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# THORIUM HANDLING ENVIRONMENTAL ASSESSMENT

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REPORT

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DOE/EA-0338
JANUARY, 1988

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# THORIUM HANDLING ENVIRONMENTAL ASSESSMENT

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO

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U.S. DEPARTMENT OF ENERGY

FINDING OF NO SIGNIFICANT IMPACT

THORIUM HANDLING, FEED MATERIALS PRODUCTION CENTER

FERNALD, OHIO

AGENCY: U.S. Department of Energy

ACTION: Finding of No Significant Impact (FONSI) for the Thorium Handling, Feed Materials Production Center

SUMMARY: The U.S. Department of Energy (DOE) has prepared an Environmental Assessment (EA) for a proposed project to remove, repackage, and temporarily store a portion of the thorium inventory at the Feed Materials Production Center (FMPC) located near Fernald, Ohio, as part of the overall environment, health, and safety improvements project of the FMPC facilities. The thorium materials considered here currently are stored at the FMPC site in a silo and a bin. Engineering analyses indicated that the storage silo was vulnerable to failure caused by natural meteorological or seismic phenomena; thus the silo and its supports were structurally reinforced to comply with current building codes. While the current storage method does not pose an immediate radiation hazard to human health or the environment, beyond the near vicinity of the silo and bins, the project is proposed to minimize the risk of a release of thorium materials. Based on the finding of the EA, the DOE has determined that the proposed action does not constitute a major federal action significantly affecting the quality of the human environment

within the meaning of the National Environmental Policy Act of 1969, 42 U.S.C. 4321 et seq. Therefore, no environmental impact statement is required. The proposed action is to remove a total of 227 cubic meters ($4.4 \times 10^5$ kg) of thorium materials with a total activity of about 48 curies from the silo and bin, repackage the materials into 55-gallon drums (or other bulk containers), and store the containers on site for an interim period. The DOE proposes to transport the repackaged thorium, along with other thorium materials from the FMPC, to a suitable site for long-term storage. This transportation activity is the subject of a separate environmental assessment currently being prepared by the DOE. The silo and bin will be decontaminated and decommissioned following removal of the thorium materials.

Alternatives to the proposed action are evaluated in the EA. These include the following:

- Upgrade the silo and storage bin to achieve structural integrity consistent with DOE design criteria for new facilities;

- Remove the thorium materials and place them into new processing bins at ground level;

- No action (thorium material would continue to be stored in the silo and bin near Plant 8).

The proposed action will result in minor and insignificant radiological and nonradiological releases of hazardous substances to air, water, and land under both routine operational and accident conditions. Airborne releases were identified as the principal environmental pathway of concern. The human and environmental impacts anticipated to result from these releases are summarized below.

Routine Operations:

The results of the evaluation of routine operational impacts are as follows:

- Releases to Air - Airborne releases of radioactive materials will be controlled during routine operations to assure compliance with the design criterion of less than $5.4 \times 10^{-8}$ microcuries per milliliter ($2.0 \times 10^{-3}$ becquerels per milliliter) of alpha activity concentration in the environment. It is calculated that a total of 1.3 microcuries ($4.7 \times 10^{4}$ becquerels) of thorium-232 will be released to the atmosphere during the 26-week project. The maximum resulting off-site concentration is calculated to be $2.1 \times 10^{-18}$ microcuries per milliliter ($7.9 \times 10^{-14}$ becquerels per milliliter). This is less than the DOE Derived Concentration Guide for Thorium 232 in air of $7 \times 10^{-15}$ microcuries per milliliter ($3 \times 10^{-10}$ becquerels per milliliter).

Nonradiological airborne releases during thorium removal operations will include pollutants generated through combustion of diesel fuel (i.e., CO, nitrogen and sulfur oxides, and particulates). All quantities of pollutants generated through the project will result in airborne concentrations far less than established air quality standards in 40 CFR Part 50, National Air Quality Standards (Primary).

- Releases to Water - Deposition of airborne radiological materials onto surface water bodies will result in some minute increases in waterborne concentrations of these materials. The calculated resulting maximum concentration of $2.1 \times 10^{-13}$ microcuries per milliliter ($7.9 \times 10^{-9}$ becquerels per milliliter) is below the DOE Derived Concentration Guide of $5 \times 10^{-8}$ microcuries per milliliters ($2.0 \times 10^{-3}$ becquerels per milliliter) of Thorium-232 in water.

  No discernible increase in waterborne concentrations of nonradiological materials is expected to result from routine project operations.

- Releases to Land - It is estimated that 8.6 cubic meters of uncompacted waste will be generated during the project. The waste will be low-level, low specific activity radioactive

waste in the form of disposed protective clothing, rags, and used filters. This waste will be subject to land disposal in compliance with applicable DOE requirements. Deposition of airborne radiological materials generated by the project is calculated to result in surface contamination at least one million times lower than natural background.

- Occupational and Public Exposures - The average radiation exposure to a project worker is anticipated to be less than 1.1 rem (11 millisieverts) annual effective dose equivalent for the project duration. This is considerably less than the permissible DOE limit of 5 rem per year (50 millisieverts per year).

The calculated effective committed dose equivalent to the maximum off-site individual resulting from the project is about $1.7 \times 10^{-2}$ millirem ($1.7 \times 10^{-4}$ millisieverts). The whole body dose equivalent to this hypothetical individual from the air pathway is $3.8 \times 10^{-4}$ millirem ($3.8 \times 10^{-6}$ millisieverts). The committed dose equivalent to the critical organ, the bone surface, is calculated to be approximately $2.6 \times 10^{-1}$ millirem ($2.6 \times 10^{-3}$ millisieverts). In all cases the exposure to the maximum individual is less than one-hundredth of the applicable DOE and EPA limits for the FMPC site (40 CFR 61, Subpart H).

Accident Conditions

The postulated worst-case credible accident, a failure in the silo near the bottom of the silo cone, is calculated to result in a maximum off-site airborne concentration of thorium-232 of 3.2 x $10^{-10}$ microcuries per milliliter (1.2 becquerels per milliliter). The maximum effective committed dose equivalent to a member of the general public resulting from this worst-case accident is 5.1 x $10^{2}$ millirem (5.1 millisieverts). This exposure carries a health risk of less than 0.01 percent of a resulting fatal cancer during the lifetime of the exposed individual.

The radiological risks presented by the proposed action are negligible. No significant impacts to other environmental parameters such as cultural resources, biological resources and socioeconomics are anticipated.

Single copies of the EA are available from:

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P.O. Box 398705
Cincinnati, Ohio 45239-8705
(513) 738-6160

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Office of NEPA Project Assistance
U.S. Department of Energy
1000 Independence Avenue, S.W.
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(202) 586-4600

Issued this 9th day of February, 1988.

Gary W. Gibbs
Acting Assistant Secretary
Environment, Safety and Health

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# THORIUM HANDLING ENVIRONMENTAL ASSESSMENT

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# 1.0 PURPOSE AND NEED FOR ACTION

The Feed Materials Production Center (FMPC) is a U.S. Department of Energy (DOE) uranium metal production facility located on a 425-hectare site near Fernald, Ohio, about 33 kilometers northwest of downtown Cincinnati (Figure 1-1). Most of the site is located within Hamilton County although approximately 81 hectares are situated in Butler County. The villages of Fernald, New Baltimore, Ross, and Shandon are all located within a few kilometers of the plant.

Currently under management of the Westinghouse Materials Company of Ohio (WMCO), the FMPC has been in operation since 1954. It consists of nine separate production plants and 47 support buildings and facilities, including radioactive waste treatment and storage facilities. The primary mission of the FMPC is the production of purified uranium metal and uranium compounds for use at other DOE defense facilities. A small amount of thorium processing has also been conducted at the FMPC.

Beginning in the early 1970s, the DOE investigated using thorium materials as part of its efforts to develop economical methods of producing defense-related nuclear reactor fuel. Thorium nitrate materials were shipped to the FMPC site from the Hanford Site, converted to thorium oxide, and have been stored since 1972 in a silo and a storage bin located at the FMPC "Plant 8" (Figure 1-2). As part of the environmental safety and health-related renovation of facilities (the Environmental, Health, and Safety Improvements Project; Line Item Project No. 87-D-159) at the FMPC, the DOE has identified the need for removal, repackaging, and temporary storage of the thorium materials. It is necessary to continue on-site storage of the thorium, at least on an interim basis, until the DOE defines the long-term disposition of the material.

In 1985, Lockwood Greene Engineers, Inc. (LGE) was contracted by the DOE to develop a conceptual design for a thorium handling system to remove the materials from the Plant 8 storage vessels. As part of the design process, LGE performed a preliminary structural analysis which indicated that the thorium storage silo was vulnerable to failure caused by natural phenomena

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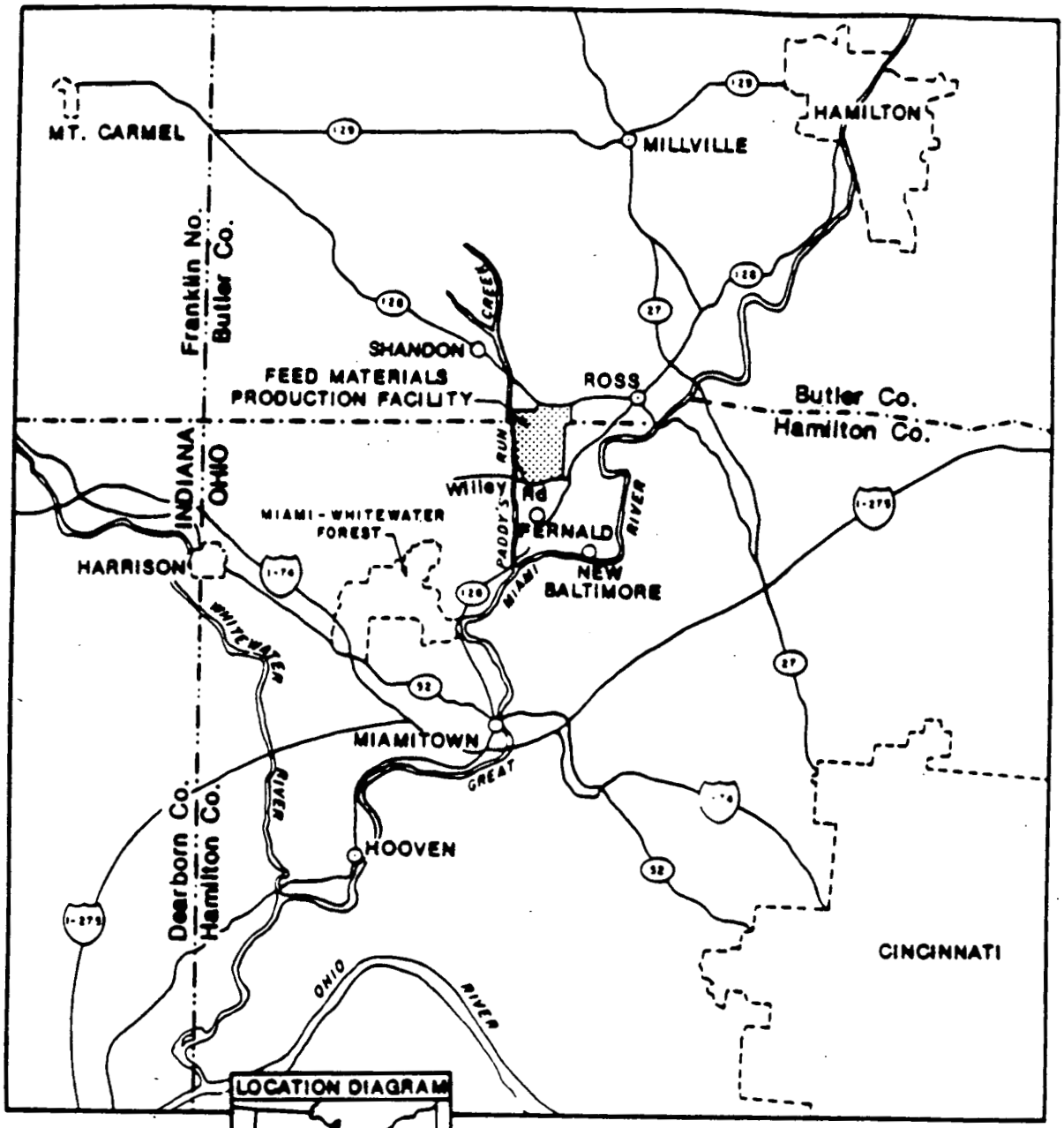


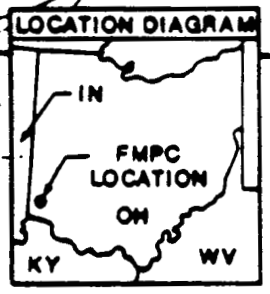


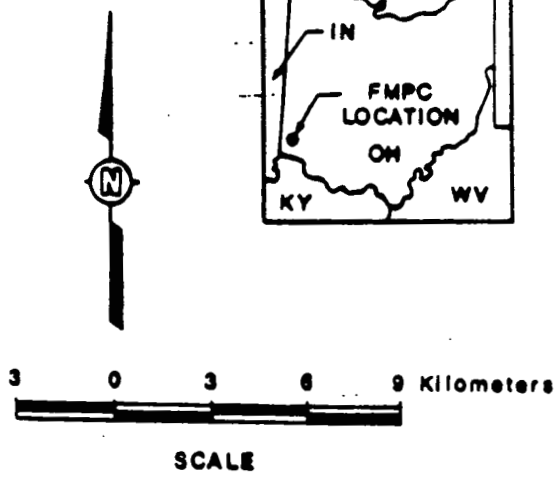


FIGURE 1-1

FEED MATERIALS PRODUCTION CENTER
REGIONAL AND LOCAL
LOCATON MAP

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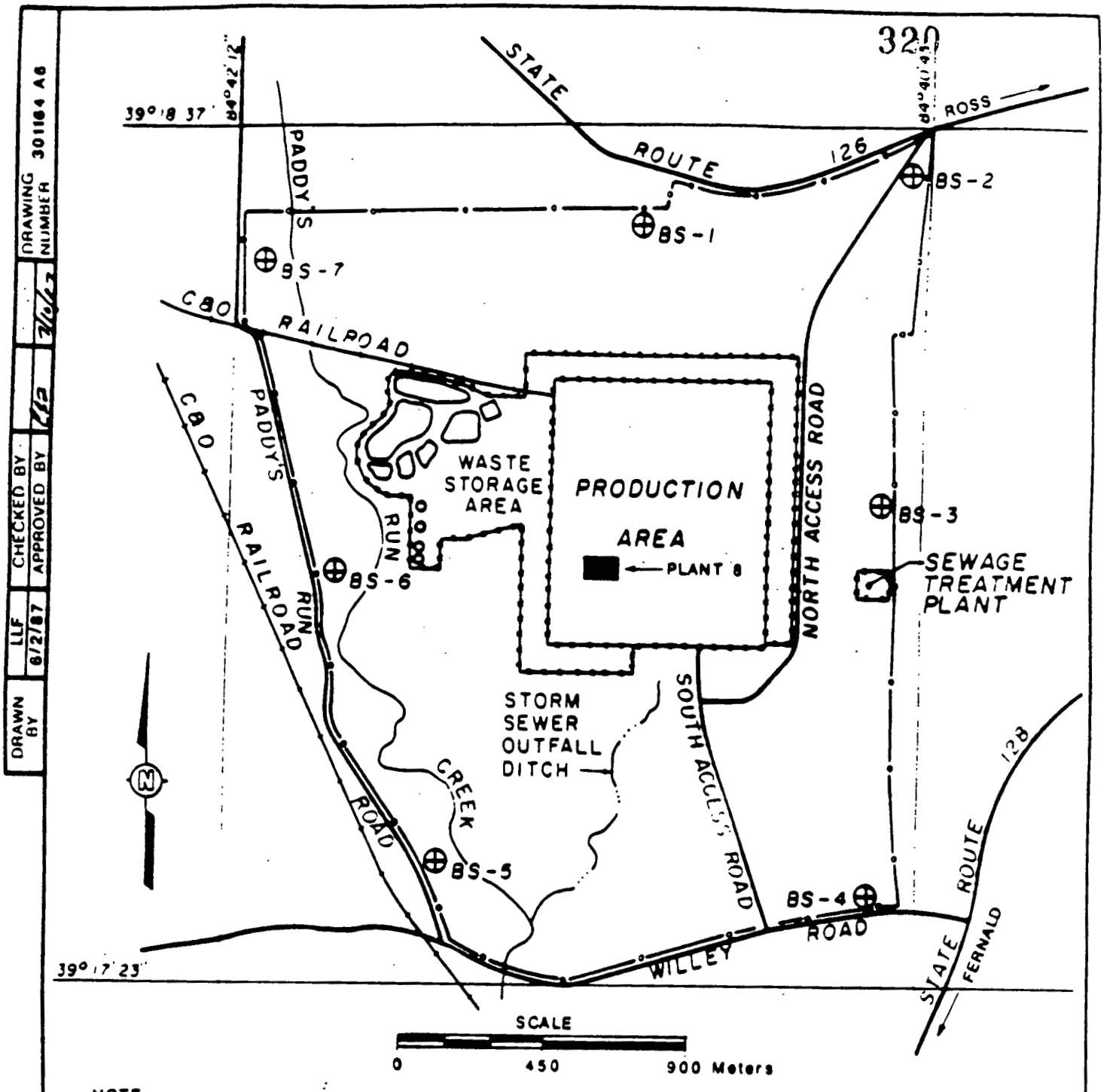


NOTE:
COORDINATES AT CENTER OF PRODUCTION AREA:
LONGITUDE 84° 41' 19", LATITUDE 39° 17' 58"

LEGEND

- SECURITY FENCE
- PROPERTY LINE FENCE
- GRID LINE
- BS-5 AIR QUALITY MONITOR SITES

FIGURE 1-2

FEED MATERIALS PRODUCTION CENTER
DETAILED LOCATION MAP

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such as high winds or earthquakes. The analysis further determined that, under the assumed thorium product loads alone, the silo was in an overloaded condition and that a number of structural members on the storage bin were overstressed. Subsequent analyses using more realistic thorium product loads clarified the immediate concern as being limited to the silo storage vessel. Subsequently, the silo and its supports were structurally reinforced to comply with the Ohio Basic Building Code and Uniform Building Code Standards. These standards require that the structure be capable of withstanding loads imposed by high (129 kilometers per hour) winds or Class 2 seismic events in addition to loads imposed by future thorium unloading procedures and equipment. Nevertheless, additional corrective action is needed to resolve the thorium storage problem and to ensure that an accidental thorium release will not occur. In addition, the continued storage of this material in the silo and bin contributes to the occupational radiation exposure to workers at Plant 8. This condition does not promote the DOE objective of maintaining radiation exposure at levels "as low as reasonably achievable" (ALARA).

The silo is a cylindrical steel tank approximately 12 meters in height and five meters in diameter with a cone-shaped bottom (Figure 1-3). It rests on four reinforced columns that elevate it approximately six meters above the ground. The rotary valve at the bottom of the silo, which was to allow thorium material to flow freely when opened, is now cracked and in a partly opened condition. The valve has been enclosed in a steel case as a precautionary measure to prevent discharge of the thorium material from the silo. The condition of the thorium material in the silo, whether loose and capable of flowing freely from the structure or rigidly caked inside, is not presently known.

