ASSESSMENT OF POTENTIAL AIRBORNE RADIOACTIVITY EMISSIONS FROM A PROPOSED NEW GYPSUM DISPOSAL FIELD

For

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SUMMARY

An assessment was made of the potential airborne radioactivity emissions from the new gypsum disposal field proposed by Gardinier, Inc. near its East Tampa Phosphate Chemical Plant. This was accomplished by examining the off-site effects of airborne radon and radon progeny and airborne and deposited radium-226 in fugitive dust.

Airborne Radon and Radon Progeny

Five nearby receptor locations in various directions from the disposal site were considered. For these locations, the contribution of the completed pile to airborne radon concentrations was estimated to range from 0.03 to 0.1 pCi/l, in addition to the expected ambient background. In this case of radon transported through the atmosphere from the gypsum pile source, there would not be any trapping and build-up of indoor radon concentrations; contributions to indoor radon concentrations may be assumed to be the same as contributions to outdoor radon.

The significance of the radon lies in the resulting airborne radon progeny concentrations. It was estimated that radon progeny concentrations attributable to the gypsum pile source would be on the order of 0.0002 to 0.0009 WL. This corresponds to increases of 5 to 25% over the expected indoor background of 0.003 to 0.004 WL and represents absolute increments too small to be discerned by usual measurement techniques. The projected gypsum pile contributions to radon progeny concentrations fall below the various suggested limits for indoor radon progeny concentrations which range from 0.005 to 0.05 WL above background.

Radium-226 in Fugitive Dust

Using fugitive dust modeling provided by another consultant, airborne radium-226 and ground deposition were estimated for 15 receptor locations around the proposed gypsum disposal site. The maximum airborne radium-226 concentration was predicted to be 2×10^{-7} pCi/m^3, a value about one ten-millionth of the State of Florida Maximum Permissible Concentration for uncontrolled areas. It was predicted that the maximum radium-226 deposition rate would be on the order of 0.2 pCi/m^2-yr. One hundred years of deposition at this rate without erosion would result in a cumulative contribution to the soil that is 0.2% of the radium normally expected in the top cm of soil. Thus it is concluded that fugitive dust does not constitute a problem in terms of either airborne or deposited radium-226.

Significance of the Predicted Radon and Radon Progeny Levels

It was estimated that the theoretical lifetime excess lung cancer risk associated with the projected increase in radon progeny concentrations is on the order of 3×10^{-6} (three in a million) for six years of attendance at the nearby school and on the order of 1.0×10^{-4} to 4.7×10^{-4} (one to five in 10,000) for full time residence at the five modeled off-site locations. In comparison to the normally-expected lung cancer risk of 0.03 (3 in 100) for the U.S. population, the projected theoretical risks represent a 0.01% increase for the school and 0.3% to 1.6% for the residences. The maximum projected risk is comparable to that from receiving one chest x-ray per year. In terms of other risks, the maximum radon concentration is comparable to smoking three packs of cigarettes per year or driving in an automobile 160 miles per year.

ASSESSMENT OF POTENTIAL AIRBORNE RADIOACTIVITY EMISSIONS FROM A PROPOSED NEW GYPSUM DISPOSAL FIELD

INTRODUCTION

This report constitutes an assessment of the significance of potential airborne radioactivity emissions from the new gypsum disposal field being proposed by Gardinier, Inc. for its East Tampa Phosphate Chemical Plant (1).

Phosphate rock contains natural radionuclides of the uranium decay series in association with the phosphate mineral. This radioactivity is described in Appendix A. Briefly, in the production of phosphoric acid, one member of the series, radium-226, is co-precipitated with the gypsum by-product and hence is present in the stored phosphogypsum. Through radioactive decay, radium-226 is a source of constant production of radon-222, a radioactive noble gas. Some of the radon is released from the crystalline structure of the radium-bearing material, is transported to the surface, crosses this interface, and becomes dispersed in the atmosphere. Radioactive decay of radon produces a series of radioactive decay products known collectively as radon progeny or radon daughters. Radon decay in the atmosphere results in the presence of airborne radon progeny, either as free ions or attached to dust particles. Radon progeny levels are commonly expressed as concentrations in units of "working level" (WL); cumulative exposures to airborne radon progeny are expressed in units of "working level months" (WLM).

