represent the tornado distribution. The X^2 test is used to compare the expected results with the data. The mean and standard deviation are estimated using the maximum likelihood method given by Equations 2.2 and 2.3.

$$\widehat{m} = \bar{x} = \frac{\sum_{i}^{n} x_i}{n} \qquad (2.2)$$

$$\widehat{\sigma}^2 = \frac{\sum_{i}^{n} (x_i - \widehat{m})^2}{n - 1} \qquad (2.3)$$

where:

$\widehat{m}$ = Mean value.

$\widehat{\sigma}$ = Standard deviation.

n = Number of elements in the sample.

x_i = Wind speed (mph).

The point process is based on the Poisson process which assumes the rate of occurrence is constant and independent of time. Using the Poisson process allows for the relationship between the risk level and the ratio of the return period to life expectancy to be site independent.

In the Poisson process the density function for t, the time between occurrences is given by Equation 2.4 (Dames, 1976).

$$f_T(t) = \mu e^{-\mu t} \qquad (2.4)$$

and the distribution function of t is given by Equation 2.5 (Dames, 1976).

$$F_T(t) = 1 - e^{-\mu t} \qquad (2.5)$$

and the probability function for 'N' occurrences as a function of the rate of occurrence μ is given by Equation 2.6.

$$P(N = n/\mu,t) = \frac{e^{-\mu t}}{n!}(\mu t)^n, \quad n = 0, 1, 2, \ldots \qquad (2.6)$$

where:

μ = Rate of occurrence.
T = Life expectancy.
t = Time of interest.
$f_T(t)$ = Probability density function.
$F_T(t)$ = Probability distribution function.
n = Number of elements in the sample.
P(N,t) = Probability of 'N' occurrences.

If the rate is assumed uniform inside the area, then the rate in a smaller area can be obtained by reducing the rate by an areal ratio. For example if 'a' and 'A' denote the reduced and original areas, respectively, then the rate inside the smaller area 'a' will be given by Equation 2.7.

$$\mu' = \mu\left(\frac{a}{A}\right) \qquad (2.7)$$

The probability mass function inside the 'a' (in this analysis 'a' represents the area of influence for the silo structures) is then given by Equation 2.8.

$$P(N' = n'/\mu',t) = \frac{e^{-\mu' t}}{n'!}(\mu' t)^{n'}, \quad n' = 0, 1, 2, \ldots \qquad (2.8)$$

The method of maximum likelihood is easily applied to the density function where the only parameter, μ, is given by Equation 2.9.

$$\hat{\mu} = \frac{n}{\sum_{i=1}^{n} t_i} \tag{2.9}$$

Tables 2.4 and 2.5 delineate the data and results of applying the statistical analysis to the tornado data, while the risk factor, for the Poisson process, can be represented by Equation 2.10.

$$r = 1 - e^{-L_x(x)\hat{\mu}} \times T \tag{2.10}$$

The reliability function, $L_x(x)$, for wind speed x, is defined as the probability of the wind speed being at least x and is obtained by numerical integration. The risk factor is estimated assuming that there is a single tornado event in the life of the facility.

Incorporating this assumption removes the conditional probability of tornado occurrence from the calculations. In this way the damage potential of the wind and pressure forces are presented in terms of a risk estimate. The nature of risk estimates dictates that the basic constituents of the probability and consequence calculations be clearly stated and defined. When considering two different risk numbers a comparison can only be made when the basic components are similar.

The calculations presented here form the basis of the final risk estimates associated with the tornado as an initiator. The next step is to evaluate and compare the consequences of a single tornado event. The consequences associated with each phase of the study, such as the estimation of the damage to the silo structure, the release of radon and other radionuclides, and finally the environmental transport leading to human exposure form the basis for overall risk comparisons. Finally the consequences of concern for the overall study are the increases in cancer fatalities (or incidence in the EPA methodology) associated with the exposure to radioactive materials. In order to achieve a basis for comparison the risk estimates provided in Column A of Table 2.5 are presented. The risk factor for the single tornado event in the life of the plant at first glance appear to overestimate the risk of silo failure as a result of a tornado. The intent is to illustrate the significant probabilities and risks associated with the relatively low wind speeds. The numbers provide a comparison that would be less obvious when the probability of the tornado occurring is factored in.

Table 2.4: Results Of The Statistical Analysis

intensity	number of occurrences	expected value	mean wind velocity (mph)
F0	18	16.85	60.0
F1	68	71.32	95.0
F2	23	21.43	135.0
F3	5	4.79	185.0
F4	2	1.37	230.0
F5	1	0.78	290.0

μ	σ	χ^2
105.0	37.3	0.71

Table 2.5: Probabilities And Risk Factors

intensity	probability $L(x) = 1 - F(x)$	wind velocity (x, mph)	Column A risk factor* r (x)	Column B Risk Based on Probability of Tornado in Five Years
F1	2.5 E - 1	112	3.7 E - 1	2.3 E - 4
F2	1.75 E - 2	135	4.13 E - 2	2.6 E - 5
F3	3.34 E - 3	185	5.78 E - 4	3.6 E - 7
F4	2.78 E - 6	230	6.13 E - 6	3.8 E - 9
F5	2.43 E - 7	290	7.35 E - 8	4.6 E - 11

$$r(x) = 1 - \exp(-L(x)\,\hat{\mu}\,T\,x) \qquad \hat{\mu} = \frac{n}{\Sigma t_i}$$

* Based On A Single Event Occurring In The 5 Year Life Time

The obvious comparison here is that the damage potential (risk factor) is significant for average wind speeds on the order of 112 miles per hour. The probability of this wind speed occurring is quite large at 25%. The forces associated with this wind speed are 288 (psf) tension and approximately 50 (psf) compression. These forces are considered (based on the structural analysis) to be sufficient to fail the silo dome. Although these forces are not the maximum values the damage to the silo is expected to be such that a significant quantity of the radionuclide inventory could be released. The risk (consequence of the tornado on the silo) associated with the failure of the K-65 silos over the next five years is best represented by the risk factors in column A of Table 2.5. The risk estimates provided in column B of Table 2.5 are presented to approximate the total probability (tornado frequency and damage potential) and are therefore form a basis of risk comparison with the chronic or continuous release of radon. The values in column B include the damage potential, for each intensity class, and the probability of a tornado event in the five year assessment period.

The probabilities and risk factors presented in Table 2.5 were used to evaluate the maximum damage potential and therefore the maximum quantity of radioactive material that could be released to the environment. The probabilities of silo dome failure, due to natural degradation, and of a tornado occurring, per year and per square mile, were used in the final risk estimates relating the total cancer fatalities or cancer incidence as a result of human exposure to the radioactive material that hypothetically could be released. These values are delineated in Table 2.6. The central difference.between the probabilities listed in Table 2.6. and those in Table 2.5 is that the net effect or consequence considered is different. The values in Table 2.6 refer to the frequency of occurrence, of a tornado, and not to the specific damage potential. The values in Table 2.6 were used in the overall risk estimates in order to form a comparative basis of the consequences. The inclusion of the specific damage potential would appear to underestimate the risk from the silo contents on the public.