The bin is a rectangular steel vessel about five and one-half meters by six meters in dimension and eight meters deep with an inside plate that divides the vessel into two compartments designated A and B for the purpose of this report. The bin is located on top of and within the southeast corner of the Plant 8 building, above the third floor. It extends downward through the roof with the bin bottom approximately 12 meters above ground level (Figure 1-4). The thorium material in the bin is currently held in place by slide valves and feed discharge screw feeders. There is some exposed material which is

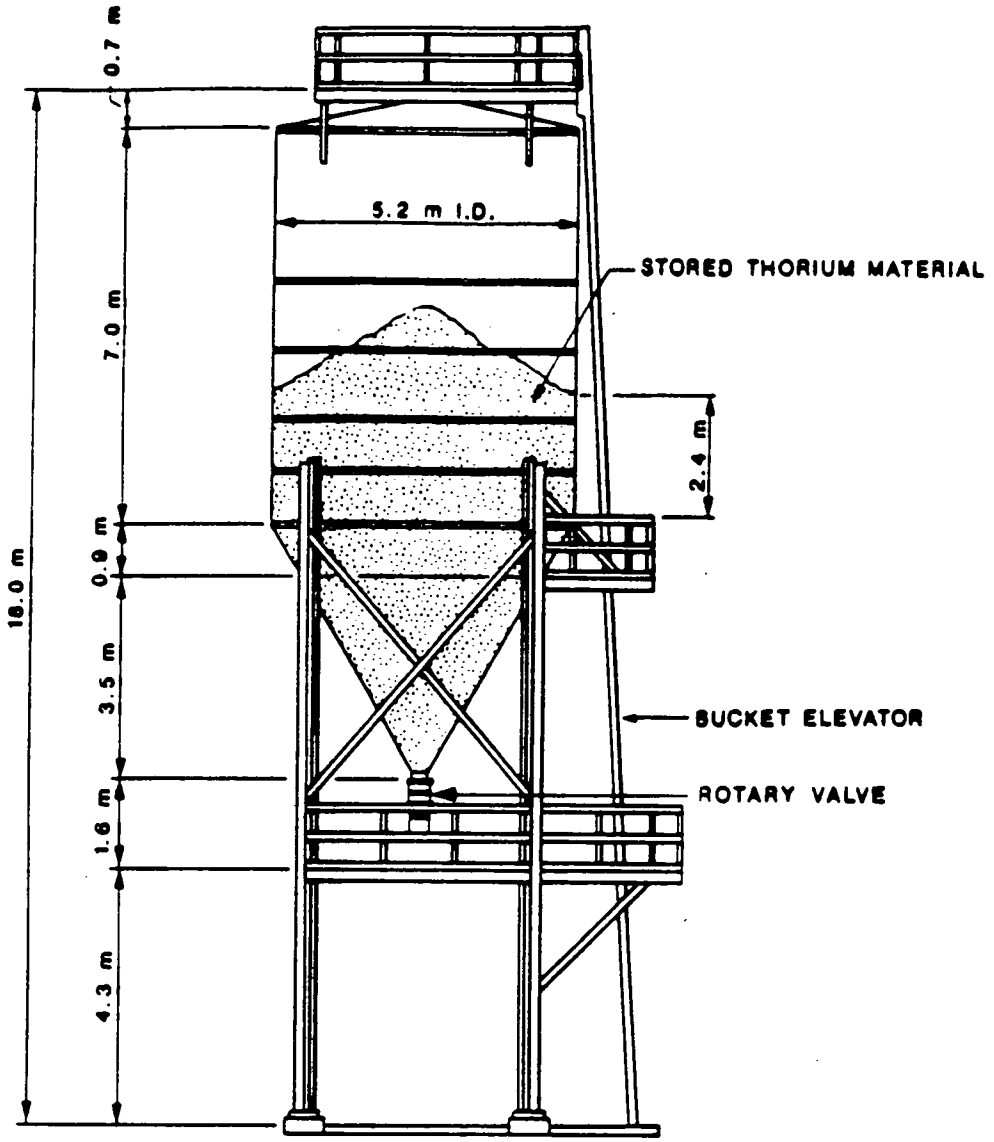


FIGURE 1-3

THORIUM STORAGE SILO
ADJACENT TO PLANT 8

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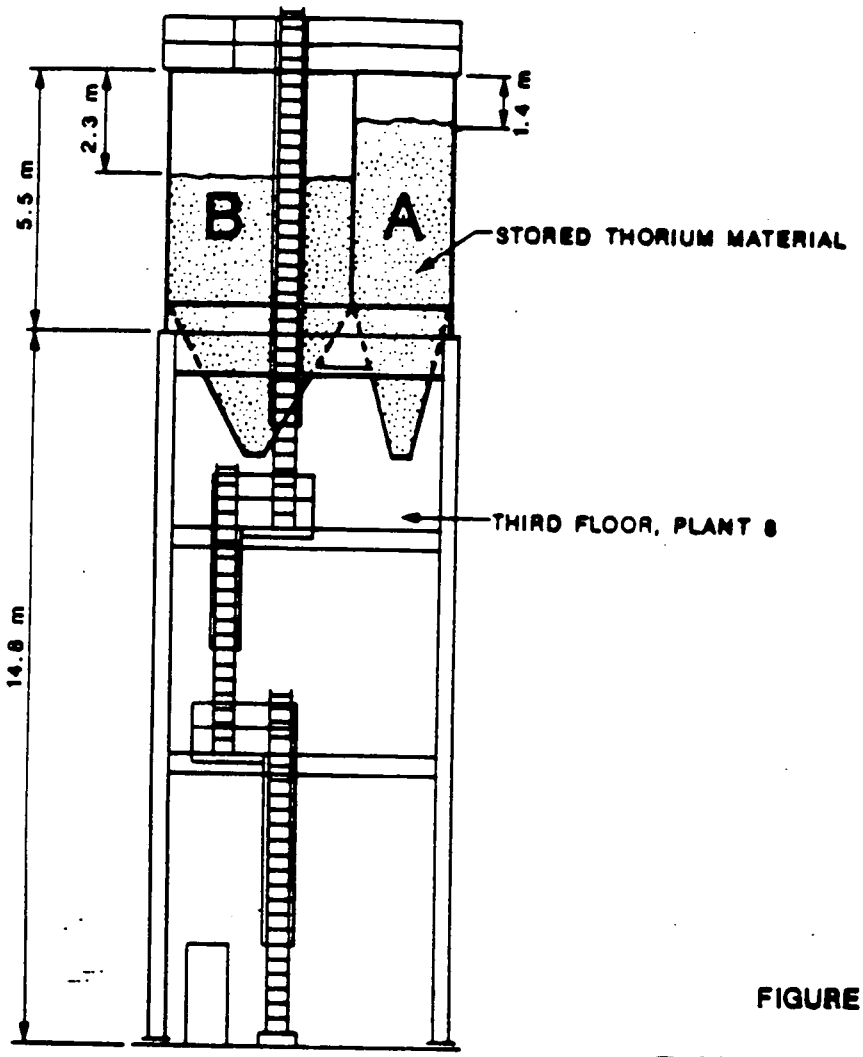


FIGURE 1-4

THORIUM STORAGE BIN
IN PLANT 8

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granular and capable of flowing. If the screw feeders are removed with the slide valves open, some thorium material could be made to flow out of the storage bin.

In summary, the silo and storage bin in the Plant 8 area at the FMPC have questionable long-term structural integrity. While the thorium storage structures do not pose any immediate radiation hazard to human health and the environment outside the plant boundary or even beyond the near vicinity of the silo and bins, corrective actions are necessary to minimize the risk of the release of thorium material to the environment. The silo and bin are scheduled for decontamination and decommissioning (D&D) after thorium materials have been removed. Alternative methods of implementing the needed corrective actions are evaluated in this Environmental Assessment.

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# 2.0 DESCRIPTION OF PROPOSED ACTION AND ALTERNATIVES

This section discusses the proposed action and alternative actions which addresses the interim disposition of thorium compounds currently stored within the FMPC Plant 8 silo and bin. The proposed action is to:

- Remove the thorium compounds from the silo and bin and repackage the material for interim on-site storage in an environmentally safe manner. The DOE proposes to transport the thorium material to a suitable site for long-term retrievable storage. This activity, as well as possible alternative actions, is the subject of a separate environmental assessment which is currently in preparation.

Other alternatives considered are:

- Upgrade the silo and storage bin to achieve structural integrity consistent with DOE design criteria for new facilities (DOE, 1983)
- Remove the thorium material and place it into new processing bins at ground level
- No action [an alternative which must be addressed in all National Environmental Policy Act (NEPA) documentation]. With this alternative, the thorium material would continue to be held in storage in the silo and bin located in the Plant 8 area.

The overall purpose of this section is to describe the proposed action and alternatives in sufficient detail to allow for a reasoned comparative evaluation of possible impacts. The evaluation of impacts is contained in Section 4.0.

## 2.1 PROPOSED ACTION

The preferred alternative is to remove the thorium materials from the Plant 8 silo and bin, repackage them in 55-gallon drums (or other bulk containers), and store them on-site for an interim period. The silo and bin will be decontaminated and decommissioned following completion of the thorium material removal.

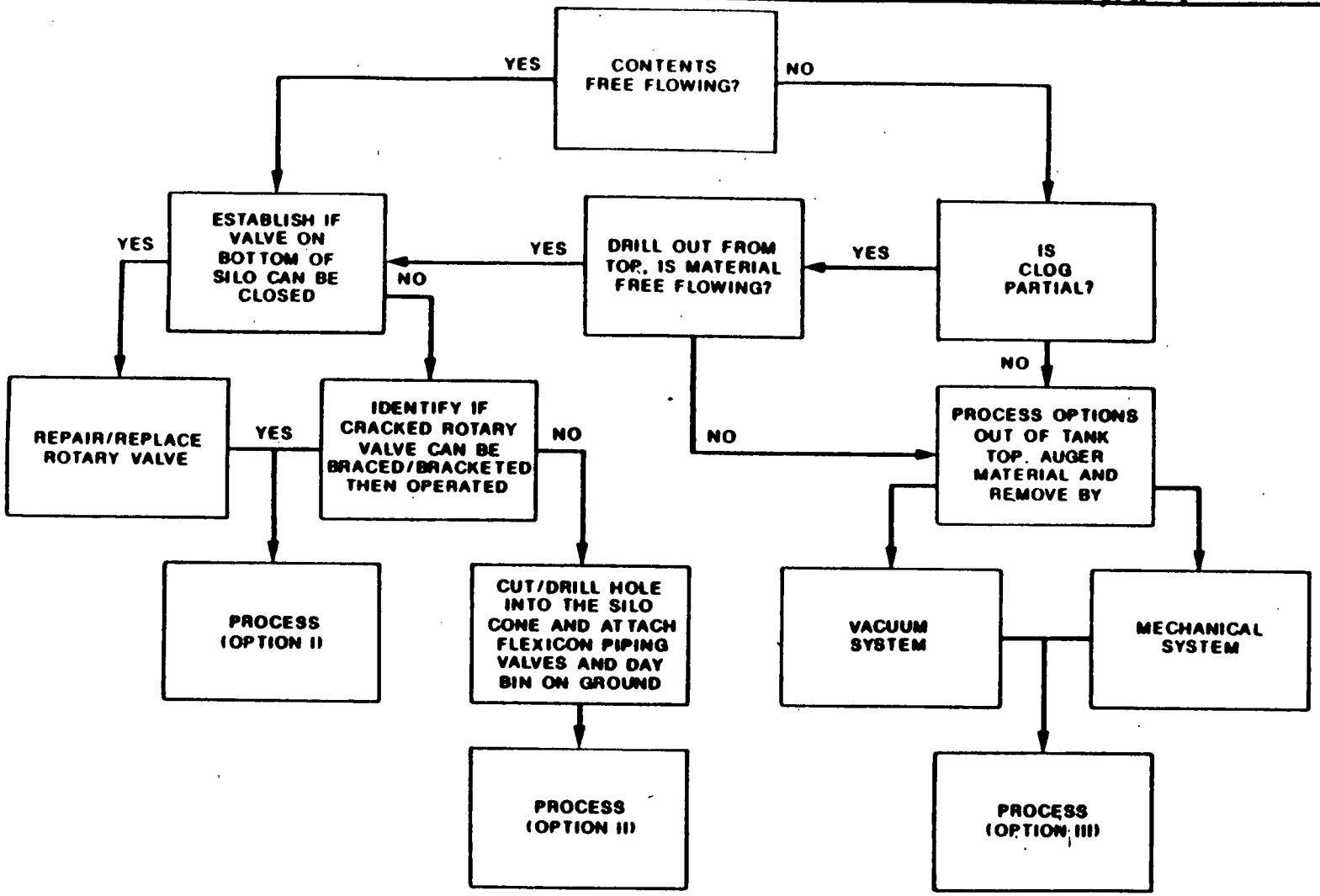


FIGURE 2-1

LOGIC DIAGRAM-SILO
THORIUM REMOVAL SEQUENCE

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### 2.1.1 Removal From Existing Storage

Several approaches were considered for removal of the thorium material from the silo following the decision tree analysis shown in Figure 2-1. The method(s) to be adopted will depend on whether material is free-flowing or partially or totally caked. The basic approaches considered were as follows:

(1) Remove the thorium material from the bottom of the silo using existing silo removal equipment.

(2) Remove the material from the silo cone using a motor-driven auger (Flexicon) unit.

(3) Remove the material through a man-way on top of the silo using either a mechanical or a vacuum system.

The success of the first approach will depend on whether the material is free-flowing and whether there is a need to replace or repair the rotary valve at the bottom of the silo cone (Figure 1-3). If the valve cannot be repaired or replaced, removal from the bottom will require drilling a ten-centimeter hole into the cone and using a motor-driven auger (Flexicon Unit) to feed the material from the silo through a chute to a temporary enclosure. The third option--removal through the top--will require using either a mechanical or vacuum lift system.

The same health, safety, and environmental safeguards will be employed for all three of the thorium removal methods. All three involve the conveying of the material from the current storage configuration to smaller containers and share the potential for routine and accidental airborne release of thorium. All are subject to the same design criteria requirements and environmental standards. Since the methods of removing thorium materials from the silo should not have significantly different environmental consequences, each method was not considered as a separate alternative.

Several approaches were also considered for removal of the thorium material from the storage bin following the decision tree analysis shown in Figure 2-2. As with the silo, the method to be adopted will depend on the physical condition of the material.

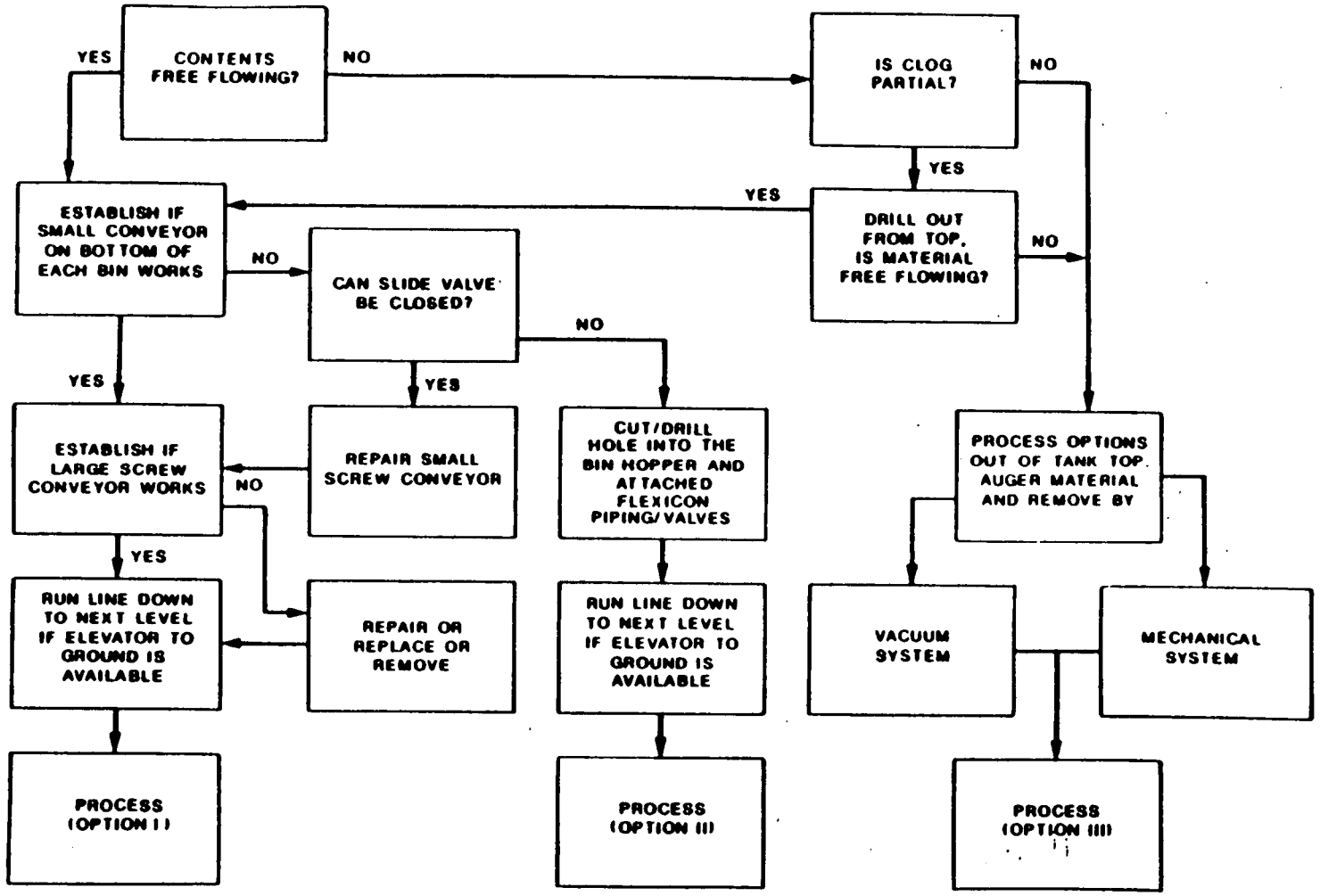


FIGURE 2-2

LOGIC DIAGRAM-BIN
THORIUM REMOVAL SEQUENCE

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The thorium material in the bin is currently held in place by two screw feeders at the outlet of slide valves. It is not currently known whether the open slide valves can be operated or closed. One method of removal of the thorium materials would involve the activation of two screw feeders and a large screw conveyor. The materials would be conveyed to a packaging (drumming) station located in the conveyor area. Alternatively, a chute could be constructed to the fill drums at ground level.

If the screw feeders cannot be activated, an optional approach would be to penetrate the hoppers with Flexicon feeders using the same technique described above for removal of material from the silo. Removal of material through the top of the storage bin, the third alternative, will be considered only if the first two options are not viable.

### 2.1.2 Repackaging

As an integral and continuous part of the removal operation from either the silo or the bin, the thorium oxide material will be repackaged in a dual containment configuration to control both the Radon-220 (thoron) emissions and the potential release of respirable particles. Since the rate of formation of thoron is equal to its rate of decay, pressurization of sealed containers is not a concern. Containers will meet both Department of Transportation (DOT) Specification 7A packaging requirements (49 CFR 173.415) and DOE requirements for retrievable storage. The material will be placed in containers selected to reduce the void "head space," i.e., the unfilled portion of the container. The following are examples of repackaging containers that may be used:

- 48-gallon drums overpacked in 55-gallon drums
- 55-gallon metal drums lined with a 90-mil polyethylene liner
- 55-gallon drums placed inside a 96-cubic-foot containment box
- 55-gallon drums placed inside an engineered concrete overpack capable of holding up to 14 drums.

Regardless of the type of packaging, removed thorium oxide material will be transported to an existing on-site storage area within 50 meters of the silo and bin for interim storage. The method of on-site transportation may vary, depending upon the type of container used.

### 2.1.3 Decontamination and Decommissioning

Equipment associated with the silo and bin and the thorium removal system (e.g., bucket elevator, conveyor, screw feeder, filters, etc.) will be surveyed (by established radiation survey protocols) and decontaminated. The decontamination goal is to limit residual surface contamination to an average of less than 1,000 disintegrations per minute of alpha activity per 100 square centimeters (16.6 becquerels per 100 square centimeters) and removable contamination to less than 200 disintegrations per minute of alpha activity per 100 square centimeters (3.3 becquerels per 100 square centimeters). These levels will allow future unrestricted use of the decontaminated equipment.

Decontamination may include, but not be limited to, application of high-pressure water with abrasive grit and dry abrasive blasting. Water used in decontamination activities will be held in a closed system, filtered, and reused. All residues associated with decontamination operations will be classified according to radioactivity content and disposed of in accordance with DOE 5820.2 (DOE, 1984).

The silo and bin structures themselves will then be demolished (employing appropriate employee protection precautions). Structural components which cannot be decontaminated to meet the unrestricted use criteria will be reduced in size and treated as low-level radioactive waste. Demolition rubble satisfying the unrestricted use criteria will be disposed of in a conventional disposal site.

### 2.1.4 Health, Safety, and Environmental Quality Control Programs

The basic health and safety and environmental quality control program is common to the proposed action and the alternatives. Because these are integral to the entire thorium handling system to meet DOE health and safety objectives, and other regulatory requirements, they are not considered as additional "mitigative" measures for the purposes of this EA.

#### Engineering Controls

Engineering controls will be installed to minimize the release of any radionuclides to air, water, or soil during the removal and repackaging activities

at the silo and the bin. A temporary enclosure constructed of a steel framework and metal panels will surround the package filling operation to capture fugitive dust emissions at the point where the thorium material is withdrawn from the silo or bin. This enclosure will be large enough to surround both a single container and the chute used to fill the container. The repackaging technicians will work inside a second enclosure, suitable for containing releases from the filling operation. This enclosure will be equipped with a ventilation and filtration system. The system will consist of an exhaust fan and a series of filters, including a roughing filter and a high efficiency particulate air (HEPA) filter capable of removing at least 99.97 percent of the 0.3 micron or greater diameter airborne particles before release to the environment. Thoron releases to the environment will be limited by means of a charcoal filter which is capable of absorbing the gas from the airstream and delaying its discharge.