For this report, the off-site effects of the following airborne emissions were examined:

1) Airborne radon and radon progeny - the result of radon production in gypsum, emanation to the atmosphere, and transport to the off-site area; and

2) Airborne and deposited radium-226 - as a consequence of fugitive dust emissions.

THE RADIOACTIVITY SOURCE

Two radiological characteristics of the storage pile are necessary as input to this evaluation:

1) The radium-226 concentration of the gypsum, and

2) The radon exhalation rate (or radon flux); that is, the rate at which radon-222 enters the atmosphere from the pile surface.

These characteristics are reviewed in Appendix B. On the basis of the available data, it is concluded that the parameters to use for this assessment are:

1) Radium-226 content of gypsum - 24 pCi/g, and

2) Radon-222 exhalation rate from dry stacked gypsum - 26 pCi/m^2-s.

OFF-SITE RECEPTOR LOCATIONS

Fifteen off-site receptor locations, suggested by Dames and Moore (2), are described in Table 1 and Figure 1. Five were used for radon and radon progeny modeling; all fifteen were used for modeling concentrations and deposition of radium-226 in fugitive dust.

AIRBORNE RADON AND RADON PROGENY

Method

Two radon source models were considered:

1) The early pile - the entire disposal area is convered with a several meter depth of gypsum; this depth constitutes an "infinite" thickness with regard to generation and exhalation of radon. The

Table 1. Receptor Points

Location	Description	Calculations For: Ra	Rn
1	Housing near southwest quadrant of gypsum field	X	-
2	Housing near southwest quadrant of gypsum field	X	X
3	Housing near northwest quadrant of gypsum field	X	-
4	Housing near northwest quadrant of gypsum field	X	-
5	Housing near northwest quadrant of gypsum field	X	-
6	Housing near northwest quadrant of gypsum field	X	X
7	Housing near southeast quadrant of gypsum field	X	-
8	Housing near southeast quadrant of gypsum field	X	-
9	Housing near southeast quadrant of gypsum field	X	X
10	Housing near southeast quadrant of gypsum field	X	-
11	Housing near southeast quadrant of gypsum field	X	-
12	Housing near southeast quadrant of gypsum field	X	X
13	Progress Village housing near northeast quadrant of gypsum field	X	-
14	Progress Village Elementary School near northeast quadrant of gypsum field	X	X
15	Progress Village housing near northeast quadrant of gypsum field	X	-

Ra = Calculation for gypsum dust and radium-226; airborne concentration and ground deposition.

Rn = Calculation for airborne radon concentration and indoor radon decay product concentration.

From Dames and Moore designations (2).

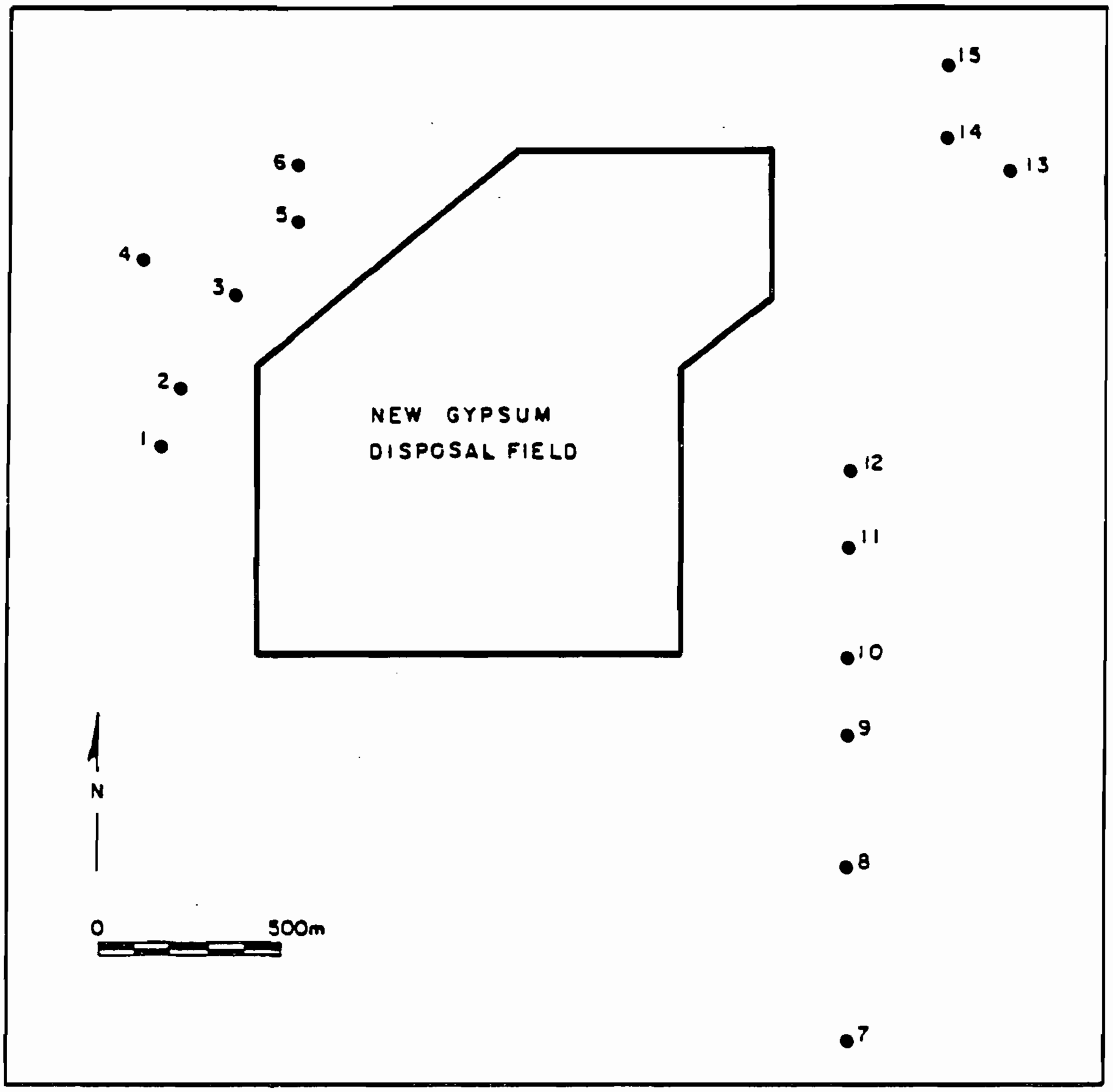

Figure 1. Location of Receptor Points Used For Modeling Purposes.

From Dames and Moore designations (2).

flux was adjusted to 75% of the dry gypsum value to account for an average 25% of the gypsum surface being covered with standing water.

2) Completed pile - gypsum stack 200 ft. high with sloped sides and no standing water. It was assumed that there is negligible radon attenuation by any stabilization cover. Radon flux is 102% of that from a slab equivalent to the base dimensions of the pile and 136% of that from the early pile.

Airborne radon concentrations were estimated for the five off-site locations identified in Table 1 using a mathematical model presented by Schaiger (3) for dispersion near an extended plane radon-emanating source (see Appendix C). Joint frequency distributions of wind speed, wind direction, and stability class were used to determine the annual average concentration. The meteorological data set used was derived from a five-year observation period at the Tampa International Airport.

It was assumed that the average annual radon concentration contributions attributable to the gypsum pile were approximately the same indoors as outdoors. In general, radon and radon progeny concentrations are higher indoors than outdoors due to contributions from building materials, indoor sources such as off-gasing of radon-bearing domestic water and accumulation of radon emanated from the ground under closely-coupled structures. However, for the case of the radon transported through the atmosphere from the gypsum stack, there will be no "trapping" and build-up of concentration.