Air samples will be collected downstream of the filters using isokinetic conditions to monitor for radioactive materials while the ventilation system is operating. A continuous air monitor (CAM), equipped with an alarm, will provide real time monitoring of the discharged air. If thorium, thoron gas, or other radioactive decay products are discharged in excess of permissible limits, an alarm will sound and the operation will be shut down. Set points for the alarm and steps to shut down the operation will be established in the work procedure. In accordance with the design criteria for the project, environmental releases will not be allowed to exceed 0.54 picocuries of alpha activity per cubic meter (0.02 becquerels per cubic meter) of discharged air (WMCO, 1986).

No release of liquid effluent to the environment is anticipated during thorium removal or decontamination activities. Any water used in the decontamination process will be held in a "closed loop" system, i.e., returned to a holding tank, filtered, and reused. Upon completion of decontamination, the spent water will be tested for Th-232 residual. If it is found to be contaminated, it will be disposed and treated as low-level radioactive waste in accordance with DOE requirements (DOE, 1984). Used filters will also be treated as low-level radioactive waste.

The FMPC site has already in place a run-off and run-on control system, including a high-density-polyethelene-lined lagoon system, to control releases of contaminants to surface water. Any spills of radioactive material (solid or liquid) will be managed according to the Spill Prevention, Control and Countermeasure (SPCC) Plan adopted for the FMPC. The plan specifically calls for covering or building a dike around all sewer or floor drains to preclude releases to run-off lagoons. These lagoons, in turn, provide for management of liquid effluent and precipitation run-off from the site.

Health Controls

The repackaging operation will be designed to minimize worker exposure to radiation. Routine monitoring will serve to identify sources of exposure and optimize the methods and procedures where necessary to assure that the exposures meet ALARA objectives. Written procedures describing the health physics program will satisfy the specific requirements of the proposed action as well as general DOE requirements (DOE, 1986).

All repackaging contractor's operators and technicians will receive training on the methods to be used for the repackaging. Mock-ups will be used for certain tasks to permit "hands-on" exercises to test the procedures, such as attaching the removal equipment or filling a drum. Other training courses will include specific methods to reduce individual exposure to radiation as well as fulfilling the site requirements for all workers.

External radiation exposure to repackaging personnel will be minimized by the use of temporary radiation shielding. The shielding will be suitable to lower the background radiation levels for the large enclosure where technicians will spend the majority of their time. Direct radiation levels will be monitored routinely using both portable instruments and passive dosimetry. Administrative controls will also be implemented to limit exposure to workers. For example, as drums are filled with thorium, they will be removed from the enclosure promptly to minimize unnecessary exposure within the enclosure.

Exposure to airborne and surface contamination will be minimized by personal protective equipment (PPE), routine monitoring, and operational procedures. Personnel exposure will be controlled to levels which meet DOE requirements or

ALARA objectives. Surface contamination levels inside the enclosure will be surveyed routinely in order to assign adequate clothing and respiratory protection. Air samples will be collected during repackaging operations to document that personnel exposures are acceptable. Airborne thorium concentrations within the working area will not be allowed to exceed 0.54 picocuries of alpha activity per cubic meter (0.02 becquerels per cubic meter) averaged over a 40-hour work week (WMCO, 1986), the Derived Air Concentration for Th-232 (ICRP, 1979b). An air lock will be used to gain access to the working area in order to maintain the controlled area at a negative pressure. Control zones will be established to minimize the spread of contamination to other areas so that PPE can be removed before exiting the enclosure. Radiological health and safety procedures which prohibit smoking, drinking, and eating on the job will be enforced. Survey instruments will be used to "frisk" technicians leaving the control zone. These controls, both engineered and administrative, are suitable to maintain personnel exposures to within the radiation exposure limits for worker health protection. Appropriate application of administrative controls will be assured through implementation of the project quality assurance program.

Much of the work proposed involves worker hazards which are not unique to a facility handling radioactive materials. Other health and safety concerns, besides radiation exposure, have been considered and can be minimized. For this project, special emphasis will be placed on:

- Slips, trips and falls
- Safe lifting techniques
- Heat stress.

Standards for minimum protection have been established by the Department of Energy (DOE, 1986) and by the Occupational Safety and Health Administration (29 CFR 1910). Compliance with these standards will be accomplished by implementing the health and safety program.

A safety and health plan will be prepared by the thorium handling contractor and approved by WMCO before the work begins. Work procedures will incorporate the safety measures that are necessary, such as use of appropriate personal protection equipment. All employees will participate in a site specific

training program before work begins. The applicable mitigation measures will be discussed and demonstrated so that all employees have a clear understanding how to minimize the risks of an injury. Nonradiological health and safety issues will be controlled in a safe and efficient manner. The training program will serve as the forum for identifying the necessary controls for this project.

## 2.2 ALTERNATIVES TO THE PROPOSED ACTION

In the process of selecting the preferred alternative, other reasonable alternatives were examined in detail. These included the alternatives of upgrading the silo and bin structures, selecting a different package type for the removed thorium, and taking no corrective action to remedy the situation.

### 2.2.1 Structural Upgrading of Thorium Storage Silo and Bin

If storage of the thorium in existing vessels is to continue, further structural reinforcement or upgrading may be required to satisfy DOE design criteria for new facilities (DOE, 1983). Results of prior structural analyses indicated that:

- Stresses in the storage bin are well within allowable limits and no structural upgrading is considered necessary
- The stresses in the silo can exceed current DOE criteria for high wind or seismic events. The columns supporting the structure and cone-cylinder junctions are of special concern
- Interim structural reinforcement measures (which have been completed to satisfy local building code requirements) are desirable even if the thorium is to be removed from the silo.

Additional structural upgrading of the silo would occur in two distinct phases: the upgrading engineering design and the actual construction of additional support structures. Corrective measures to be employed would be dictated by the results of additional analyses of structural stresses as related to DOE design criteria for new facilities. In addition to any corrective measures, equipment could be installed to measure any structural degradation and regular inspection, monitoring, and maintenance of the structures would be employed.

### 2.2.2 Removal of Thorium From Silo and Bin and Repackaging in New Ground-Level Process Containers

Except for the package type to be employed, this alternative has the same basic features as the proposed action. Rather than using one or several "double containment" configurations of 55-gallon metal drums, this alternative would use new process bins equipped with valves and piping connections so that the thorium material could be removed and used by processing equipment. Due to weight constraints, thorium removal from the silo and bin would probably be made through a chute leading to a container at ground-level. The material would thus be available for processing when required without additional handling steps.

Under this alternative, each process bin would contain 8.5 to 11 cubic meters of thorium material. Until the thorium is needed for further processing, the new process bins would be placed in interim on-site storage areas.

### 2.2.3 No Action

The "no action" alternative would maintain the status quo. Periodic inspections would be conducted to assure the integrity of the silo and bins. Inspections would be documented according to established procedures. In addition, radiation surveys would be regularly performed to determine the level of releases of thoron from the silo and bin at the site. Routine maintenance would be continually performed: maintaining openings that may be exposed to wind or precipitation; installing legible radiation signs; and painting of the structures as required. With this no action alternative, concern about the structural integrity of the silo and the storage bin would continue to exist.

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# 3.0 DESCRIPTION OF THE AFFECTED ENVIRONMENT

This section discusses the physical, biological, land use, and demographic characteristics of the FMPC site and vicinity which could potentially be affected by thorium handling activities. This description provides the basis for the impact assessment described in Section 4.0.

## 3.1 TOPOGRAPHY

The FMPC site is situated in the Great Miami River Basin at an elevation of approximately 180 meters above sea level. The present landscape is characterized by broad flat plains, rolling surfaces along glacial moraines, and low, rounded bedrock hills which protrude through glacial deposits. The Great Miami River and its tributaries have removed substantial volumes of the glacial fill and have formed elevated terraces along the river. The FMPC is located on one of these terraces above the river and its flood plain. The Great Miami River flows in a southerly direction about one kilometer east of the site.

The 425-hectare FMPC site is relatively level in the area of the production facilities but slopes upward north of the production area, rising to an elevation of 210 meters at the northern edge of the site. Natural drainage is in a westerly direction to Paddy's Run at an elevation of 170 meters. This small meandering stream flows from north to south through the western edge of the property and discharges to the Great Miami River (Figure 1-1).

## 3.2 GEOLOGY AND SOILS

The geology of much of southwestern Ohio consists of relatively flat lying Paleozoic sedimentary rocks overlain by glacial drift deposits. In the vicinity of the FMPC, bedrock consists of indurated shale interbedded with thin limestone units of Late Ordovician age. No major geologic structures are reported to be present in the area.

Prior to glaciation, this region of southwest Ohio was drained by the Hamilton River system which was over 3.2 kilometers wide and cut down approximately 60 meters into the bedrock. Pleistocene glacial deposits associated with the

Illinoian and Wisconsin glacial advances 100,000 to 400,000 years ago overlie the Paleozoic bedrock, filling in or covering preglacial topographic features.

Filling of the Hamilton River Valley with glacial outwash and till created extensive deposits and aquifers known as the "Hamilton Trough." The trough averages 3.2 kilometers in width and 45 to 60 meters in depth near the FMPC. The basal deposits in the Hamilton Trough consist of about 30 to 55 meters of sand and gravel glacial outwash. A continuous three- to six-meter thick "blue clay" layer occurs within the sand and gravel deposits forming the two sand and gravel aquifers discussed in Section 3.3.

The top of the clay layer separating the sand and gravel units at the FMPC is at a depth of approximately 38 meters. The uppermost six to 15 meters of the Hamilton Trough in the area of the FMPC consists of predominantly clay-rich till with local lenses of sand and gravel. Locally, sand and gravel deposits crop out at the surface.

The primary soil units present at the FMPC are the Fincastle Silt Loam, Henshaw Silt Loam, Ragsdale Silty Clay Loam, Xenia Silt Loam, Martinsville Silt Loam, Hennepin Silt Loam, and Genesee Loam. The Fincastle, Henshaw, and Ragsdale soils cover the majority of the site. These soils occur on relatively flat Wisconsin till plain surfaces and are composed of silty loam at the surface. The soils are poorly drained and are characterized by low permeability and seasonal wetness.

The Xenia and Martinsville soils occur in the southeastern portion of the FMPC. Xenia soils also occur along the north boundary. These soils are silt loams which are moderately well drained and have moderate permeability.

Hennepin and Genesee soils occur along Paddy's Run in the western portion of the site. Genesee soils consist of loam and sandy loam and occur in valley floors. Hennepin soils consist of silty loam and occupy slopes along margins of drainages.

## 3.3 GROUND WATER HYDROLOGY AND WATER QUALITY

Previous research of the geology and ground water hydrology of the FMPC has identified the presence of three aquifers: (1) the surficial till or perched aquifer, (2) the shallow sand and gravel aquifer, and (3) the deep sand and gravel aquifer (DOE, 1986a; Dames and Moore, 1985a, 1985b; and IT, 1986). The surficial clay-rich till layer discussed in Section 3.2 is characterized by saturated lenses of sand and gravel. These perched zones occur from 1.2 to 2.7 meters below the ground surface. The zones are probably laterally discontinuous and are unlikely to provide direct pathways for recharge to the lower two aquifers.

The two principal aquifers at the site are referred to as the shallow and deep sand and gravel aquifers. The shallow aquifer is approximately 23 meters thick and occurs below the clay-rich till. The deep aquifer, approximately 17 meters thick, occurs approximately 43 meters below the surface and is separated from the shallow aquifer by a three- to six-meter thick layer of "blue clay."

The shallow sand and gravel aquifer is unconfined throughout the area with depth to water being approximately 17 meters below the surface. Due to the presence of the semi-pervious "blue clay" bed, the deep aquifer is classified as a semi-confined or leaky-confined aquifer at the FMPC. The transmissivity of the shallow and deep sand and gravel aquifers is reported to range from $5.0 \times 10^{-3}$ to $4.3 \times 10^{-2}$ square meters per second ($m^2/s$). The hydraulic conductivity of these two aquifers is reported to range from 80 to 110 meters per day. Total porosity has been estimated at 25 to 35 percent (Dames and Moore, 1985a).

Between Paddy's Run and New Baltimore, ground water generally flows from northwest to south-southeast under the FMPC toward the Great Miami River. Ground water pumping at the FMPC and from industrial facilities east of the site may affect groundwater flow directions within the area.

The two sand and gravel aquifers qualify as a major ground water resource throughout the area. They are thought to be recharged with water over a large area and are not greatly affected by local precipitation. FMPC wells withdraw

an average of 1,325 cubic meters of water per day. Other major ground water users within 5.6 kilometers of the site include the Southwestern Ohio Water Company, the Cincinnati Bolten Plant, and the Southwestern Butler County Water Association. These three organizations cumulatively withdraw approximately 125,000 cubic meters of water per day.

As part of on-going environmental characterization programs at the FMPC, samples of ground water have been collected for chemical analyses from both the FMPC and the surrounding area. This program includes sampling and analyses of samples from 15 on-site wells and 22 off-site wells. Sampling of on-site wells is conducted to monitor the quality of ground water at the site in conjunction with Resource Conservation and Recovery Act (RCRA) ground water monitoring requirements. Recent sampling results of the ground water quality underlying and in the vicinity of the FMPC can be found in DOE, 1986a.

## 3.4 SURFACE WATER HYDROLOGY AND WATER QUALITY

Natural drainage from the FMPC site is toward Paddy's Run, an intermittent stream which runs from north to south along the western edge of the property (Figure 1-2). A storm sewer outfall ditch runs southward from the south central portion of the site to Paddy's Run at the south boundary. The surficial till or perched aquifer (Section 3.3) intersects Paddy's Run between Willey and New Haven roads. The exact location where Paddy's Run intersects the water table and becomes perennial varies seasonally.

Treated liquid waste, sewage, and some storm water flows from the FMPC to the Great Miami River through an underground pipe. This discharge is made in compliance with a National Pollution Discharge Elimination System (NPDES) permit. In addition, overflow from the storm sewer collection system is routed to Paddy's Run via the storm sewer outfall ditch described above (Figure 1-2).

Surface water samples have been collected for chemical characterization from both the FMPC site and surrounding area. Studies have indicated that the storm sewer outfall ditch is probably the primary pathway for uranium-bearing water to reach the shallow aquifer (Dames and Moore, 1985a) (Section 3.3). Water flowing into Paddy's Run from the Waste Storage Area (Figure 1-2) may also contribute uranium-bearing water (Dames and Moore, 1985a). Throughout

most of the site, the clay-rich till minimizes infiltration of surface water into the sand and gravel aquifer. However, the till thins out in the southern part of the FMPC, allowing increased surface water percolation into the ground.

## 3.5 CLIMATE

The FMPC area climate is basically continental with a wide range of temperatures. The area is subjected to frequent changes in the weather due to the passage of numerous cyclonic storms during winter and spring and the occurrence of thunderstorms during the summer.

Mean annual precipitation is 102 centimeters which is, generally, distributed evenly throughout any 12-month period. Monthly maximum precipitation of approximately ten centimeters occurs in May and July. Monthly minimum precipitation of approximately six and one-third centimeters occurs in February, October, and December. Over a 20-year period from 1960 to 1979, the average annual precipitation measured at the FMPC was 95.9 centimeters. Based on annual averaged data, the maximum recorded 24-hour storm event is 13.2 centimeters of precipitation. The heaviest precipitation, as well as the precipitation of the longest duration, is normally associated with low pressure disturbances moving in a general southwest to northeast direction through the Ohio valley south of the FMPC area.

Summers are warm and humid. The temperature may reach 40 degrees Celsius or more one year out of three. However, the temperature usually reaches 25 degrees Celsius or higher about 26 days each year. Winters are moderately cold with frequent periods of extensive cloudiness. The length of the freeze-free period is 190 days on the average. Freezing temperatures occur between late October and mid-April.

At the Greater Cincinnati International Airport, where climatic conditions closely approximate the FMPC site area, prevailing winds are from the south-southwest (toward the north-northeast) for all twelve months of the year. Average monthly wind speeds range from 10.8 kilometers per hour in August to 18.0 kilometers per hour in March. Channeling, airflow, and surface friction in the valleys reduce the wind speed and direct the airflow along the river

valleys, such as along the Great Miami River. A wind rose showing the wind direction frequencies and the average wind speeds for each direction is presented in Figure 3-1 (IT, 1986). [Meteorological data (DOC, 1985) used for dispersion modeling were provided by Oak Ridge National Laboratory and are summarized in Appendix A.]

The maximum wind velocity recorded at the airport was 64.4 kilometers per hour from the south-southwest. Wind records available for the FMPC show that there have been wind gusts in excess of 80.5 kilometers per hour on eleven occasions between 1960 and 1976; there have been gusts of up to 96.6 kilometers per hour on two occasions.

Ohio lies on the eastern edge of the area of the U.S. with the maximum tornado frequency, the center line of which extends from northern Texas to southwestern Iowa. During the 23-year period from 1953 to 1975, Ohio averaged about 13 tornados annually. During the 1900-1978 period, 15 tornados were observed in Hamilton County and eleven were seen in Butler County. Tornados may approach a location from any direction although about 90 percent come from the west through the southwest. Seventy percent of the tornados occur during April through July. The only tornado known to have touched the FMPC site occurred on May 10, 1969. There was no damage to the FMPC property, nor was there damage from another tornado which passed near the facility's northeast boundary on May 13, 1973.

## 3.6 AIR QUALITY

Air quality at and near the FMPC can be assessed for two regimes: (1) ambient air quality for the five criteria pollutants [sulfur dioxide ($SO_2$), nitrogen oxide ($NO_x$), carbon monoxide (CO), particulates, and ozone], and (2) ambient air quality for radionuclides and radon gas. Extensive air quality data have been collected at the site.

Of the criteria pollutants, atmospheric emissions of concern at the FMPC are particulates, $SO_2$, and $NO_x$. The performance of electrostatic precipitators at the FMPC boiler plant, the only existing stationary source, indicates the facility is in compliance with the Ohio Sulfur Oxide Standards (Ohio EPA, 1980). Coal having a sulfur content low enough to meet applicable stack

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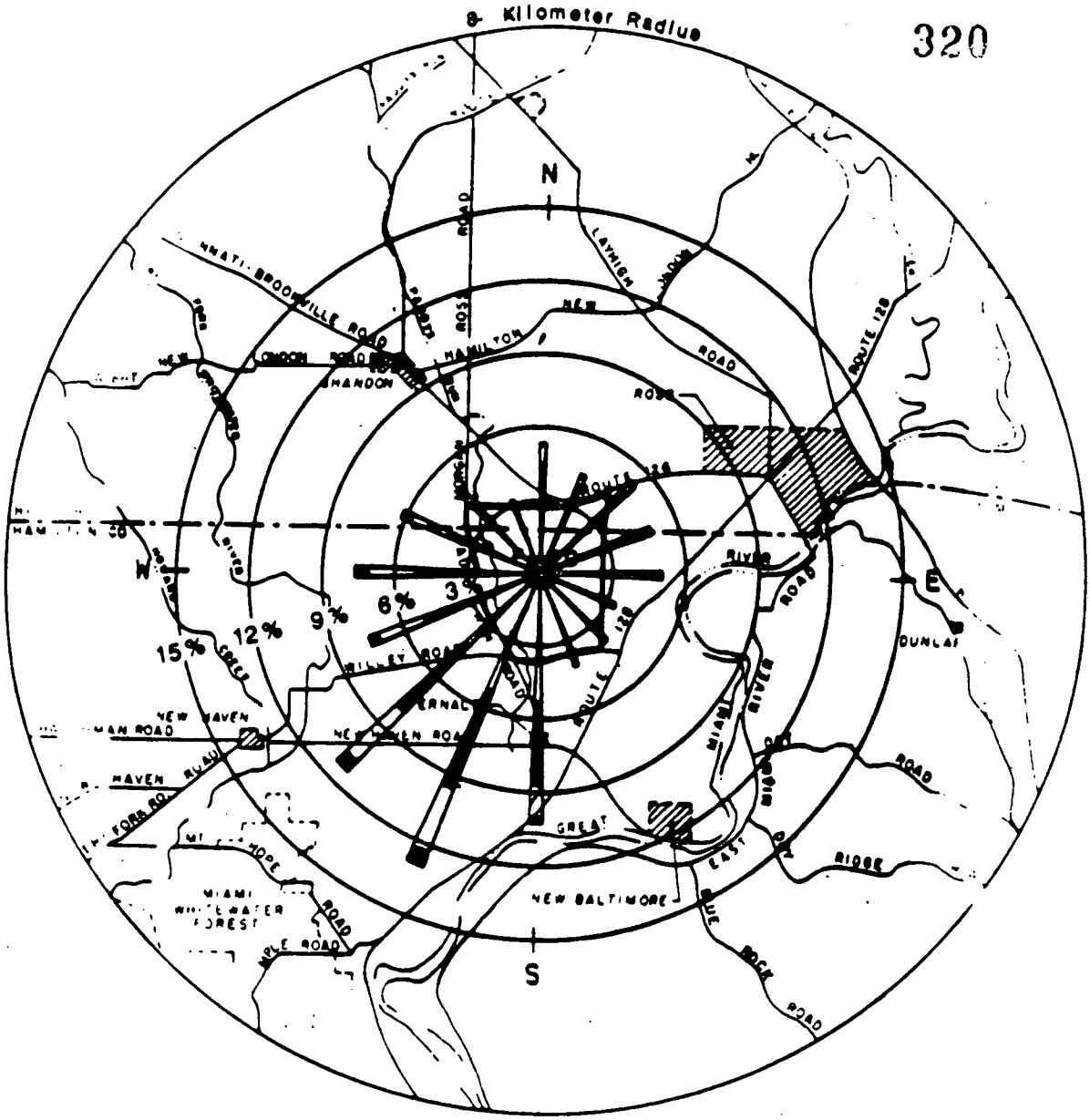

SCALE

0 1800 3600 Meters

LEGEND

2-6 7-11 12-19 20-30 31-39 > 39

WIND SPEED CLASSES
Km/Hr

FIGURE 3-1

WINDROSE FOR GREATER CINCINNATI INTERNATIONAL AIRPORT (1958-1962, 1970-1974) SUPERIMPOSED ON FMPC SITE

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emission standards for $SO_2$ is used in the boiler plant. The gaseous effluent of most concern is $NO_x$. Because there is no established federal or state limit for $NO_x$ emissions, a clear stack criterion has been established as an objective for all production operations that generate $NO_x$.

The Hamilton County-Butler County area is an attainment area for all criteria pollutants except ozone and carbon monoxide. The ozone nonattainment status is due in large part to automobile emissions and, to a lesser extent, industry hydrocarbon emissions. An inspection and maintenance program is to begin in the near future. FMPC emissions do not contribute significantly to ozone ambient concentrations. The CO nonattainment status may be changed to attainment status in the near future following review of additional data by the Ohio EPA.

Ambient monitoring data for criteria pollutants in the FMPC area are extremely sparse. Review of Hamilton County-Southwest Ohio Air Pollution Control Area (APCA) data indicates there are no monitoring stations near Fernald in the general downwind direction (northeast of the plant). The closest monitoring station is at Miamisburg which is over 48 kilometers northeast of the site.

Conversion of impure uranium and thorium compounds to reactor-grade feed materials at the FMPC involves operations which generate radioactive particulates and reaction products in an air stream. Before release to the atmosphere, this air is filtered or scrubbed. Future projects include systems to monitor the air as it is released to the atmosphere.

Air quality monitoring is conducted at seven FMPC boundary Air Monitoring Stations. The locations of these Air Monitoring Stations (AMS) are shown in Figure 1-2. Particulate samples are collected weekly for a 168-hour sampling period at an air flow rate of about one cubic meter per minute on 20- by 25-centimeter glass fiber filters. The filters are analyzed for gravimetric particulate loading, gross radioactivity, and specific radionuclides.

Five-year average concentrations (1981-1985) of particulate emissions, gross alpha radioactivity, and Th-232 are summarized in Table 3-1. These results indicate that releases at the FMPC site boundary are well within the "safe" levels established by regulatory agencies.

## 3.7 VEGETATION, WILDLIFE, AND AQUATIC ECOSYSTEMS

This section provides a description of vegetation, wildlife, and aquatic ecosystems in the general vicinity of the FMPC. A discussion of rare, threatened, or endangered species is also provided. Detailed information on FMPC site ecology is available in a three-volume report, "Biological and Ecological Site Characterization of the Feed Materials Production Center," prepared by Miami University of Ohio.

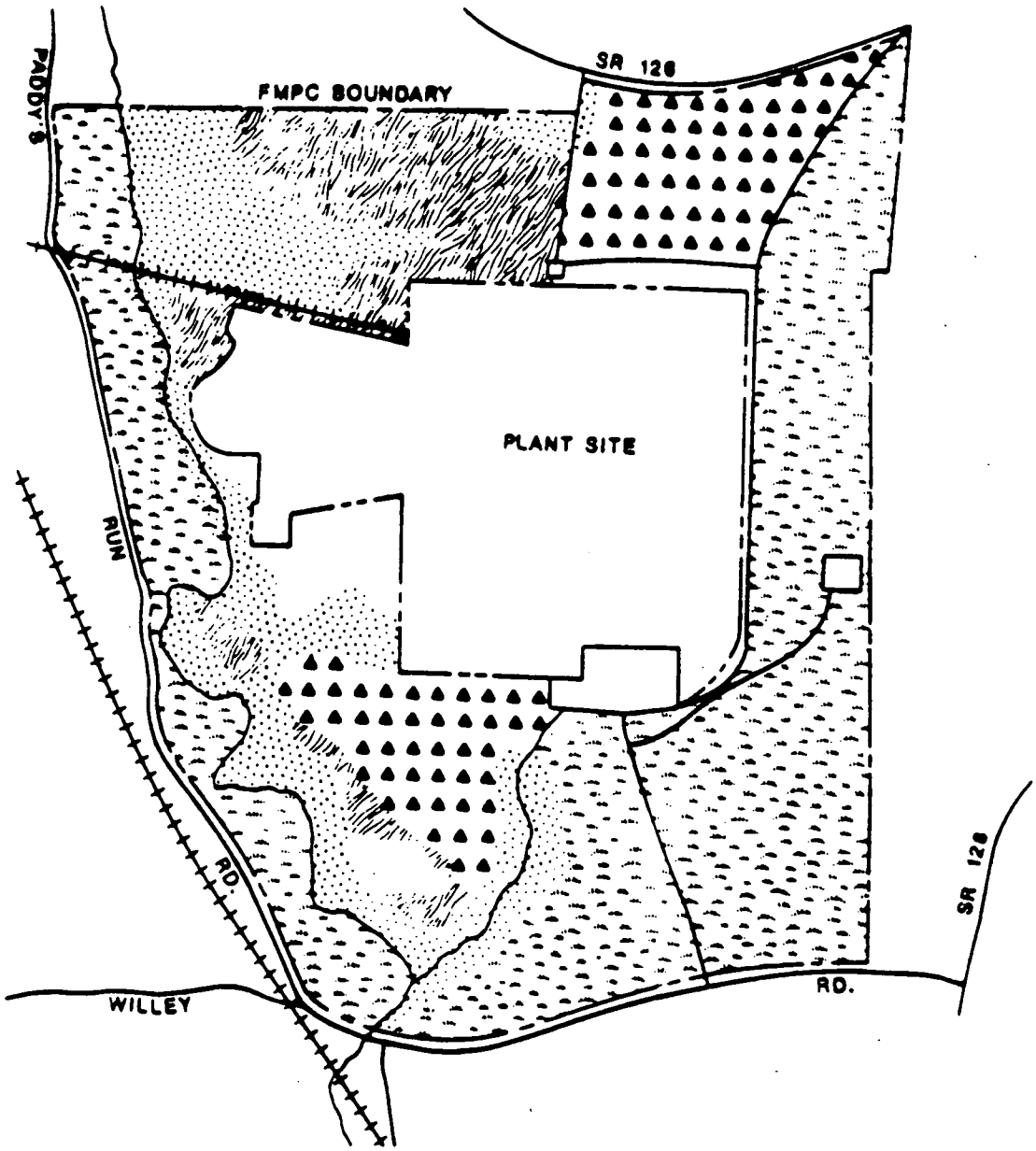
TABLE 3-1

| SAMPLING LOCATION | RADIONUCLIDE FIVE-YEAR AVERAGE CONCENTRATION microcuries per cubic meter ($Bq/m^3$) GROSS α | | $Th^{232}$ | | AIR PARTICULATE (micrograms per cubic meter) |
|---|---|---|---|---|---|
| BS-1 | $6.0\times10^{-9}$ | ($2.2\times10^{-4}$) | $2.7\times10^{-11}$ | ($1.0\times10^{-6}$) | 36 |
| BS-2 | $4.3\times10^{-9}$ | ($1.6\times10^{-4}$) | $2.2\times10^{-11}$ | ($8.1\times10^{-7}$) | 38 |
| BS-3 | $6.8\times10^{-9}$ | ($2.5\times10^{-4}$) | $6.0\times10^{-11}$ | ($2.2\times10^{-6}$) | 37 |
| BS-4 | $2.2\times10^{-9}$ | ($8.1\times10^{-5}$) | $2.3\times10^{-11}$ | ($8.5\times10^{-7}$) | 44 |
| BS-5 | $3.8\times10^{-9}$ | ($1.4\times10^{-4}$) | $2.2\times10^{-11}$ | ($8.1\times10^{-7}$) | 43 |
| BS-6 | $3.2\times10^{-9}$ | ($1.2\times10^{-4}$) | $1.7\times10^{-11}$ | ($6.3\times10^{-7}$) | 40 |
| BS-7 | $1.7\times10^{-9}$ | ($6.3\times10^{-5}$) | $1.3\times10^{-11}$ | ($4.8\times10^{-7}$) | 38 |
| Average Total | $3.8\times10^{-9}$ | ($1.4\times10^{-4}$) | $2.6\times10^{-11}$ | ($9.7\times10^{-7}$) | 39 |
| Standard Limit | --- | --- | $7\times10^{-9}$ (1) | ($3.0\times10^{-4}$) (1) | 75 (2) |

(1) DOE, 1987.
(2) State of Ohio Ambient Air Quality Standard (OEPA, 1980).
From FMPC Environmental Monitoring Annual Reports, 1981-1985.

### 3.7.1 Vegetation

The FMPC is part of a larger landscape mosaic comprised of several habitat types: woodlands (deciduous and coniferous); riparian; agricultural land in pasture or crops; and developed land. These habitat types are typical of southwest Ohio and the FMPC vicinity. The vegetation types occurring with the FMPC site boundary are illustrated in Figure 3-2.




LEGEND

- PASTURE
- MOWED GRASS
- PLANTED TREES
- WOODS
- SCRUB

FIGURE 3-2

VEGETATION TYPES
OCCURRING AT FMPC PLANT SITE

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Woodlands in the vicinity of the FMPC are typically located along streams and rivers and on steep slopes, or they are woodlots set in a matrix of agricultural land. Woodlands in this portion of Ohio are dominated by deciduous tree species.

Agricultural land in the vicinity of the FMPC is in pasture or crops. Crops grown in this area include soybeans, corn, wheat, vegetables, and hay. Pasture land vegetation is dominated by grasses and early successional and ruderal forbs. Fence rows separate many agricultural fields.

Developed land in the vicinity of the FMPC is primarily residential and typically consists of maintained lawn and planted horticultural and ornamental species. Other than the FMPC, little land in the immediate vicinity is in industrial use.

The 425-hectare FMPC site has several habitats occurring within its boundaries: deciduous woodlands, coniferous woodlands, riparian woodlands, pasture, scrub, and developed land (Figure 3-2). Total woodlands occupy 162 hectares on the site and are in various successional stages and subject to occasional disturbance in the form of cattle grazing and "bush hogging" to clear understory vegetation. The successional age of the woodlands and the severity and frequency of disturbance in these areas have influenced their composition and structure. The youngest deciduous woodlands are dominated by shellbark hickory (*Carya lacinosa*) and white ash (*Fraxinus americana*). Other common species are hackberry (*Celtis accidentalis*), black cherry (*Prunus serotina*), boxelder (*Acer negundo*), and American elm (*Ulmus americanus*). The canopy of these woodlands does not exceed 20 meters in height.

More mature woodlands also exist on the site. These areas most closely resemble a mature forest in terms of species composition, canopy cover, and canopy height. The canopy of these woodlands is approximately 24 meters high with over 80 percent cover. The dominant species are sugar maple (*Acer saccharinum*) and boxelder. Other common species are black walnut (*Juglans nigra*), Ohio buckeye (*Aesculus glabra*), and American elm. The shrub layer is dominated by sapling sugar maple and Ohio buckeye.

Coniferous woodlands (pine plantations), planted in 1972, exist on site in two locations. Both areas consist of planted white pine (Pinus strobus) and Austrian pine (Pinus nigra).

Riparian woodlands border Paddy's Run. The dominant species of this habitat type are eastern cottonwood, hackberry, American elm, and boxelder. Other common species are black walnut, Ohio buckeye, and American sycamore (Platanus accidentalis). Shrub layer species include boxelder hackberry, poison ivy, and trumpet creeper. Common herbaceous species are red fescue and goldenrod.

Land currently or recently used as pasture to graze dairy cattle occupies approximately 200 hectares of the FMPC. The vegetation of this habitat is dominated by red fescue. Other grasses such as timothy and Kentucky bluegrass are also present.

Developed land at the FMPC occupies approximately 63 hectares. Little vegetation exists in this portion of the site.

### 3.7.2 Wildlife

Wildlife populations at the FMPC and surrounding area are typical of those is southwestern Ohio where the land is a mixture of agricultural lands, woodlands, and developed land. This type of landscape creates large amounts of "edge" and "corridor" habitat which support the highest diversity of wildlife. These areas provide cover and denning areas for species which often range into other habitats during foraging activities. Two species of owls have been observed wintering on site: the eastern screech owl (Otus asio) and the great horned owl (Bubo virginianus).

The most common species of native mammals at the FMPC site and vicinity are white-tailed deer, eastern cottontail, fox squirrel, white-footed mouse, eastern chipmunk, woodchuck, and raccoon. The most abundant small mammal in the woodland areas on site is the white-footed mouse (Peromyscus leucopus noveboracensis). The house mouse (Mus musculus) is found throughout the entire region, but the species was not collected on site during the Miami University investigations. The on-site white-tailed deer population, which is concentrated in the on-site pine plantations, has an estimated herd size of 16

to 18 individuals. This concentration of deer is typical of this region of Ohio.

Avian populations also had the highest diversities in the woodland areas. The most common summer species that have been observed are yellow-billed cuckoo (Coccyzus americanus), blue jay (Cyanocitta cristata), Carolina chickadee (Parus carolinensis), and American robin (Turdus migratorius). The most common winter species include Carolina chickadee, dark-eyed junco (Junco hyemalis), American goldfinch (Carduelis tristis), northern cardinal (Cardinalis cardinalis), and song sparrow (Melospiza melodia).

The most common avian species to utilize agricultural land at the FMPC during the summer months are eastern meadowlark (Sternella magna), red-winged blackbird (Agelaius phoeniceus), and European starling (Sturnus vulgaris). In addition, the Savannah sparrow (Passerculus sandwichensis) has been observed utilizing the site for breeding. This is unusual because the Savannah sparrow does not normally breed in southwestern Ohio.

Certain mammalian species rely on agricultural land as a major food source. Such animals as racoon, woodchuck, and white-tailed deer range into these areas of the FMPC.

Wildlife utilizes developed land to a limited extent within the FMPC and the surrounding area. Certain mammalian species, such as opossum and raccoon, have habitats which encroach into developed areas. Numerous bird species, including starling, house sparrow, common grackle, mourning dove, and American robin, utilize developed sites in the area as feeding and nesting areas.

### 3.7.3 Aquatic Ecosystems

The aquatic environment of the FMPC is dominated by one intermittent, third order stream--Paddy's Run. Paddy's Run flows north to south along the FMPC's western boundary. The northern section is steeply graded and characterized by relatively high stream velocities and a rock/cobble substrate. The southern stretch, a depositional area due to its low stream gradient, is periodically dry from July to October. Paddy's Run eventually flows into the Great Miami River approximately three kilometers south of the FMPC site. Water in this

stretch of the Great Miami River has high nutrient and ammonia concentrations and low dissolved oxygen due to municipal and industrial wastewater discharges into the river.

Fish

Paddy's Run maintains a relatively diverse and abundant fish population. While data on fish populations in off-site streams are limited, the populations are expected to be the same or similar species composition as Paddy's Run. A total of thirteen species of fish have been identified. This community is dominated by juvenile cyprinids and percids. Dominant species found during the Miami University study (Osborne et al., 1987) were the creek chub (Semotilus atromaculatus) and the bluntnose minnow (Pimephales notatus).

The orangethroat darter (Etheostoma spectabile) has also been identified as being dominant (Battelle, 1981). This species was commonly found during the Miami University study of Paddy's Run but was not found to be dominant. Differences in composition are probably attributable to differences in sampling intensity between the two studies. Other species commonly found in Paddy's Run reportedly include the stoneroller minnow (Campostoma aniomalum), rosefin shiner (Notropis ardens), Johnny darter (Etheostoma nigrum), and fantail darter (Etheostoma spectabile).

Distribution of fish species in the stream is dependent upon the physical microhabitats available, e.g., riffles or pools. White suckers, (Catostoma commersoni) silverjaw minnows, (Ericymba commersoni) rosefin shiners, and Johnny darters were found to be rare or absent from riffle areas but common in pools. Conversely, fantail darters were found to be common only in riffles.

Benthic Invertebrates

A total of 44 taxa of benthic invertebrates have been identified as existing in the stretch of Paddy's Run that flows through the FMPC site, immediately upstream (100 meters) and immediately downstream (100 meters). Four taxa were identified as being dominant in the Fall/Winter survey conducted during the Miami University study (Osborne et al., 1987): midges (Chironimidae), riffle beetle (Stenelmis sp.), mayfly (Caenis sp.), and stonefly (Allocapnia sp.). Seven other taxa were also commonly found throughout the stream: the mayfly

(Stenonema bopunctatum), the isopod (Lirceus fontinalis), the caddisfly (Cheumatopsyche sp., Hydropsyche sp.), the segmented worm (Oligochaeta), the stonefly (Nemouridae), and the blackfly (Simulium sp.).

Caddisflies (Trichoptera) were the dominant taxa during the Summer (Battelle, 1981). Cheumatopsyche sp. was the most dominant species. Hydropsyche sp. and Chimaera sp. were also commonly found. Differences between the two studies are believed to be attributable to seasonal variations and differences in sampling intensities.

The abundance, types of species present, and species diversity in Paddy's Run appears to be typical of streams in southwestern Ohio. Similar benthic invertebrate communities have been documented in other studies (Osborne et al., 1987). Differences in both the number of taxa and the mean macroinvertebrate densities found along Paddy's Run appear to be attributable to natural variations in stream flow.

### 3.7.4 Threatened and Endangered Species

No federally endangered plant or animal species are known to exist at or in the vicinity of the FMPC. However, three species of birds that appear on the "Rare Species of Native Ohio Wild Animals" list (DNAP-ODNR, 1982) have been observed on site. A red-shouldered hawk (Buteo lineatus) was seen flying over the site during the Winter months of 1986-87. This species is listed as an uncommon breeder in the region and as a threatened breeder in Ohio. A northern harrier (Circus cyaneus) was sighted flying over the site in June 1986, although the bird was observed only once. It was presumed to be either a late migrating individual or an individual nesting off site. Cooper's hawks (Accipiter cooperii) were sighted on numerous occasions during the Summer and Winter of 1986-1987. Thus, the Cooper's hawks may have been breeding on site or, at least, utilizing habitats within the boundaries of the FMPC. The Cooper's hawk is listed as an uncommon but regular breeder in the region, a threatened breeder in Ohio, and an uncommon to common Fall migrant and Winter resident.

## 3.8 CULTURAL RESOURCES

The FMPC region has been extensively investigated for both historic and prehistoric (archeological) cultural resources. As a result, there are seven sites on the National Register of Historic Places within an 8.0 kilometer radius of the FMPC: two archeological districts, one historical district, two burial mounds or earthworks, and two historic structures (Figure 3-3). The archeological sites are associated with the Late Archaic Period (ca. 4000 to 1500 B.C.) and the Early Woodland Period (ca. 1500 B.C. to A.D. 100). Historic sites include the Whitewater Shaker Village which is situated about eight kilometers west of the FMPC.