Indoor radon progeny concentrations were calculated in units of working level (WL) using an assumption of 70% equilibrium between radon and radon progeny concentrations (i.e., a radon concentration of 100 pCi/l is equivalent to 0.7 WL). This is felt to be conservative on the high concentration side since reported indoor equilibrium factors generally range from 0.3 to 0.7.

Results

Results are summarized in Table 2; calculational details are presented in Appendix D. The range of results among the five locations spans less than an order of magnitude. The highest concentrations were predicted for

Table 2. Time-weighted Average Radon-222 and Indoor Radon Progeny Concentrations at Selected Locations[a)]

Location	Contributing Wind Direction	Early Pile[b)]		Completed Pile[c)]	
		Ambient Rn-222 pCi/l	Indoor Rn Progeny WL[d)]	Ambient Rn-222 pCi/l	Indoor Rn Progeny WL[d)]
2	E, ENE	5.8×10^{-2}	4.0×10^{-4}	7.8×10^{-2}	5.5×10^{-4}
6	E, SE, SSE, ESE	8.9×10^{-2}	6.1×10^{-4}	1.2×10^{-1}	8.5×10^{-4}
9	NW, NNW	2.6×10^{-2}	1.8×10^{-4}	3.6×10^{-2}	2.5×10^{-4}
12	W, WNW, NNW	5.5×10^{-2}	3.8×10^{-4}	7.5×10^{-2}	5.2×10^{-4}
14	WSW, SW, SSW	2.0×10^{-2}	1.4×10^{-4}	2.7×10^{-2}	1.9×10^{-4}

a) Reported concentrations represent calculated contributions from the gypsum storage pile source and do not include background or contributions from any other source.

b) Early Pile - Stack one or two meters high (infinite thickness for radon generation); flux adjusted to 0.75 to account for average 25% coverage with standing water.

c) Completed Pile - Stack 200 ft. high with sloped sides; no standing water; negligible radon attenuation by stabilization cover.

d) Indoor radon progeny concentration based on radon progeny/radon equilibrium fraction of 0.7. Values may range from 0.3 to 0.7.

the location northwest of the storage site; intermediate concentrations were predicted for the locations directly west and directly east; the lowest concentrations were projected for locations to the northwest and to the southwest.

Contributions of the "early pile" source to ambient radon-222 concentrations range from 0.02 to 0.09 pCi/l for the five locations. These contributions can be compared to an expected background ambient radon concentration on the order of 0.2 pCi/l (Appendix B) and, thus, represent additions to background on the order of 10 to 45%. Contributions of the "completed pile" source range from 0.03 to 0.1 pCi/l or additions to background on the order of 15 to 50%.

The maximum predictions are of the same order of magnitude as values estimated by EPA investigators (4) for Polk County, Florida gypsum stacks. Using meteorological data from McCoy Airport in Orlando, those investigators estimated an annual average radon concentration on the order of 0.2 pCi/l for a location in the maximum wind direction and 800 m from the center of the pile.

The significance of radon lies not in the radon concentrations themselves, but rather in the resulting exposure to airborne radon progeny. Contributions of the gypsum pile to radon progeny concentrations are predicted to range from 0.0001 to 0.0006 WL for the early pile source and from 0.0002 to 0.0009 WL for the completed pile source. These values are consistent with the average of 0.0006 WL and range of 0.0002 to 0.0013 WL (including background) observed in four short-term measurements over Florida phosphogypsum piles (Appendix B). The measurements included one over the existing Gardinier gypsum pile where a value of 0.0003 WL was observed.

The maximum predicted concentration is also comparable to the EPA estimate (4) that Central Florida gypsum piles would contribute on the order of

0.001 WL to the indoor radon progeny concentrations in a structure located 800 m from the center of the pile in the maximum wind direction.

Average concentrations of 0.003 WL (5) to 0.004 WL (6) may be expected for Florida structures constructed over lands without enhanced soil radium. Thus, the projected gypsum pile-related contributions represent an increase above the expected background of 4% to 18% for the early pile source and 5% to 25% for the completed pile. The absolute increase, on the order of 0.0001 to 0.001 WL is of the same magnitude or even lower than the limit of uncertainty for measurements by current techniques and could not be detected by measurement.