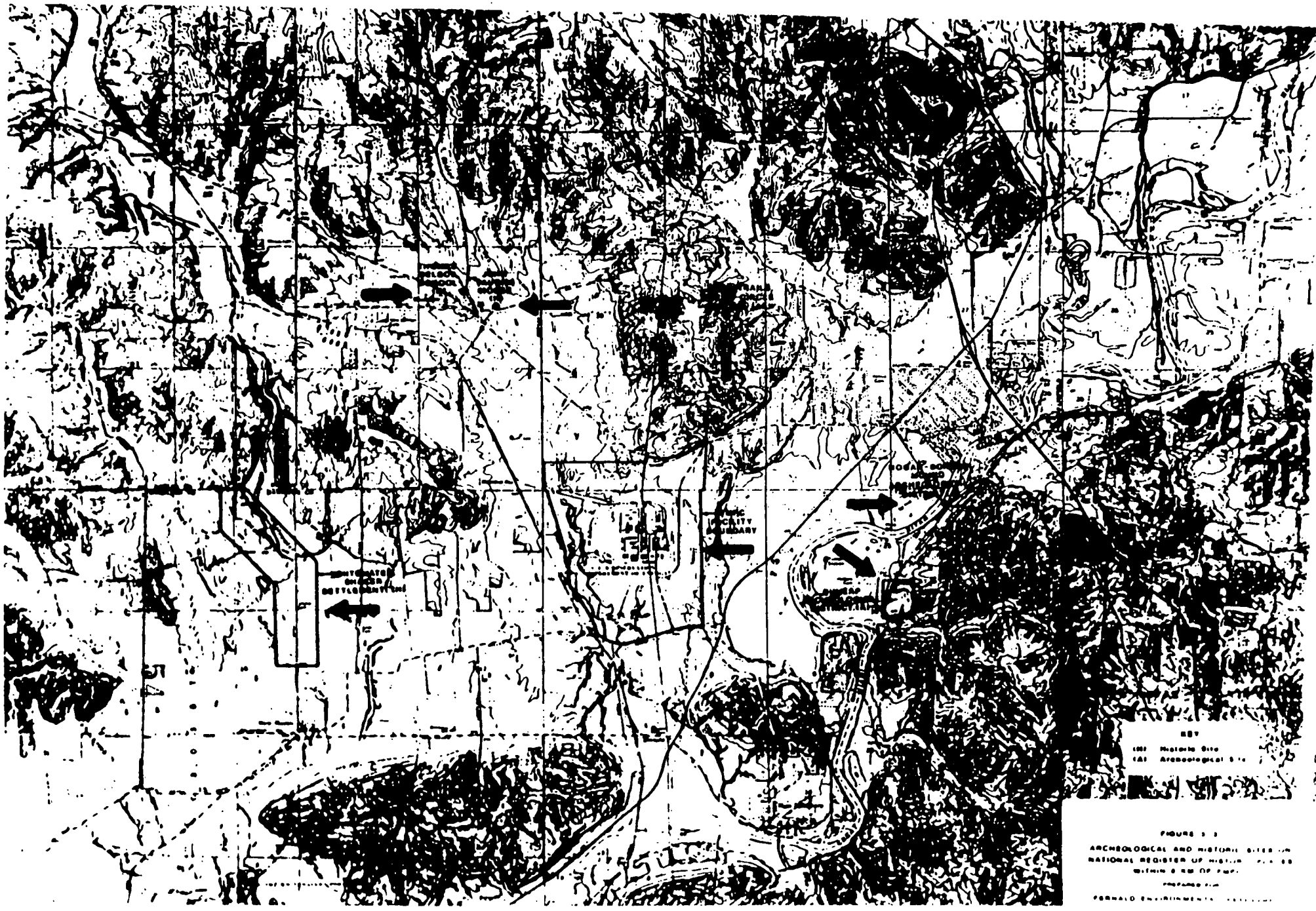
The Miami Purchase Association for Historic Preservation conducted a reconnaissance level survey of the New Haven Trough area in the Spring of 1985 (Genheimer and Gatus, 1986). This investigation, which covered a 10,000,000 square meter area south and west of the FMPC, did not identify any sites eligible for inclusion on the National Register. However, Crosby Township has 240 surveyed historic properties including: Whitewater Shaker Village (10); New Haven (27); Fernald (11); and New Baltimore (11).

## 3.9 DEMOGRAPHY AND LAND USE

The FMPC is located in a rural area of northwestern Hamilton County and southwestern Butler County, approximately 32 kilometers northwest of downtown Cincinnati (Figure 1-1). Approximately the northern 30 percent of the property is in Butler County (Figure 1-1).

The 1984 estimated population for Hamilton County was 863,989; the estimated population for Butler County was 265,458. Hamilton County population decreased by 1.1 percent from 1980 to 1984 while Butler County population increased by 2.6 percent during the same period. Fernald and New Baltimore in Hamilton County and Shandon and Ross in Butler County are the communities closest to the FMPC site.

The population of the seven small communities nearest the FMPC, and their approximate distances from the site, are as follows:


KEY
Historic Site
Archaeological Site
FIGURE
ARCHEOLOGICAL AND HISTORIC SITES IN
NATIONAL REGISTER OF HISTORIC
WITHIN 5 KM OF FEMP
PREPARED FOR
FERNALD ENVIRONMENTAL

| COMMUNITY | 1980 ESTIMATED POPULATION | APPROXIMATE DISTANCE FROM FMPC (kilometers) |
|---|---|---|
| Fernald | 50* | 2.5 |
| Shandon | 200* | 4 |
| Ross | 2,767 | 3.5 |
| New Baltimore | 710 | 4 |
| New Haven | 300* | 5 |
| Harrison | 5,855 | 10.6 |
| Miamitown | 1,559 | 8.1 |

*These are rough estimates only because population data are available on a "neighborhood" basis. Fernald and New Haven are part of the West Crosby Township neighborhood with a 1980 population of 1,760.

The land surrounding the FMPC is primarily used for pasture land and cultivated crops (Section 3.8.1). There are several small, scattered subdivisions north and northeast of the site.

The nearest public park or resource area is the 823-hectare Miami Whitewater Forest located approximately eight kilometers southwest of the FMPC site in northwest Hamilton County (Figure 1-1). Other recreational areas near the plant site include: Fort Scott Camps, 3.2 kilometers southeast of the FMPC, owned by the Archdiocese of Cincinnati; and Camp Ross Trails, a Girl Scouts of America camp located about 1.8 kilometers to the northeast.

Other than the Chesapeake and Ohio Railroad which runs along the west boundary, there are no major transportation arteries in the immediate vicinity of the FMPC site. Interstates 275 and 74 traverse the area east to west about 8.8 kilometers south of the FMPC (Figure 1-1).

## 3.10 OTHER ENVIRONMENTAL PARAMETERS

Due to the nature of the proposed action and alternatives, description of the environmental parameters of noise, traffic, employment, and visual resources were not considered necessary for the impact assessment.

# 4.0 ENVIRONMENTAL CONSEQUENCES

This section examines the potential environmental consequences associated with the proposed action and the alternatives for the removal and repackaging of thorium material currently stored at the FMPC Plant 8. The assessment was accomplished by defining potential radiological and nonradiological releases and release pathways, calculating the resulting exposure or contaminant levels, and assessing the resulting impacts to health, safety, and the environment. Both routine operations and potential accidents were considered in the assessment. Section 4.1 defines the basis and methods for the assessment, Sections 4.2 through 4.4 evaluate releases, exposures, and impacts resulting from routine operation and postulated accidents, Section 4.5 examines the environmental impacts of the alternatives, and Section 4.6 provides a comparative summary of the environmental consequences of each. It should be pointed out that exposures resulting from releases of radiological or nonradiological contaminants to air, water, or land are not the equivalent of environmental impacts. For the purpose of this EA, environmental impacts are evaluated as adverse human health effects or as effects adverse to natural ecosystems.

## 4.1 ASSESSMENT BASIS AND METHODOLOGY

In addition to the physical and operational descriptions provided in Sections 1.0 and 2.0, the impact assessment required that certain characteristics of the thorium material be known or estimated. Based on this information, releases during routine operations and under postulated accident conditions were approximated. The impacts of such releases on human health and the environment were then calculated using appropriate modeling methods.

### 4.1.1 Thorium Material Inventory Characteristics

The estimated volume of thorium material currently stored in the silo and bin is 227 cubic meters: 82 cubic meters in the silo and 145 cubic meters in the bin. Physical sampling and radiation measurements were performed to characterize the thorium material in its current storage configuration. Thorium characterization information pertinent to this assessment is summarized below.

#### Silo

The material in the silo is known to contain thorium oxide, thorium hydroxide, and diatomaceous earth. The thorium material level is 4.6 meters from the top

of the silo. Additional physical thorium material characteristics are as follows:

- Estimated volume is 82 cubic meters
- Density ranges from 3.3 grams per cubic centimeter at the top of the silo to 6.4 grams per cubic centimeter at the cone-cylinder junction (determined by ultrasonic testing)
- Particle size at the top of the silo is within the 10- to 20-mesh size range (2,000 to 1,000 microns)
- Samples from the top of the silo contained 82 percent Th-232 by weight
- Direct radiation exposure readings taken from the ladder at the side of the silo were reported to range from 7.0 to 37.0 milliroentgens per hour. For gamma radiation, this direct radiation level is equivalent to an absorbed dose rate of 7.0 to 37.0 millirem per hour (0.07 to 0.37 millisieverts). The maximum direct contact reading at the cone-cylinder junction was reported to be 55.0 milliroentgen per hour or an equivalent gamma dose rate of 55.0 millirem (0.55 millisieverts) per hour)
- Direct radiation measured at ground level below the silo has been reported to be 2.0-3.0 milliroentgens per hour, or an equivalent gamma dose rate of 2.0-3.0 millirem (0.02-0.03 millisieverts) per hour
- Ambient thoron daughter concentrations downwind from the top of the silo have been measured at 71 working levels and, in the upwind direction, at 2.7 working levels.

If the average of the measured densities is assumed to be a uniform average density, the total mass of Thorium-232 is estimated to be $3.3 \times 10^5$ kilograms having a total radioactivity of 36 curies. This estimate is conservative, since the density of thorium in the silo is believed to be closer to the lower value measured at the top of the silo.

Bin

The material contained in two compartments of a common bin structure are known to contain a wide variety of thorium compounds, including thorium oxide, thorium hydroxide, and some refuse in the form of rags. The storage bin is located within 15 meters of the silo. The top of the bin extends five meters

above the roof of Plant 8 and its bottom rests inside the building above the third floor level. The bin is divided into two separate compartments. Compartment A (located on the west side) represents about one third of the total bin volume (74 cubic meters) with Compartment B occupying the remainder (150 cubic meters). The material is 1.4 meters below the top of Compartment A and 2.3 meters below the top of Compartment B. Pertinent physical characteristics of the thorium material stored within the bins are presented below:

- Total volume of thorium material stored in compartments A and B is 56 and 89 cubic meters, respectively
- Density measurements range from 0.69 grams per cubic centimeter at the top of the bin to 3.0 grams per cubic centimeter at the bottom of the hopper (roof-line). As with the silo, density is variable throughout the bin but generally increases toward the bottom
- Samples taken from the top of Compartment A contained about 38 percent thorium material by weight. For Compartment B, the weight percent thorium is about 41 percent
- External direct radiation levels measured at the bins were reported at 11.0 to 24.0 milliroentgens per hour, or a gamma equivalent dose rate of 11.0 to 24.0 millirem (0.11 to 0.24 millisieverts) per hour. Contact readings at the bin-hopper junction were reported to be 45.0 milliroentgens per hour, or a gamma equivalent dose rate of 45.0 millirem (0.45 millisieverts) per hour
- Ambient thoron daughter concentrations at the top of the bin range from 0.15 to 0.44 working levels.

The total mass of thorium-232 was similarly conservatively estimated using an average of minimum and maximum measured densities to be $1.1 \times 10^5$ kilograms, with a total activity of 11.8 curies.

For the purpose of developing source terms (amount of radioactive material released in becquerels) associated with routine and accidental releases, the following conservative assumptions were made:

- The thorium material is assumed to be Th-232 in oxide form
- For purpose of radiological analysis, airborne particulates are assumed to be represented by a particle size of 0.3 microns.

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4.1.2 Dose Assessment Methodology

Potential releases of thorium associated with the proposed action and alternatives during routine operations and credible accidents were evaluated. Release source terms and pathways to the environment were based on conservative assumptions or, where available, site specific data. Evaluations of hazards to workers were based on design criteria that have been established for the proposed action (WMCO, 1986) and on best industry practice. Accident assessments were based upon "worst case" conditions in the absence of known parameters. The dose assessment methodology and assumptions are detailed in Appendix A and are summarized below.

From the description of the proposed action and alternatives presented in Section 2.0, airborne releases were identified as the principle environmental pathway of concern. Pathways to ground water, surface water, and soil were concluded to be inconsequential. The computer model AIRDOS.EPA, recommended by both the U.S. Environmental Protection Agency (EPA) and the DOE, was employed to calculate doses and evaluate resulting environmental consequences. This model utilizes meteorological data (taken from the Greater Cincinnati International Airport weather station), demographic data, release geometry, and local agricultural use data to project radiation doses to the human population within 80 kilometers of the site.

Dose assessment for routine operations was accomplished by applying annual average meteorological conditions to the postulated releases and calculating the resulting air concentrations and surface contamination levels in all directions and at various distances from the FMPC site. The radiological exposure was then calculated by summing the exposures from all potential pathways. The modes of exposure from airborne releases that were considered in the dose-to-man calculations include the following pathways: (1) direct radiation due to immersion in air, (2) exposure to contaminated ground surfaces, (3) inhalation of contaminated air, (4) immersion in water such as by swimming, and (5) ingestion of contaminated drinking water and food grown on contaminated land. To assess the maximum exposure to a member of the public, a hypothetical individual was assumed to reside at the FMPC site boundary at the point where the maximum annual average concentration would occur for

releases from the FMPC Plant 8. This location would not correspond to the point of maximum annual average concentration for FMPC site-wide releases identified in FMPC environmental monitoring annual reports.

Accident assessments were accomplished in a similar manner but assumed stable meteorological conditions which allow little dispersion of a release, in order to maximize the resulting hypothetical dose to man. The wind direction was selected to correspond with the closest FMPC site boundary to FMPC Plant 8. The receptor for accident assessments was assumed to be a hypothetical member of the public who remained at that site boundary location and at the center line of the release plume for the duration of each postulated accident.

## 4.2 PROPOSED ACTION ROUTINE OPERATIONAL CHARACTERISTICS

The proposed action involves thorium removal, repackaging, and handling activities with subsequent decontamination and decommissioning of the silo and bin (Section 2.0). Releases may result from airborne particulates, liquid effluents, or the generation of solid waste. Expected quantities for each of these pathways are discussed below.

### 4.2.1 Radiological Releases to Air

Thorium removal operations from both the silo and the bin are likely to release small quantities of thorium particulates to the atmosphere even with all environmental control systems in place and operating. As discussed in Section 2.1.4, design criteria established for the proposed activity to protect human health and the environment specify that the thorium emissions to the on-site environment be less than $5.4 \times 10^{-8}$ microcuries per milliliter ($2.0 \times 10^{-3}$ becquerels per milliliter) of alpha radioactivity (WMCO, 1986). Assuming that all releases are controlled to meet these environmental criteria, and using an average ventilation air flow rate of 45 cubic meters per minute over the 26-week project duration, it can be calculated that 1.3 microcuries ($4.7 \times 10^{4}$ becquerels) of Th-232 may be released to the atmosphere over the 26-week project duration. The maximum resulting off site concentration is calculated to be $2.1 \times 10^{-18}$ microcuries per milliliter ($7.9 \times 10^{-14}$ becquerels per milliliter). For comparison, this concentration is a small fraction of the Derived Concentration Guide for Th-232 in air of $7 \times 10^{-15}$ microcuries per milliliter ($3 \times 10^{-10}$ becquerels per milliliter) (Vaughn, 1985).

As discussed in Section 2.1.4, airborne radioactivity concentrations inside the operational area will be monitored and procedurally limited to $5.4 \times 10^{-13}$ microcuries per milliliter ($2 \times 10^{-8}$ becquerels per milliliter) of alpha radioactivity averaged over a 40-hour work week. Internal exposure to workers was evaluated on the basis of this average air concentration.

### 4.2.2 Nonradiological Releases to Air

Small quantities of criteria pollutants (CO, $NO_2$, $SO_2$, and particulates) may be emitted to the atmosphere from the use of diesel powered equipment. Maximum concentrations resulting from these emissions are shown in Table 4-1. Specialized equipment which may be employed during the course of the proposed action include: a boom truck or crane to lower repackaged thorium containers to the ground; a fork lift for conveying containers to an interim storage area; and an air compressor and/or diesel generator to assist in the thorium removal or decontamination and decommissioning operations. The combined criteria pollutant emissions calculated using standard emission factors for this type of equipment (EPA, 1984) over the expected use duration are: 615 kilograms of CO; 2,850 kilograms of $NO_2$; 190 kilograms of $SO_2$; and 391 kilograms of particulates.

TABLE 4-1
MAXIMUM AIRBORNE CONCENTRATIONS NONRADIOLOGICAL EMISSIONS

| POLLUTANT | AVERAGING PERIOD | CONCENTRATION (micrograms per cubic meter) | NAAQS LIMIT[1] (micrograms per cubic meter) |
|---|---|---|---|
| Sulphur Dioxide ($SO_2$) | Annual | 0.5 | 80 |
| | 24-hour | 0.7 | 365 |
| | 3-hour | 1.5 | -- |
| Nitrogen Dioxide ($NO_2$) | Annual | 2.5 | 100 |
| Carbon Monoxide (CO) | 8-hour | 3.7 | 10,000 |
| | 1-hour | 5.3 | 40,000 |
| Particulate Matter (TSP) | Annual | 0.004 | 75 |
| | 24-hour | 0.015 | 260 |

[1] 40 CFR Part 50, National Ambient Air Quality Standards (Primary).

### 4.2.3 Radiological and Nonradiological Releases to Land

Removal of thorium material from the silo and bin will create low-level, low-specific activity radioactive waste in the form of disposed protective clothing, rags, and used filters. The total volume of this uncompacted waste generated over the course of the proposed action is estimated to be 8.6 cubic meters. Debris from the dismantling of structures and related equipment may also contribute some low-level radioactive waste volume if decontamination to the unrestricted use criteria cannot be met. All low-level radioactive waste will be managed in accordance with applicable DOE requirements (DOE, 1984). Nonradioactive solid waste generated as a result of the proposed action (this includes portions of the silo, bin, and other related equipment), which has been decontaminated to meet the unrestricted use criteria, will be disposed at a sanitary landfill or sold as scrap.

### 4.2.4 Releases to Surface Water

There are three potential pathways by which thorium could enter surface waters: (1) surface deposition of airborne particulates, (2) run-off of precipitation (rain or snow) from the current thorium storage area to off-site areas, and (3) spills of decontamination water used to clean the silo, bin, and related equipment.

Possible surface water concentrations resulting from surface deposition of airborne thorium particulates (Table 4-2) would be insignificant. The maximum total surface deposition of Th-232 during routine operations has been calculated to be $2.1 \times 10^{-7}$ microcuries per square meter ($7.9 \times 10^{-3}$ becquerels per square meter). Assuming an average mixing depth in nonflowing water at one meter results in a surface water concentration of $2.1 \times 10^{-13}$ microcuries per milliliter ($7.9 \times 10^{-9}$ becquerels per milliliter). This is far below the derived concentration guide for Th-232 in water allowable concentration of Th-232 in water of $5 \times 10^{-8}$ microcuries per milliliter ($2.0 \times 10^{-3}$ becquerels per milliliter) (Vaughn, 1985).

TABLE 4-2
MAXIMUM AIR CONCENTRATION AND GROUND DEPOSITION OF
TH-232 RELEASED DURING ROUTINE OPERATIONS

| DISTANCE (meters) | AIR CONCENTRATION[1] microcuries per milliliter (Bq/ml) | | SURFACE DEPOSITION microcuries per square meter ($Bq/m^2$) | |
|---|---|---|---|---|
| 250 (inside site boundary) | $5.1 \times 10^{-18}$ | ($1.9 \times 10^{-13}$) | $2.1 \times 10^{-7}$ | ($7.9 \times 10^{-3}$) |
| 750 | $2.1 \times 10^{-18}$ | ($7.9 \times 10^{-14}$) | $8.4 \times 10^{-8}$ | ($3.1 \times 10^{-3}$) |
| 1,500 | $7.6 \times 10^{-19}$ | ($2.8 \times 10^{-14}$) | $3.2 \times 10^{-8}$ | ($1.2 \times 10^{-3}$) |
| 2,500 | $3.5 \times 10^{-19}$ | ($1.3 \times 10^{-14}$) | $1.7 \times 10^{-8}$ | ($6.2 \times 10^{-4}$) |
| 3,500 | $2.1 \times 10^{-19}$ | ($7.8 \times 10^{-15}$) | $1.1 \times 10^{-8}$ | ($4.1 \times 10^{-4}$) |
| 4,500 | $1.5 \times 10^{-19}$ | ($5.5 \times 10^{-15}$) | $8.1 \times 10^{-9}$ | ($3.0 \times 10^{-4}$) |
| 7,500 | $7.0 \times 10^{-20}$ | ($2.6 \times 10^{-15}$) | $4.3 \times 10^{-9}$ | ($1.6 \times 10^{-4}$) |
| 15,000 | $3.0 \times 10^{-20}$ | ($1.1 \times 10^{-15}$) | $9.5 \times 10^{-9}$ | ($3.5 \times 10^{-4}$) |
| 25,000 | $1.3 \times 10^{-20}$ | ($4.8 \times 10^{-16}$) | $1.9 \times 10^{-9}$ | ($7.1 \times 10^{-5}$) |
| 35,000 | $8.1 \times 10^{-21}$ | ($3.0 \times 10^{-16}$) | $6.2 \times 10^{-10}$ | ($2.3 \times 10^{-5}$) |
| 45,000 | $5.7 \times 10^{-21}$ | ($2.1 \times 10^{-16}$) | $4.6 \times 10^{-10}$ | ($1.7 \times 10^{-5}$) |
| 55,000 | $3.8 \times 10^{-21}$ | ($1.4 \times 10^{-16}$) | $3.2 \times 10^{-10}$ | ($1.2 \times 10^{-5}$) |
| 70,000 | $1.9 \times 10^{-21}$ | ($6.9 \times 10^{-17}$) | $1.8 \times 10^{-10}$ | ($6.6 \times 10^{-6}$) |

[1] Maximum concentration occurs north northeast of site on plume centerline.

Surface water contamination caused by precipitation run-off from the FMPC is not expected to occur due to administrative controls provided by the Spill Prevention, Control and Countermeasure Plan for the FMPC and the run-off/ run-on control system described in Section 2.1.4. It is not likely that these environmental controls, which are integral to the entire FMPC facility, would malfunction or fail to operate.

A potential method for decontamination of the silo and bin after the thorium materials are removed is to employ high-pressure water. Any decontamination water will be collected, filtered to remove suspended thorium and then recycled. Residual liquids resulting from decontamination activities will be disposed of as solid, low-level radioactive waste once they have either been concentrated by evaporation or solidified by using cement or a similar fixing agent. No other liquid effluents are associated with the proposed action or alternatives.

## 4.3 ROUTINE OPERATIONAL EXPOSURE RESULTING FROM PROPOSED ACTION

This section describes radiological and nonradiological exposures to workers and the public and evaluates possible public health and ecological consequences. The environmental consequences of radiological exposures are also summarized in Section 4.6 and Table 4-6.

### 4.3.1 Radiological Exposure to Workers

Radiation exposure to workers will result from direct (external) radiation and from inhalation of Th-232 particles. It is estimated that the collective direct radiation exposure to occupational workers involved in the proposed action will be 12.0 person-rem (0.12 person-sieverts). External whole body doses to direct radiation will be maintained to less than 80.0 millirem per person per week (0.8 millisieverts per person per week), the DOE health based limit (DOE, 1986). For the average technician, this dose rate represents less than 500 millirem (5 millisieverts) for a 13-week calendar quarter or approximately 1 rem (10 millisieverts) for the entire project.

Radiation exposure due to inhalation was calculated using the allowable concentration of airborne thorium specified in the project design criteria (Section 2.1.4). Dose equivalent rates for airborne Th-232 were estimated using models accepted by the scientific community, specifically the International Commission on Radiation Protection (see Appendix A). Expressed as an effective committed dose equivalent (the 50-year dose resulting from radionuclides deposited in the body), this internal exposure was calculated to be 12 millisieverts per worker. The effective annual dose equivalent, which is the internal exposure accrued in the first year of exposure, was calculated to be 0.3 millisieverts per worker.

The total radiation exposure to a typical worker is the summation of the external and internal radiation exposures identified above. The combined annual exposure to the average technician was estimated to be less than 11 millisieverts for the duration of the project. This total is considerably less than the permissible annual limit of 5 rem per year (50 millisieverts per year). Table 4-3 summarizes occupational and public exposures and compares them with applicable dose limits.

TABLE 4-3
RADIATION EXPOSURES FROM ROUTINE THORIUM HANDLING OPERATIONS

| | CALCULATED DOSE | | ANNUAL DOSE LIMIT FOR ALL FMPC OPERATIONS | |
|---|---|---|---|---|
| Annual Effective Dose Equivalent to Average Occupational Worker, rem (millisieverts) | 1.1 | (11) | 5 | (50)[1] |
| Effective Committed Dose Equivalent to Total Population, person-rem (person-sieverts) | $1.2 \times 10^{-2}$ | ($1.2 \times 10^{-4}$) | none | |
| Effective Committed Dose Equivalent to Average Individual, millirem (millisieverts) | $4.6 \times 10^{-6}$ | ($4.6 \times 10^{-8}$) | 100 | (1.0)[2] |
| Effective Committed Dose Equivalent to Maximum Individual, millirem (millisieverts) | $1.7 \times 10^{-2}$ | ($1.7 \times 10^{-4}$) | 100 | (1.0)[2] |
| Whole Body Dose Equivalent to Maximum Individual, millirem (millisieverts) | $3.8 \times 10^{-4}$ | ($3.8 \times 10^{-6}$) | 25 | (0.25)[3] |
| Committed Dose Equivalent to Critical Organ, millirem (millisieverts) | $2.6 \times 10^{-1}$ | ($2.6 \times 10^{-3}$)[4] | 75 | (0.75)[5] |

(1) DOE, 1986.
(2) Vaughn, 1985.
(3) 40 CFR 61, Subpart H, dose equivalent to whole body from air pathway only.
(4) In this case, the critical organ is the bone surface.
(5) 40 CFR 61, Subpart H, committed dose equivalent for the critical organ from air pathway only.

### 4.3.2 Radiological Exposure to the Public

The radiological exposure to the public resulting from routine thorium removal operations was calculated using AIRDOS.EPA. Approximately 99 percent of the potential exposure of humans to Th-232 results from the inhalation pathway. There are two radiation dose limits of interest in evaluating exposures to members of the public: DOE guidelines of 100 millirem per year (1.0 millisievert per year) effective committed dose equivalent to any member of the public from all routine operations at the FMPC (Vaughn, 1985) and EPA regulations for airborne emissions from DOE facilities of 75 millirem per year (0.75 millisievert per year) committed dose equivalent to the critical organ or 25 millirem per year (0.25 millisieverts per year) dose equivalent to the whole body of any member of the public (40 CFR 61). Exposures relating to each of these facility limits are addressed below. An additional calculation of interest is

the projected collective radiation exposure to the entire population resulting from routine releases.

From the maximum anticipated release of 1.2 microcuries ($4.7 \times 10^4$ becquerels) during the 26-week project, an effective committed dose equivalent to the combined population within 80 kilometers of the site was calculated to be $1.2 \times 10^{-2}$ person-rem ($1.2 \times 10^{-4}$ person-sieverts). Based upon a total population of 2,598,114, the average effective committed dose equivalent per person would be about $4.6 \times 10^{-6}$ millirem ($4.6 \times 10^{-8}$ millisieverts). Thus, the average individual exposure is a small fraction of the effective committed dose equivalent limit of 100 millirem per year (1.0 millisievert per year) for the FMPC (Table 4-3).

The same model was used to calculate the dose to a hypothetical individual who resides at the site boundary at the point of maximum annual concentration of Th-232. Routine releases over the 26-week project duration gives this maximum individual an effective committed dose equivalent of $1.7 \times 10^{-2}$ millirem ($1.7 \times 10^{-4}$ millisieverts). This exposure is a small fraction of the DOE prescribed maximum individual limit of 100 millirem per year (1.0 millisievert per year) applicable to the FMPC (Table 4-3).

The EPA limit of 75 millirem (0.75 millisieverts per year) committed dose equivalent to the critical organ or 25 millirem (0.25 millisieverts per year) dose equivalent to the whole body applies to a member of the public at the point of maximum annual air concentration in an unrestricted area where any member of the public resides. For the FMPC site, this point is approximately 250 meters north of the site boundary at an existing residence. An individual at this location is estimated to receive a committed dose equivalent to the critical organ of $2.6 \times 10^{-1}$ millirem ($2.6 \times 10^{-3}$ millisieverts). The critical organ (i.e., most exposed human organ) for exposure to Th-232 oxide from airborne emissions is the bone surface. The estimated whole body dose equivalent to the maximum individual is $3.8 \times 10^{-4}$ millirem ($3.8 \times 10^{-6}$ millisieverts). Table 4-3 summarizes annual effective dose equivalents to members of the public and compares them with applicable dose limits.

4.3.3 Health Impacts Resulting from Routine Exposure 66

Potential risk to public health resulting from radiation exposure is principally in the form of an increase in cancers arising in a variety of organs and

tissues. The cancer risk for the exposures calculated above are addressed in Section 4.6.

### 4.3.4 Ecological Impacts

Thorium compounds of the type stored in the silo and bin at the FMPC are commonly found in soils throughout the United States; they contribute to the natural "background" alpha radioactivity levels in soils. It has been calculated that Th-232 activity levels in the upper soil horizon nationwide average about 0.3 microcuries per square meter ($1 \times 10^4$ becquerels per square meter) (Whicker, 1987). Thus, as can be seen from Table 4-2, projected releases from routine thorium handling operations would contribute only an extremely small portion to the existing natural background levels.

Maximum off-site air concentrations from routine operations (Table 4-2) are estimated to be about 4,000 times lower than the DOE recommended limit of $7 \times 10^{-15}$ microcuries per milliliter ($3 \times 10^{-10}$ becquerels per milliliter). Surface contamination will be at least one million times lower than natural background. These levels would have to be increased many orders of magnitude to cause adverse ecological impacts (see Section 4.4.4).

### 4.3.5 Impacts from Criteria Pollutants

As Table 4-1 indicates, the projected possible concentrations of nonradiological air pollutants associated with the proposed action are minuscule when compared to the allowable National Ambient Air Quality Standards (NAAQS) concentration limits. Because these standards are based on achieving protection of public health and the environment, no deleterious consequences are foreseen for either human health or ecological systems.

### 4.3.6 Nonradiological Occupational Health and Safety

Nonradiological health and safety concerns such as heat stress will be controlled through the application of the routine procedures described in Section 2.1.5. Potential accidents involving trips and falls are also a matter of concern associated with the proposed activities. The training program will serve as the forum to discuss the controls for this project. All work procedures will comply with DOE and OSHA requirements.

### 4.3.7 Impacts on Other Environmental Parameters

The proposed action and alternatives will not generate significant noise, traffic, or additional employment. No type of land disturbance from roads or structures is contemplated. Therefore, there will be no adverse impacts on cultural resources, land use, visual resources, ambient noise levels, or the socioeconomic environmental.

## 4.4 POTENTIAL ACCIDENTAL EXPOSURES AND IMPACTS RESULTING FROM THE PROPOSED ACTION

This section assesses the environmental and health consequences of postulated accidents associated with the proposed action. A small probability exists that unplanned releases of thorium material may occur during the course of removing, repackaging, and handling operations. For the purpose of evaluating the potential range of such events, credible accident scenarios were formulated and the resulting impacts evaluated. Environmental and health consequences from accidents are summarized in Section 4.6.

### 4.4.1 Release Scenarios

Four accidents were postulated to provide a basis for assessing the potential magnitude of impacts that could conceivably occur during the proposed action. In all cases, the result is an unplanned airborne particulate release of Th-232 to the atmosphere. Considering the nature of the proposed action, such airborne releases are the most likely pathway of accidental exposure to the public. In addition, inhalation is the dominant mode of exposure for Th-232. Accidents involving the on-site release of contaminated liquids during decontamination activities are conceivable but were judged not to be an off-site concern because of the presence of existing run-on and run-off control measures and the SPCC plan described in Section 2.1.4.

The accident scenarios were formulated from an examination of the available methods for removing, repackaging, and handling the thorium material stored in the bins and silo. Because of the higher Th-232 concentration in the silo and the fact that removal of thorium material from the bins will likely be accomplished from within the Plant 8 Building, all accident scenarios were conservatively assumed to be associated with silo operation. The four accident scenarios are discussed below.

(1) Failure in Silo Near Bottom of Silo Cone. The first, and most severe, postulated accident involves a spill from near the bottom of the silo cone during the mounting of thorium removal equipment, presumed to be a motor-driven screw auger. As discussed in Section 2.1.1, mounting of the removal equipment would require drilling a ten-centimeter hole in the cone. As a result of a postulated failure during the drilling and equipment mounting process, it was assumed that 10,000 kilograms of thorium material could be spilled to the ground a distance of six meters below the operations level. A similar release could result from failure of the thorium removal equipment during subsequent thorium removal operations. This postulated accident was evaluated by considering an initial release associated with the spill to the ground and a subsequent release due to resuspension of the spilled material. The initial release was modeled as a cloud of six meters in diameter with an airborne thorium concentration of 100 milligrams per cubic meter which accounts for agglomeration and settling of particles (Elder et al., 1986). The resuspension phase of the accident assures that 0.2 percent of the spilled material is resuspended by aerodynamic entrainment before the spill can be covered (Mishima et al., 1973). The resulting environmental release would be 20.1 kilograms or 2.2 millicuries ($8.1 \times 10^7$ becquerels) of Th-232. It was conservatively assumed that the entire release would be carried off site by prevailing light winds and stable atmospheric conditions. The probability of such an accident is judged to be extremely low due to the planned mock-up and personnel training to be employed prior to the actual operation.

(2) Breach of HEPA Filtration System. The second postulated accident involves the breach of the filtration system so that Th-232 is released without the benefit of HEPA filter mitigation. For the purpose of source term development, it was assumed that the prevailing concentration of airborne Th-232 particulates within the enclosure at the time of the accident is 100 times the permissible 40-hour weekly average of $5.4 \times 10^{-13}$ microcuries per milliliter ($2 \times 10^{-8}$ becquerels per milliliter). It was further assumed that the ventilation exhaust fans were allowed to operate for a ten-minute period at a flow rate of 45 cubic meters per minute before the breach was detected and the fans secured. The resulting release was calculated at 20 nanocuries ($7.5 \times 10^2$ becquerels) of Th-232.

(3) Failure of Air Vacuum Collection Filter. A third accident scenario was developed in consideration of the possible use of an air vacuum system for removal of thorium material through the top of the silo. By its nature, such a system would operate at a pressure less than atmospheric. Any leakage that might develop would draw outside air into the conveyance duct work rather than allowing thorium material to escape. However, in the event of a failure of the collection filter located at ground level, all material in transit within the duct work could flow out by gravity. Based upon current designs, the system was assumed to deliver 27.8 cubic meters per minute at an average line volume of 0.1 percent, which corresponds to a thorium density of $6.4 \times 10^{-3}$ grams per cubic centimeter. The duration of the accident was assumed to be two minutes resulting in a spill of 356 kilograms of Th-232. The accident was assumed to result in an initial 10 cubic meter cloud of particulates at a concentration of 100 milligrams per cubic meter. Resuspension results in 0.2 percent of the remaining material being resuspended before the spill can be contained. The total airborne release would be 0.713 kilograms or 78 microcuries ($2.9 \times 10^{6}$ becquerels of Th-232).

(4) Drum Handling Accident. The proposed action is intended to repackage the thorium material into smaller and more manageable containers. The container type most likely to be used is a 55-gallon drum. The fourth accident scenario postulates a drum handling accident, either a drum drop or puncture by a forklift tine. In either event, it was assumed that 25 percent of the drum content was spilled and the release modeled as the previous accident. Based upon a 380 kilogram drum loading limit, this accident would result in a 21 microcurie ($7.7 \times 10^{5}$ becquerel) airborne release of Th-232.

### 4.4.2 Radiological Exposures Resulting from Accidents

The radiological exposures resulting from the accidents postulated above would be a function of the immediate conditions prevailing at the time of each event. In all cases, releases would be of short duration, measured in minutes, and the cloud of particulates would be subject to the existing meteorological conditions (wind speed, wind direction, and atmospheric stability). Workers at the scene of the accident would be trained in procedures to minimize their exposure and to mitigate the off-site consequences of the accident.

Radiological exposure of the public as a result of the accidents described above was conservatively estimated by assuming that very stable meteorological conditions exist for the duration of the cloud passage. Wind speed was fixed at two meters per second and Pasquill atmospheric stability category F conditions were assumed. These conditions would result in a slow moving and concentrated cloud of particulates off site.

For the purpose of dose assessment, it was assumed that a member of the public (maximum individual) was located at the FMPC facility site boundary in the downwind direction during cloud passage. This maximum individual was assumed to be exposed to the highest resulting air concentration of Th-232 particulates, that being at the centerline of the plume. Table 4-4 summarizes the effective committed dose equivalent to this hypothetical individual for each of the postulated accidents. Because of the conservatism of the assessment assumptions, these exposures should be considered to be at the upper range of the possible exposures that would occur from the postulated events.

TABLE 4-4
DOSE CONSEQUENCES OF POSTULATED ACCIDENTS

| ACCIDENT | RELEASE | EFFECTIVE COMMITTED DOSE EQUIVALENT(1) | COMMITTED DOSE EQUIVALENT TO LUNGS(1) | COMMITTED DOSE EQUIVALENT TO BONE SURFACE(1) |
|---|---|---|---|---|
| | curies (becquerels) | millirems (millisieverts) | | |
| Failure of Removal Equipment | $2.2\times10^{-3}$ ($8.1\times10^{7}$) | $5.1\times10^{2}$ (5.1) | $6.5\times10^{2}$ (6.5) | $1.6\times10^{3}$ ($1.6\times10^{1}$) |
| HEPA Filter failure | $2.0\times10^{-8}$ ($7.5\times10^{2}$) | $5\times10^{-3}$ ($5\times10^{-5}$) | $6.0\times10^{-3}$ ($6.0\times10^{-5}$) | $1.5\times10^{-2}$ ($1.5\times10^{-4}$) |
| Air Vacuum Filter Failure | $7.8\times10^{-5}$ ($2.9\times10^{6}$) | $1.8\times10^{1}$ ($1.8\times10^{-1}$) | $2.3\times10^{1}$ ($2.3\times10^{-1}$) | $5.7\times10^{1}$ ($5.7\times10^{-1}$) |
| Drum Handling Accident | $2.1\times10^{-5}$ ($7.7\times10^{5}$) | 4.9 ($4.9\times10^{-2}$) | 6.2 ($6.2\times10^{-2}$) | $1.5\times10^{1}$ ($1.5\times10^{-1}$) |
| Siting and Design Limit(2) | --- --- | $2.5\times10^{4}$ ($2.5\times10^{2}$) | $7.5\times10^{4}$ ($7.5\times10^{2}$) | $3.0\times10^{5}$ ($3.0\times10^{3}$) |

(1) Maximum calculated dose to any member of the general public.
(2) DOE Design Criteria, DOE 6430.1, Chapter 1 (DOE, 1983).

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### 4.4.3 Health Impacts Resulting from Accidental Exposures

The health consequence of the radiation exposure to the hypothetical individual resulting from postulated accidents is principally an increase in the risk of cancer. This risk is discussed in Section 4.6.

### 4.4.4 Ecological Effects of Accidents

The effects of the postulated accident scenarios on ecological systems were also considered. According to Professor F. Ward Whicker at the Colorado State University Department of Radiology and Radiation Biology, who reviewed the AIRDOS.EPA modeling data (Table 4-5), the highest projected air concentration and surface contamination levels under accident conditions would have to be increased several orders of magnitude to cause any detectable ecological effects (Whicker, 1987).

## 4.5 EVALUATION OF ALTERNATIVES

A brief evaluation of the alternatives to the proposed actions considered by this environmental assessment is provided in this section. Where possible, quantitative estimates have been made of the routine operational and potential accident-related impacts for each.

**TABLE 4-5**
**PEAK AIR CONCENTRATION AND TOTAL GROUND DEPOSITION OF TH-232 RESULTING FROM WORST CASE ACCIDENT**

| DISTANCE (meters) | PEAK AIR CONCENTRATION[1] uCi/ml | (Bq/ml) | SURFACE DEPOSITION uCi/m$^2$ | (Bq/m$^2$) |
|---|---|---|---|---|
| 250 | $2.6\times10^{-9}$ | ($9.5\times10^{1}$) | $1.8\times10^{-2}$ | ($6.7\times10^{2}$) |
| 750 | $3.2\times10^{-10}$ | ($1.2\times10^{1}$) | $2.6\times10^{-3}$ | ($9.5\times10^{1}$) |
| 1,500 | $9.5\times10^{-11}$ | (3.5) | $8.7\times10^{-4}$ | ($3.2\times10^{1}$) |
| 2,500 | $4.3\times10^{-11}$ | (1.6) | $4.3\times10^{-4}$ | ($1.6\times10^{1}$) |
| 3,500 | $2.6\times10^{-11}$ | ($9.5\times10^{-1}$) | $2.7\times10^{-4}$ | ($1.0\times10^{1}$) |
| 4,500 | $1.8\times10^{-11}$ | ($6.7\times10^{-1}$) | $2.0\times10^{-4}$ | (7.6) |
| 7,500 | $8.6\times10^{-12}$ | ($3.2\times10^{-1}$) | $1.0\times10^{-4}$ | (3.9) |
| 15,000 | $3.5\times10^{-12}$ | ($1.3\times10^{-1}$) | $4.6\times10^{-5}$ | (1.7) |
| 25,000 | $1.7\times10^{-12}$ | ($6.1\times10^{-2}$) | $2.2\times10^{-5}$ | ($8.1\times10^{-1}$) |
| 35,000 | $1.1\times10^{-12}$ | ($3.9\times10^{-2}$) | $1.4\times10^{-5}$ | ($5.2\times10^{-1}$) |
| 45,000 | $7.0\times10^{-13}$ | ($2.6\times10^{-2}$) | $9.7\times10^{-6}$ | ($3.6\times10^{-1}$) |
| 55,000 | $4.6\times10^{-13}$ | ($1.7\times10^{-2}$) | $4.9\times10^{-6}$ | ($1.8\times10^{-1}$) |
| 70,000 | $2.0\times10^{-13}$ | ($7.3\times10^{-3}$) | $2.7\times10^{-6}$ | ($1.0\times10^{-1}$) |

[1] Peak air concentration occurs during cloud passage.