Comparison to Standards

While there presently are no generally applicable standards for non-occupational exposure, standards are under development and various recommendations have appeared (see Appendix B). The predicted gypsum pile-related increases in indoor radon progeny concentrations, on the order of 0.0001 to 0.001 WL, are well below all the suggested limits which fall in the range of 0.005 to 0.05 WL above background (7,8).

RADIUM-226 IN FUGITIVE DUST

Method

Ranges of airborne concentrations and deposition of particulate matter due to fugitive dust emissions from the proposed gypsum pile were modeled by Dames and Moore (2) for the 15 receptor locations described in Table 1. These estimates were derived using the U.S. Environmental Protection Agency's Industrial Source Complex Long-term Model (ISCLT) and a meterological data set based on observations from the Tampa International Airport.

Geometric means for each site were calculated from the given ranges and mean radium-226 concentrations and deposition rates were calculated by assuming that all dust had an average radium-226 concentration of 24 pCi/g.

Airborne Dust and Radium-226

The predicted range of annual average airborne dust concentration, as provided by Dames and Moore, the calculated mean dust concentration, and the calculated airborne radium-226 concentration in pCi/m^3 for each location are presented in Table 3, columns 2, 3, and 4, respectively. The resulting radium-226 concentrations are in the range of:

$$5 \times 10^{-8} \text{ to } 2.0 \times 10^{-7} \ pCi/m^3.$$

By comparison, the State of Florida uncontrolled area* Maximum Permissible Concentration (MPC) for radium-226 in the insoluble form (9) is:

$$2 \times 10^{-12} \ \mu Ci/ml \quad (\text{i.e., } 2 \ pCi/m^3).$$

Thus, the maximum annual average airborne radium-226 at any of the modeled locations is 10^{-7} (i.e., 1/10-millionth) of the uncontrolled area standard. Therefore, airborne radium-226 from fugitive dust does not constitute a problem.

Deposition of Radium-226

The predicted range of annual average dust deposition rates as provided by Dames and Moore, the calculated mean deposition rates, and the calculated radium-226 deposition rates in pCi/m^2-yr for each location are presented in Table 3, columns 5, 6 and 7, respectively. The resulting radium-226 deposition rates are in the range of:

$$0.02 \text{ to } 0.2 \ pCi/m^2\text{-yr}.$$

By comparison, normal soil that has not been enhanced in radium has a radium-226 concentration on the order of 0.5 pCi/g. At a density of 1.5 g/cm^3, a 1-cm depth of soil contains 7,500 pCi/m^2. One hundred years of deposition

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*Members of the general public.

Table 3. Gypsum Dust and Radium-226 Airborne Concentration and Deposition Modeling.

Receptor Point	Annual Average Gypsum Dust Concentration Range Attributable to Proposed Gypsum Disposal Field[a]: Dust, μg/m³ Range[b]	Dust, μg/m³ $\bar{x}g$[c]	Radium-226, pCi/m³[d)]	Annual Gypsum Dust Deposition Range Attributable to Proposed Gypsum Disposal Field[a]: Dust, g/m²-yr Range[b]	Dust, g/m²-yr $\bar{x}g$[c]	Radium-226, pCi/m²-yr[d)]
1	0.005 - 0.01	0.007	2×10^{-7}	0.004 - 0.008	0.006	0.1
2	0.005 - 0.01	0.007	2×10^{-7}	0.004 - 0.008	0.006	0.1
3	0.005 - 0.01	0.007	2×10^{-7}	0.004 - 0.008	0.006	0.1
4	0.003 - 0.006	0.004	1×10^{-7}	0.002 - 0.004	0.003	0.07
5	0.005 - 0.01	0.007	2×10^{-7}	0.005 - 0.01	0.007	0.2
6	0.005 - 0.009	0.007	2×10^{-7}	0.003 - 0.006	0.004	0.1
7	0.002 - 0.003	0.002	5×10^{-8}	0.0005 - 0.001	0.0007	0.02
8	0.003 - 0.005	0.004	1×10^{-7}	0.002 - 0.003	0.002	0.06
9	0.004 - 0.007	0.005	1×10^{-7}	0.002 - 0.004	0.003	0.07
10	0.004 - 0.008	0.006	1×10^{-7}	0.003 - 0.006	0.004	0.1
11	0.005 - 0.009	0.007	2×10^{-7}	0.004 - 0.007	0.005	0.1
12	0.005 - 0.01	0.007	2×10^{-7}	0.004 - 0.007	0.005	0.1
13	0.002 - 0.004	0.003	7×10^{-8}	0.002 - 0.003	0.002	0.06
14	0.003 - 0.005	0.004	1×10^{-7}	0.002 - 0.003	0.002	0.06
15	0.002 - 0.004	0.003	7×10^{-8}	0.001 - 0.002	0.001	0.03
Summary	0.002 - 0.01	0.003-0.007	$(0.5-2) \times 10^{-7}$	0.0005 - 0.008	0.0007 - 0.006	0.02 - 0.2