### 4.5.1 Removal to Process Bins

As discussed in Section 2.0, this alternative is the same as the proposed action except that the thorium material would be removed to process bins, each with a capacity of about 8.6 cubic meters. Because of the larger capacity, the time required to remove thorium material from the silo and storage bin to process bins would be slightly less than that for removal to drums. The total amount of material handled and the removal methods would not change significantly. Therefore, the anticipated exposures to occupational workers and the general public may be considered to be the same as for the proposed action. No accidents unique to this alternative were identified.

### 4.5.2 Structural Upgrading

Structural upgrading of the thorium storage silo, in addition to that described in Section 2.0, is estimated to result in occupational exposure at least as great as the structural enhancement which has been completed to date. [Collective occupational exposure resulting from the prior structural enhancement was estimated at 8.3 person-rem (0.083 person-sieverts)]. In addition, occupational exposure resulting from the current storage configuration would be prolonged. The direct radiation exposure rate at ground level beneath the silo has been measured to be 2.0 to 3.0 millirem per hour (0.02 to 0.03 millisieverts per hour). This contributes to the radiation exposure to individuals who work in the vicinity of the silo during operations at Plant 8. (No significant occupational exposure is currently associated with the bin.) No routine public exposure to radiation or criteria pollutants would be expected from this alternative.

The structural upgrading alternative would merely postpone the removal of thorium material from both the silo and bin. The material will be removed at some time in the future, either for processing as a resource or for off-site storage. The same health, safety, and environmental consequences as for the proposed action would be incurred at that time. Thus, the combined occupational exposure from near-term upgrading and future removal operations would be greater than for the proposed action.

In addition to the routine impacts discussed above, a catastrophic failure of the silo could conceivably occur during the course of structural upgrading activities. The likelihood of such a failure would be minimized by use of temporary supports and appropriate safety margins in the design of temporary and permanent structural members. The maximum off-site consequence of a total failure of the silo is a 25 rem (250 millisieverts) effective committed dose equivalent to the maximum individual, approximately 50 times the consequence of the worst postulated accident for the proposed action.

### 4.5.3 No Action

Unlike the proposed action and other alternatives, the no action alternative prolongs the risk of damage to or destruction of the silo and bin from a severe windstorm (e.g., tornado) or an earthquake. A release resulting from such a low probability event could result in radiation exposures to workers and the public that far exceed those estimated for the proposed action. The maximum off-site consequence of structural failure of the silo is estimated to be an effective committed dose equivalent to the maximum individual of 25 rem (250 millisieverts), approximately fifty times greater than that for the worst case accident postulated for the proposed action. Ambient radiation associated with this thorium storage would continue to be a source of exposure to FMPC workers at Plant 8. The no action alternative would only postpone the consequences of the proposed action because thorium material will eventually have to be removed from the silo and bin.

## 4.6 COMPARISON OF ENVIRONMENTAL CONSEQUENCES

Potential risks to human health from routine operations related to thorium handling and postulated accidents are compared in Table 4-6. The consequence of radiation exposure is reported as a risk of contracting a fatal cancer at any time in the future as a result of the estimated radiation exposure. In the health risk assessment, the following accepted principles have been employed:

- A carcinogenic risk due to radiation exposure is defined as the probability that a specified dose will cause fatal cancer in some fraction of the people exposed

- Dose-response relationship is chosen to be linear with no threshold, i.e., it is assumed that the probability

of late stochastic effects (somatic and genetic) is proportional to radiation exposure received no matter how small that exposure

- Dose response is considered to be independent of dose rate (BEIR 80).

The absolute risk model as set forth by the Committee on the Biological Effects of Ionizing Radiation (BEIR 80) was used in addition to reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (UN 77) and the ICRP (ICRP 77). A comparison of the proposed action and alternatives in terms of the risk of contracting a fatal cancer over the lifetime of exposed individuals is presented in Table 4-6. These risks consider only the exposures associated with releases of Th-232 and do not include the risk of cancer from other environmental causes. The risk of cancer during the lifetime of an individual resulting from all natural and man-made causes has been estimated at 26 percent (BEIR, 1980). As shown in Table 4-6, the increased risk represented by the proposed action or alternatives is negligible by comparison.

TABLE 4-6

HEALTH RISK COMPARISON: RADIOLOGICAL EXPOSURE TO INDIVIDUALS[1]

| | ROUTINE OPERATIONS | | | POSTULATED WORST ACCIDENT[2] |
|---|---|---|---|---|
| | OCCUPATIONAL WORKER AVERAGE | PUBLIC AVERAGE INDIVIDUAL | PUBLIC MAXIMUM INDIVIDUAL | PUBLIC MAXIMUM INDIVIDUAL |
| Proposed Action: Removal to Drums | $2 \times 10^{-4}$ | $5 \times 10^{-13}$ | $2 \times 10^{-9}$ | $5.1 \times 10^{-5}$ |
| Alternative 1: Removal to Process Bins | $2 \times 10^{-4}$ | $5 \times 10^{-13}$ | $2 \times 10^{-9}$ | $5.1 \times 10^{-5}$ |
| Alternative 2: Structural Upgrading | $1 \times 10^{-4}$[3] | 0[4] | 0[4] | $2.5 \times 10^{-3}$ |
| Alternative 3: No Action | $1 \times 10^{-4}$[3] | 0[4] | 0[4] | $2.5 \times 10^{-3}$ |

(1) Health risks are expressed as the probability of an individual contracting a fatal cancer during their lifetime from the activity.
(2) The health risk assuming that the worst accident occurs; i.e., the probability of the accident is not included.
(3) Health risk based upon assumption that involved worker exposure will be maintained below 1 rem (10 millisieverts).
(4) No incremental routine exposure to the public should result.

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# 5.0 MITIGATION MEASURES

Health, safety, and environmental control programs and measures are described throughout this Environmental Assessment, particularly in Section 2.1.4. Most of these reflect DOE and/or EPA objectives and requirements. Because the proposed action addresses these environmental directives, pertinent additional mitigation measures have not been identified.

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## 6.0 PERSONS AND ORGANIZATIONS CONSULTED

The following individuals and organizations were consulted during the preparation of this EA:

- Richard Boisvert, State of Ohio Historic Preservation Office, Columbus, Ohio
- Rita Wynn, Ohio-Kentucky-Indiana Regional Council of Governments, Cincinnati, Ohio
- Oak Ridge National Laboratory, Oak Ridge, Tennessee
- F. Ward Whicker, Department of Radiology and Radiation Biology, Colorado State University, Fort Collins, Colorado
- Mary Ann Brown, Executive Director, Miami Purchase Association for Historic Preservation, Cincinnati, Ohio.

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# GLOSSARY

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| Accident Scenario: | Description of unforeseen events or circumstances which have a finite but low probability of occurring during the duration of the project. |
| Aerodynamic Equivalent Diameter: | The diameter of a uniform-density sphere that would have the same terminal velocity due to gravity in air as the particle under consideration. |
| ALARA: | DOE objective to maintain radiological exposure levels to as low as reasonably achievable. |
| BEIR: | Biological Effects of Ionizing Radiation (National Academy of Sciences Committee). |
| Becquerel (bq): | A unit measuring the radioactivity of an element. One becquerel is defined as one nuclear disintegration per second. |
| CEQ: | U.S. Council on Environmental Quality. |
| CO: | Carbon monoxide. |
| Committed Dose: | The radiation dose received during the period of exposure plus the dose accumulated over a period of years (in this case 50 years) of exposure resulting from radionuclides deposited within the body during the exposure period. |
| Coniferous: | Pertaining to cone-bearing species such as pines. |
| Critical Organ: | The human body organ receiving a radiation dose which results in the greatest overall damage to the body. |
| Curie: | A unit measuring the radioactivity of an element. One curie is defined as $3.7 \times 10^{10}$ nuclear disintegrations per second. |
| DOE: | U.S. Department of Energy. |
| DOT: | U.S. Department of Transportation. |
| Deciduous: | Pertaining to a tree or shrub that sheds its leaves seasonally. |
| Diatomaceous Earth: | Earth material abounding in fossilized plankton. |
| Dispersion: | The process of natural mixing in the atmosphere. |
| Dose: | A general term denoting the quantity of radiation energy absorbed in biological tissue. The unit of dose is a sievert. |

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| Dose Equivalent: | The product of absorbed dose and appropriate factors to account for differences in biological effectiveness due to the quality of the radiation and its distribution in the human body. The unit of dose equivalent is the sievert. |
| Dose Response: | The immediate and long-term results (effects) of exposure to a radiation dose. |
| EPA: | U.S. Environmental Protection Agency. |
| Edge Habitat: | The transition zone between two plant communities. |
| Effective Dose Equivalent: | The sum of the products of the dose equivalents to individual organs and tissues and appropriate weighting factors representing the risk relative to that of an equal dose to the whole body. The unit is the sievert. |
| Environment: | The physical and biological surroundings (habitat) existing for humans, plants, and animals. Includes atmosphere, water, and land as well as the environment "built" or developed by man. |
| Environmental: | Pertaining to biosphere, the complex physical, chemical, and biotic factors which act upon an organism. |
| Environmental Impact: | The consequences, effects, or outcomes resulting from changes in the human or natural environment. In this EA, impacts are generally confined to human health effects or adverse effects on natural ecosystems. |
| Exposure: | The absorption of ionizing radiation or ingestion/ inhalation of a radionuclide. The product of dose rate and time. |
| FMPC: | Feed Materials Production Center, Fernald, Ohio. |
| Forb: | Broad-leaved herbaceous plant as distinguished from the grasses. |
| Gray: | Measure of absorbed dose of 1 joule of energy per gram; equivalent to 100 roentgents absorbed in air. |
| HEPA: | High efficiency particulate air filter capable of removing at least 99.97 percent of airborne particulates greater than 0.3 microns in diameter. |
| Habitat: | The physical environment where an organism lives. |
| Herbaceous: | Non-woody plants. |

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| Milligray: | One thousandth (0.001) gray equal to 100 milliroentgents of gamma radiation absorbed in air. |
| Millisievert: | One thousandth (0.001) sievert, equal to 100 millirem. |
| NEPA: | National Environmental Policy Act. |
| $NO_x$: | Nitrogen oxide. |
| NPDES: | National Pollutant Discharge Elimination System. Refers to a type of State of Ohio or federal permit for discharging wastewater to a surface water body. Derives from Section 402 of the federal Clean Water Act. |
| NTS: | Nevada Test Site. |
| National Register of Historic Places: | A listing and designation of nationally significant historical or archeological sites given special protection under the federal Historic Preservation Act. The national Register is managed by the National Park Service. |
| OSHA: | U.S. Occupational Safety and Health Administration. |
| Off Site: | Any location beyond the site boundary where a member of the public can be legally situated beyond the control of the owner and operator of a nuclear facility. |
| Paddy's Run: | An intermittent stream (flowing only part of the year) running from north to south along the western boundary of the FMPC. |
| Population Dose: | An estimate of total radiation dose received by members of a population group (units are person-sieverts). |
| Radon 220: | A naturally occurring radioactive gas created in the radioactive decay of Thorium, often called Thoron. |
| Rare, Threatened, or Endangered Species: | A classification of a terrestrial or aquatic plant or animal species given special protection under the federal Endangered Species Act. |
| Rem: | Acronym of roentgen equivalent man. The unit of radiation dose equivalent that expresses all kinds of radiation on a common scale. |
| Riparian: | Along the bank of a river or lake. |
| Roentgen: | A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying one electrostatic unit of electrical charge in one cubic centimeter of dry air under standard conditions. |

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| Ruderal: | A type of disturbed habitats. |
| $SO_2$: | Sulfur dioxide. |
| Sievert: | A unit of radiation energy deposited in tissue equivalent to one joule per kilogram. |
| Site Boundary: | The boundary of a property over which the owner or operator can exercise strict control without the aid of outside authorities. The site boundary does not have to be a fence or other physical barrier. |
| Site Specific Data: | Data collected for use in radiological assessment models applicable to the particular location for which assessment is performed. |
| Somatic: | Radiation effects manifested in the exposed individual. |
| Source Term: | The amount of radioactive material released from primary confinement to the biosphere in dispersible form (units are becquerels). |
| Species Diversity: | A measure of variety of different species of a community: describes the number of species within that community and their relative abundances. |
| Stochastic: | Effects whose probability of occurrence in an exposed population is a direct function of dose. |
| Third-Order Stream: | Classification of stream based on size; third-order streams are formed by the joining of two second-order streams which have lower yearly flow. |
| Thorium: | A naturally-occurring radioactive element. |
| Unrestricted Use: | Meeting regulatory criteria established to protect public safety in any type of future use. |
| WMCO: | Westinghouse Materials Company of Ohio. |
| Working Level (WL): | Any combination of radon daughters in one liter of air that will result in the ultimate emission of $1.3 \times 10^5$ Mev of potential alpha decay particle energy. |
| Worst Case: | Calculation made based on assumptions intended to bias results toward overestimation of negative impacts. |

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# APPENDIX

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# APPENDIX A
# DOSE ASSESSMENT METHODOLOGY

This appendix provides an overview of the methodology and assumptions used to assess the radiological consequences to members of the public from airborne radioactivity releases from the FMPC facility.

## A.1 DOSE CALCULATION MODELING

The AIRDOS-EPA computer code was used to estimate the radiation dose to man resulting from the atmospheric release of radionuclides from thorium material removal activities at the FMPC. The code, which is a modified version of AIRDOS-II, is described in Moore, 1979 and was used for both routine and accidental release assessments. Most input parameters required by the code characterize the area surrounding the site or are specific to the radionuclides released. As such, these input data were identical for both release assessments. Other input, such as the source terms and the meteorological assumptions used, were specific to the release assessment. The following discussion differentiates between routine release modeling and accident release modeling where differences exist. Unless otherwise specified, the input data for the AIRDOS-EPA code were provided by Oak Ridge National Laboratory, which is currently preparing the Environmental Impact Statement for the Fernald Site.

## A.2 OVERVIEW OF AIRDOS-EPA

In general, AIRDOS-EPA estimates the radiation dose to either a maximum individua or to a collective population resulting from the airborne release of radionuclides specified as input to the code. Based upon a characterization of the area surrounding the site and the meteorological conditions specified, the code estimates: (1) concentrations of radioactivity in air, (2) rates of deposition on ground surfaces, and (3) ground surface concentrations. These results are then coupled with intake rates for man to estimate the radiation dose to an adult receptor associated with all possible exposure pathways. For a maximum individual, doses are calculated along the release plume centerline. For a collective population dose, the model calculates an average concentration of the release plume for each sector (distance and direction pair) and uses this calculation to compute a dose.

## A.3 METEOROLOGICAL MODELING

The area surrounding the FMPC site was modeled as a 80-kilometer radius circular grid system with the site located at the center. For the assessment of routine annual releases, site-specific meteorological data typical of annual average conditions were specified. First, the annual frequency of wind direction was determined for each of the 16 compass directions starting at direction 1 for winds toward the north and then proceeding counterclockwise through direction 16. Next, the frequency of each Pasquill stability category for each of the 16 compass directions was determined for the six stability classes ranging from A (very unstable) to F (extremely stable). The average wind speed was entered for each wind direction and Pasquill category. The average depth of the atmospheric mixing layer (lid) for the area was specified to limit the vertical dispersion of the plume after it travels some distance downwind of the source. The value used for the lid height was 700 meters for releases due to routine operations and a more conservative 450 meters for accidental releases. The site-specific meteorological data used in the assessment of routine releases were taken from Greater Cincinnati International Airport and are summarized in Tables A-1 through A-4.

For the assessment of accidental releases, meteorological assumptions were specified to intentionally maximize the calculated dose consequences to a hypothetical off-site individual. The release was confined to a single 22.5° sector, and assuming a constant 2 meter per second wind speed, a comparison was made of the ground level air concentrations at all distances downwind for each Pasquill stability class. The stability class and distance resulting in the highest off-site air concentration of released radionuclides was assumed for the duration of the accident. The meteorological assumptions determined in this manner for the assessment of accidental releases as derived above are summarized in Table A-5.

## A.4 EFFLUENT MODELING

AIRDOS-EPA requires input describing the area or point of release. Releases due to routine thorium removal activities were assumed to occur as a point source at ambient temperature (20°C), 6.1 meters above the ground with an effective "stack" velocity of 2.54 meters per second due to ventilation

exhaust velocity. Stack data input is given in Table A-6. Effective stack heights were estimated using Rupp's equation for momentum dominated plumes, Rupp, 1948. Accidental releases were calculated using both point source and an area source at ground level at ambient temperature and an effective "stack" velocity of 0.3 meters per second.

## A.5 DISPERSION MODELING

The basic equation used to estimate plume dispersion in the downwind direction is the Gaussian plume model of Pasquill, 1961, as modified by Gifford, 1961. The values of the horizontal and vertical dispersion coefficients ($\sigma_y$ and $\sigma_z$) used for dispersion and depletion calculations are those recommended by Briggs, 1969. With respect to deposition of radionuclides on ground surfaces, the code permits considering both dry deposition and scavenging. Dry deposition is the process by which particles deposit on grass, leaves, and other surfaces by impingement, electrostatic deposition, chemical reactions, or chemical reactions with surface components. The rate of deposition on earth surfaces is proportional to the ground-level concentrations of the radionuclides in air (Slade, 1986):

$$R_d = V_d x$$

where:

$R_d$ = Surface deposition rate, pCi/cm$^2$-sec,
$x$ = Ground level concentration in air, pCi/cm$^3$, and
$V_d$ = Deposition velocity, cm/sec.

It should be noted that even though $V_d$ has units of velocity, it is a constant of proportionality and as such must be experimentally determined from field studies in which the ratio $R_d/x$ can be reliably determined. For particles less than 4 microns in diameter, $V_d$ is set at 0.1 cm/sec (Heinemann, 1979). This value is, however, based on vegetation cut at a specific height and fails to measure total deposition on a unit area basis. The value must therefore be divided by the fraction of atmospherically depositing nuclides intercepted by the above-ground edible portion of the vegetation to arrive at a total value of $V_d$. Using a mean forage grass interception fraction of 0.57 produces a deposition velocity ($V_d$) of 0.18 cm/sec for small particulates. Since specific values for $V_d$ (total) have not been published for vegetable crops, it is assumed that the value is the same as that used for forage.

The rate of deposition by scavenging is a function of the precipitation rate since it is principally a mechanism of washout of particles from a plume by rain or snow. The scavenging coefficient is averaged over an entire year which includes all periods during which rain or snow does not fall. The treatment of scavenging can thus be described as a continuous removal of a fraction of the plume per second over the entire year. The scavenging coefficient thus has units of $sec^{-1}$. The rate of scavenging ($R_s$) in $pCi/cm^2$-sec is:

$$R_s = \emptyset x_{ave} L$$

where:

$\emptyset$ = Scavenging coefficient, $sec^{-1}$

$x_{ave}$ = Average concentration of nuclide in a column of air to the lid height, $pCi/cm^3$

L = Height of the lid, cm

The value for the total ground deposition rate used in assessing routine releases was the sum of the dry deposition and the scavenging rates. For accident release assessment, the scavenging rate due to precipitation was conservatively ignored, thus maximizing the plume concentration. The code maintains a mass balance along the plume to reduce the concentration of the plume by accounting for removal of the deposited fraction.

## A.6 TERRESTRIAL MODELING

As previously described, the area surrounding the FMPC site was modeled as a 80-kilometer radius circular grid system with the site located at the center. For the circular grid, 13 distances were specified in each of the 16 compass directions, each distance representing the midpoint of a sector. The distances were specified as 250, 750, 1,500, 2,500, 3,500, 4,500, 7,500, 15,000, 25,000, 35,000, 45,000, 55,000, and 70,000 meters from the center of the site. Within each sector formed by the grid system, FMPC data used for population, agricultural and water area, and beef and dairy cattle were overlayed in arrays. These data are summarized in Table A-7.

Other factors used in modeling terrestrial and food crop transport are essentially those recommended by the U.S. Nuclear Regulatory Commission (NRC) (NRC, 1977). The period of time allowed for long-term buildup of radioactivity on surface soils was 150 days, the anticipated duration of thorium removal operations. The depth of the plow layer was assumed to be 15 cm with an areal density of 215 $kg/m^2$. The fallout interception fraction was set at 0.57 to be consistent with a deposition velocity of 0.18 cm/sec, reference 33. The fallout interception fraction for food crops is the NRC recommended value of 0.20. The weathering removal rate constant used was 2.9E-03 $hr^{-1}$ and it was assumed that pasture grass was exposed for 720 hours during the growing season while crops were exposed for 1440 hours. Agricultural productivity for the grass-cow-milk pathway was set at 0.28$kg/m^2$ and for produce and leafy vegetables 0.716 $kg/m^2$. Foraging animals were assumed to be on pasture during the 150-day duration of thorium removal and received an additional food supply fraction of 0.47. Forage was assumed to be consumed at a rate of 15.6 kg/day dry weight, (Baes, 1984).

The muscle mass of the steers at slaughter was 200 kg. The fraction of the beef herd slaughtered each day is 0.0038 which allows for slaughter of 1/3 of the herd during the project. Bioaccumulation factors were taken from Baes, 1984. Dairy cow milk production was set at 11 liters/day. All of the leafy vegetables and other produce were assumed to be grown in the assessment area. These and other input parameters related to terrestrial modeling and food crop transport are summarized in Tables A-8 and A-9.

## A.7 DOSE MODELING

Using the ground-level concentrations in air and ground deposition rates computed from the meteorological input, the code estimates intake rates at specified environmental locations and calculates the resultant doses through various modes of exposure. For the purpose of assessing the total dose to the population, the air concentrations and ground deposition rates are average values in the cross wind direction over each sector. The average individual dose is then determined by dividing the population dose by the number of individuals in the exposed population. The dose to a maximum individual is determined directly by the code and assumes that the individual is located on the center line of the discharge plume at the point of highest off-site

ground-level concentration. Human inhalation rates, ingestion rates and other factors utilized in modeling the dose receptors are summarized in Table A-10.

The modes of exposure considered in the dose include the following pathways: (1) immersion in air, (2) exposure to contaminated ground surfaces, (3) inhalation of contaminated air, (4) immersion in water such as by swimming in a river or lake, and (5) ingestion of contaminated water and food grown on contaminated land. The total dose to each of the following organs was calculated: total body, lungs, red bone marrow, lower large intestine wall, stomach wall, kidneys, liver, endosteal cells, thyroid, testes and ovaries. The doses calculated were 50-year dose commitments resulting from a one-year exposure for routine releases or one-time exposure for accident releases. (Only the most highly exposed organs are included in the results reported in the text.)

The dose conversion factors used in the calculation are those reported in Dunning, 1986. The inhalation factors are based on the ICRP Task Group Lung Model, which simulates the behavior of particulate matter in the respiratory tract. The inhalation factors used correspond to a median aerodynamic diameter of 0.3 microns. The ingestion factors are based on a four-segment catenary model with exponential transfer of radioactivity from one segment to the next. Retention of nuclides in other organs is represented by linear combinations of decaying exponential functions. In both the inhalation and ingestion models, cross-irradiation (irradiation of one organ by nuclides contained in another) is included.

The Th-232 was assumed to be in oxide form and a quality factor of 20 was used in the calculation in accordance with the recommendation of ICRP Publication 26, (ICRP, 1977). Radionuclide specific input parameters are summarized in Table A-11.

TABLE A-1
METEOROLOGICAL DATA - ASSESSMENT OF ROUTINE RELEASES

| PARAMETER | VALUE (UNITS) |
|---|---|
| Lid Height | 700 (m) |
| Average Temperature | 293.3 (°K) |
| Average Rainfall | 102 (cm/yr) |
| Frequency of Stability Class for Each Direction | Table A-2 |
| Frequency of Wind Direction and True Averaged Wind Speed | Table A-3 |
| Frequency of Wind Direction and Reciprocal - Average Wind Speed | Table A-4 |

Pasquill Category Temperature Gradients

| | |
|---|---|
| E | 0.0728 (°K/m) |
| F | 0.1090 (°K/m) |
| G | 0.1455 (°K/m) |

TABLE A-2

FREQUENCY OF ATMOSPHERIC STABILITY CLASSES FOR EACH DIRECTION

| SECTOR | FRACTION OF TIME IN EACH STABILITY CLASS | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| 1 | 0.0031 | 0.0517 | 0.0843 | 0.2477 | 0.2550 | 0.3582 | 0.0000 |
| 2 | 0.0052 | 0.0610 | 0.0901 | 0.2517 | 0.2765 | 0.3155 | 0.0000 |
| 3 | 0.0094 | 0.0809 | 0.1100 | 0.2354 | 0.2725 | 0.2919 | 0.0000 |
| 4 | 0.0018 | 0.0637 | 0.1005 | 0.2070 | 0.2392 | 0.3877 | 0.0000 |
| 5 | 0.0044 | 0.0606 | 0.1005 | 0.1932 | 0.2805 | 0.3608 | 0.0000 |
| 6 | 0.0064 | 0.0615 | 0.1156 | 0.2071 | 0.2523 | 0.3570 | 0.0000 |
| 7 | 0.0084 | 0.0654 | 0.1052 | 0.2089 | 0.2923 | 0.3157 | 0.0000 |
| 8 | 0.0018 | 0.0688 | 0.1012 | 0.2244 | 0.2631 | 0.3407 | 0.0000 |
| 9 | 0.0079 | 0.0508 | 0.1035 | 0.2393 | 0.3134 | 0.2851 | 0.0000 |
| 10 | 0.0106 | 0.0814 | 0.0787 | 0.3293 | 0.3183 | 0.1817 | 0.0000 |
| 11 | 0.0067 | 0.0607 | 0.0909 | 0.2823 | 0.3497 | 0.2096 | 0.0000 |
| 12 | 0.0051 | 0.0483 | 0.0765 | 0.3576 | 0.3406 | 0.1720 | 0.0000 |
| 13 | 0.0087 | 0.0576 | 0.0935 | 0.3757 | 0.3118 | 0.1466 | 0.0000 |
| 14 | 0.0031 | 0.0691 | 0.1201 | 0.3468 | 0.2358 | 0.2250 | 0.0000 |
| 15 | 0.0051 | 0.0476 | 0.1150 | 0.3252 | 0.2256 | 0.2815 | 0.0000 |
| 16 | 0.0048 | 0.0331 | 0.0918 | 0.2619 | 0.2320 | 0.3765 | 0.0000 |

TABLE A-3

FREQUENCIES OF WIND DIRECTIONS AND RECIPROCAL-AVERAGED WIND SPEEDS

| WIND TOWARD | FREQUENCY | WIND SPEEDS FOR EACH STABILITY CLASS (METERS/SEC) | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 1 | 0.120 | 1.28 | 2.26 | 2.62 | 3.69 | 3.60 | 1.58 |
| 2 | 0.040 | 1.39 | 1.64 | 2.41 | 3.43 | 3.54 | 1.56 |
| 3 | 0.050 | 2.32 | 1.78 | 2.83 | 3.40 | 3.71 | 1.65 |
| 4 | 0.040 | 2.57 | 1.80 | 2.99 | 3.40 | 3.06 | 1.58 |
| 5 | 0.060 | 2.37 | 1.88 | 2.86 | 3.58 | 3.43 | 1.71 |
| 6 | 0.040 | 2.37 | 2.22 | 2.73 | 3.38 | 3.42 | 1.86 |
| 7 | 0.040 | 2.28 | 1.76 | 2.54 | 3.66 | 3.72 | 1.80 |
| 8 | 0.040 | 2.57 | 1.73 | 3.13 | 3.90 | 3.61 | 1.69 |
| 9 | 0.050 | 1.38 | 2.05 | 2.64 | 4.21 | 3.96 | 2.21 |
| 10 | 0.030 | 2.37 | 1.82 | 3.42 | 4.48 | 4.25 | 2.29 |
| 11 | 0.040 | 1.17 | 1.53 | 3.51 | 4.59 | 4.53 | 2.30 |
| 12 | 0.060 | 1.56 | 1.98 | 3.02 | 4.73 | 4.26 | 2.32 |
| 13 | 0.090 | 1.49 | 1.83 | 3.02 | 4.63 | 3.87 | 1.93 |
| 14 | 0.070 | 0.99 | 1.95 | 3.61 | 4.75 | 3.79 | 1.65 |
| 15 | 0.100 | 1.81 | 2.26 | 2.68 | 4.62 | 3.71 | 1.50 |
| 16 | 0.120 | 1.53 | 1.86 | 2.69 | 5.04 | 3.77 | 1.58 |

WIND DIRECTIONS ARE NUMBERED COUNTERCLOCKWISE STARTING AT 1 FOR DUE NORTH

TABLE A-4

FREQUENCIES OF WIND DIRECTIONS AND TRUE-AVERAGE WIND SPEEDS

| WIND TOWARD | FREQUENCY | WIND SPEEDS FOR EACH STABILITY CLASS (METERS/SEC) | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 1 | 0.120 | 1.79 | 3.00 | 3.61 | 4.81 | 4.68 | 2.29 |
| 2 | 0.040 | 1.92 | 2.45 | 3.11 | 4.22 | 4.18 | 2.19 |
| 3 | 0.050 | 2.49 | 2.47 | 3.54 | 4.18 | 4.46 | 2.30 |
| 4 | 0.040 | 2.57 | 2.70 | 3.65 | 4.27 | 4.09 | 2.19 |
| 5 | 0.060 | 2.51 | 2.61 | 3.66 | 4.23 | 4.32 | 2.43 |
| 6 | 0.040 | 2.51 | 3.05 | 3.69 | 4.33 | 4.44 | 2.61 |
| 7 | 0.040 | 2.47 | 2.55 | 3.24 | 4.43 | 4.56 | 2.50 |
| 8 | 0.040 | 2.57 | 2.55 | 3.95 | 4.78 | 4.63 | 2.44 |
| 9 | 0.050 | 1.90 | 2.81 | 3.60 | 4.81 | 4.92 | 2.91 |
| 10 | 0.030 | 2.51 | 2.77 | 4.18 | 5.29 | 5.18 | 3.00 |
| 11 | 0.040 | 1.64 | 2.78 | 4.13 | 5.43 | 5.28 | 3.01 |
| 12 | 0.060 | 2.08 | 2.68 | 3.85 | 5.85 | 5.51 | 3.02 |
| 13 | 0.090 | 2.01 | 2.76 | 3.99 | 5.85 | 5.41 | 2.75 |
| 14 | 0.070 | 1.34 | 2.93 | 4.39 | 5.75 | 5.14 | 2.44 |
| 15 | 0.100 | 2.25 | 3.15 | 3.72 | 5.65 | 5.28 | 2.24 |
| 16 | 0.120 | 2.04 | 2.86 | 3.77 | 5.91 | 5.01 | 2.31 |

WIND DIRECTIONS ARE NUMBERED COUNTERCLOCKWISE STARTING AT 1 FOR DUE NORTH

TABLE A-5
METEOROLOGICAL DATA - ASSESSMENT OF ACCIDENT RELEASES

| PARAMETER | VALUE (UNITS) | BASIS |
|---|---|---|
| Lid Height | 450 (m) | Baes, 1984 |
| Temperature | 293.2 (°K) | |
| Rainfall | 0.01 (cm/y) | Smallest non-zero value accepted by code |
| Frequency of Stability Class for Each Direction | 100%, Class F, any single sector | Yields maximum off-site dose |
| Frequency of Wind Direction for True Averaged Wind Speed | 100%, 2 (m/sec) | Yields maximum off-site dose |
| Frequency of Wind Direction for Reciprocal Averaged Wind Speed | 100%, 2 (m/sec) | Yields maximum off-site dose |

Pasquill Category Temperature Gradients

| | |
|---|---|
| E | 0.0728 (°K/m) |
| F | 0.1090 (°K/m) |
| G | 0.1455 (°K/m) |

TABLE A-6
STACK INFORMATION

| PARAMETER | RELEASE DURING ROUTINE OPERATIONS | ACCIDENT RELEASES |
|---|---|---|
| Effective Stack Height | 6.1 (m) | 0.002 (m) |
| Effective Stack Diameter | 0.61 (m) | -- |
| Source Diameter | -- | 10 (m) |
| Effective Velocity of Stack Gas | 2.5 (m/sec) | 0.3 (m/sec) |
| Heat Release | 0 | 0 |

**TABLE A-7**
**POPULATION INPUT FOR FERNALD 0 - 80,000 m**

| DIRECTION | DISTANCE (m) 250 | 750 | 1,500 | 2,500 | 3,500 | 4,500 | 7,500 | 15,000 | 25,000 | 35,000 | 45,000 | 55,000 | 70,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2,830 | 17,015 | 4,142 | 5,351 | 4,916 | 16,336 |
| NNW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,626 | 2,436 | 4,103 | 3,294 | 17,174 | 51,716 |
| NW | 0 | 0 | 0 | 0 | 0 | 200 | 1,880 | 128 | 749 | 1,158 | 712 | 23,040 | 11,815 |
| WNW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,393 | 2,756 | 2,374 | 3,233 | 1,616 | 13,471 |
| W | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,270 | 2,767 | 6,756 | 2,348 | 18,109 |
| WSW | 0 | 0 | 0 | 0 | 0 | 0 | 2,194 | 6,590 | 2,316 | 4,625 | 3,717 | 5,807 | 6,061 |
| SW | 0 | 0 | 0 | 0 | 1,747 | 0 | 0 | 1,676 | 6,413 | 6,014 | 2,608 | 1,442 | 4,019 |
| SSW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8,163 | 4,573 | 4,357 | 3,401 | 3,645 | 7,795 |
| S | 0 | 0 | 0 | 0 | 0 | 0 | 48 | 10,679 | 12,064 | 12,658 | 5,317 | 1,159 | 10,176 |
| SSE | 0 | 0 | 0 | 0 | 0 | 710 | 0 | 63,585 | 139,295 | 76,739 | 10,793 | 6,032 | 7,745 |
| SE | 0 | 0 | 0 | 0 | 0 | 0 | 2,113 | 78,021 | 309,164 | 88,939 | 23,775 | 9,115 | 11,851 |
| ESE | 0 | 0 | 0 | 0 | 0 | 0 | 6,684 | 64,586 | 142,725 | 66,021 | 27,658 | 10,275 | 14,907 |
| E | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,554 | 25,058 | 20,795 | 10,523 | 8,633 | 8,845 |
| ENE | 0 | 0 | 0 | 0 | 0 | 2,767 | 43 | 25,968 | 10,244 | 11,556 | 21,606 | 8,339 | 32,900 |
| NE | 0 | 0 | 0 | 0 | 0 | 0 | 805 | 62,936 | 11,543 | 58,810 | 34,968 | 62,144 | 519,111 |
| NNE | 0 | 0 | 0 | 0 | 0 | 0 | 758 | 6,777 | 3,944 | 3,253 | 6,520 | 12,140 | 70,312 |

Beef cattle for all sectors: 10,000
Dairy cattle for all sectors: 10,000
Cultivated agricultural land for all sectors: $1 \times 10^{20}$ $m^2$

TABLE A-8
TERRESTRIAL MODELING ASSUMPTIONS

| PARAMETER | VALUE (UNITS) | BASIS |
|---|---|---|
| Buildup Time for Surface Deposition | 150 (days) | NRC, 1977 |
| Fraction of Locally Grown Produce | 1.0 | Conservatism |
| Fraction of Radioactivity Retained on Leafy Vegetables After Washing | 0.5 | NRC, 1977 |
| Time Delay for Ingestion: | | |
| Pasture Grass by Animals | 0 (hrs) | Conservatism |
| Stored Feed by Animals | 2160 (hrs) | |
| Leafy Vegetables by Man | 24 (hrs) | |
| Produce by Man | 24 (hrs) | |
| Removal Rate Constant for Physical Loss by Weathering | $2.9 \times 10^{-3}$ (/hr) | NRC, 1977 |
| Period of Exposure During Growing Season: | | NRC, 1977 |
| Pasture Grass | 720 (hrs) | |
| Crops and Leafy Vegetables | 1440 (hrs) | |
| Agricultural Productivity per Unit Area: | | Baes, 1979 |
| Grass-Cow-Milk Pathway | 0.28 ($kg/m^2$) | |
| Produce and Leafy Vegetable | 0.716 ($kg/m^2$) | |
| Effective Surface Density of Soil | 215 ($kg/m^2$) | Moore, 1979 |
| Fraction of Yearly Feed from Pasture | .4 | NRC, 1977 |
| Daily Feed from Pasture | .43 | NRC, 1977 |
| Consumption Rate of Contaminated Feed or Forage by Animals | 15.6 (kg/day) | Baes, 1979 |
| Transport Time from Animal Feed-Milk-Man | 2.0 (days) | NRC, 1977 |
| Average Time from Slaughter of Meat to Consumption | 20.0 (days) | NRC, 1977 |
| Fraction of Meat Producing Herd Slaughtered Each Day | $3.8 \times 10^{-3}$ | |
| Muscle Mass of Meat Producing Animal | 200 (kg) | |
| Milk Production of Cow | 11 (l/day) | |
| Fallout Interception Fraction: | | |
| Pasture | 0.57 | Miller, 1979 |
| Vegetables | 0.20 | Chamberlain, 1790 |
| Fraction of Food Grown in Local Gardens: | | Conservatism |
| Produce | 1.00 | |
| Leafy Vegetables | 1.00 | |

TABLE A-9
BIOACCUMULATION FACTORS

| ELEMENT | UPTAKE FRACTIONS MILK (DAYS/LITER) | UPTAKE FRACTIONS MEAT (DAYS/KG) | CONCENTRATION FACTORS PASTURE | CONCENTRATION FACTORS CROPS |
|---|---|---|---|---|
| Th-232 | $5.0 \times 10^{-6}$ | $6.0 \times 10^{-6}$ | $8.5 \times 10^{-4}$ | $3.3 \times 10^{-5}$ |

From Baes, 1984.

TABLE A-10
DOSE RECEPTOR ASSUMPTIONS

| PARAMETER | VALUE (UNITS) | BASIS |
|---|---|---|
| Breathing Rate of Man | $9.17 \times 10^5$ ($cm^3/hr$) | NRC, 1977 |
| Depth of Water for Immersion Dose | 244 (cm) | Conservatism |
| Fraction of Time Spent Swimming | 0.01 | Conservatism |
| Rate of Human Ingestion: | | NRC, 1977 |
| Average Individual: | | |
| Produce | 190 (kg/yr) | |
| Milk | 110 (l/yr) | |
| Meat | 95 (kg/yr) | |
| Leafy Vegetables | 18 (kg/yr) | |
| Maximum Individual | | |
| Produce | 520 (kg/yr) | |
| Milk | 310 (l/yr) | |
| Meat | 110 (kg/yr) | |
| Leafy Vegetables | 64 (kg/yr) | |

## TABLE A-11
## RADIONUCLIDE SPECIFIC PARAMETERS

| ISOTOPE | SOLUBILITY CLASS | DECAY CONSTANT (/DAY) | PHOTON DOSE RATE CONVERSION FACTORS(1) IMMERSION IN AIR (Rem-cm$^3$/pCi-hr) | IMMERSION IN WATER (Rem-cm$^3$/pCi-hr) | SURFACE (Rem-cm$^2$/pCi-hr) |
|---|---|---|---|---|---|
| Th-232 | Y | 1.9E-13 | 1.035E+00 | 2.614E-03 | 2.365E-03 |

| CONVERSION FACTOR | T. BODY | R.MAR. | LUNGS | ENDOST. | S.WALL | LLI WALL | THYROID | LIVER | KIDNEYS | TESTES | OVARIES |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Photon Organ Dose(1) | 0.0906 | 0.0433 | 0.0657 | 0.1110 | 0.0551 | 0.0510 | 0.0984 | 0.0580 | 0.0620 | 0.1139 | 0.0490 |
| Inhalation Dose(2) | 1.9E+3 | 2.4E+3 | 6.0E+3 | 3.0E+4 | 3.8E+0 | 3.8E+0 | 3.8E+0 | 3.1E+1 | 3.9E+0 | 3.7E+0 | 3.7E+0 |
| Ingestion Dose(2) | 2.7E+0 | 5.5E+0 | 4.7E-3 | 6.8E+1 | 8.0E-3 | 1.6E-1 | 4.5E-3 | 3.8E-2 | 4.8E-3 | 4.6E-3 | 4.6E-3 |

(1) From Kocher, 1981.
(2) From Dunning, 1986.