a) Rounded to one significant digit.
b) Range from modeling by Dames and Moore (2).
c) Geometric mean calculated from given range
d) Calculated from geometric mean of gypsum dust assuming ^{226}Ra @ 24 pCi/g (24×10^{-6} pCi/μg).

of gypsum dust at the maximum predicted rate (0.2 pCi/m^2-yr) without any erosion would contribute 20 pCi/m^2. This is 1/375 or 0.27% of the radium in the top cm of soil! Thus, deposition constitutes a miniscule addition to the radium that is already present in the soil.

SIGNIFICANCE OF PREDICTED RADON AND RADON PROGENY LEVELS

Health Impact

The major potential health hazard (if any actually exists) due to the exposure of radionuclides associated with the concentration of naturally-occurring radioactive materials in gypsum would be from the inhalation and lung deposition of radon decay products. Any other exposure to the body from radon and radon progeny or from radium-226 in dust from the gypsum pile can be considered to be of so much less significance that health impact calculations are not warranted.

Although the actual health risk of radiation exposures has never been observed at these low levels, it is often desirable to calculate theoretical risk. In this case the best available information on the probability of the occurrence of lung cancer due to the radiation exposure to radon and radon progeny is from studies involving concentrated levels of radon progeny in unventilated uranium mines (10).

From the uranium miner studies, several groups have estimated the values of the total lifetime risk of excess lung cancer to range from 1×10^{-4}/WLM (11) to 8.5×10^{-4} /WLM (12), a range of from one chance in 10,000 to 8.5 chances in 10,000. The 1×10^{-4} model as derived by Evans et al., although more recent, is the result of extensive review of the uranium miner data by the Radon Task Force and appears to have substantial support in the USA and nationally. The 8.5×10^{-4} model currently is recommended by EPA. In order to be conservative for this report a risk model of

$$3 \times 10^{-4} \text{ excess lung cancers per WLM}$$

is used. It is the upper bound in the model of $(2 - 3) \times 10^{-4}$ excess lung cancers per WLM developed by the ICRP (10) based on uranium miner data. Table 4 summarizes the risk of lung cancer from the predicted radon progeny exposures in the six locations of interest. Location 14 is divided into two categories; 14a, children in the school and 14b, residences.

In order to interpret these calculations, one must keep in mind that lung cancer occurs in about 3 out of every 100 people (a 0.03 or 3% probability) (13). The increased risk due to gypsum pile exposures range from 0.000003 (0.0003% probability) at location 14a to 0.00047 (0.047% probability) at location 6. These projected theoretical risks represent a 0.01% increase for school children and a 0.3% to 1.6% increase for the residences.

Comparison of Risk to Other Radiation Exposures

In order to develop a perspective for radiation risk, it is convenient to compare the exposure of interest to other, more familiar types of radiation exposure. In this situation, one could state that:

living at location 6, the area of potentially the highest radiation exposure from the proposed gypsum pile is comparable to having a chest x-ray once a year.*

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*Based on an approximately 40 mrem dose from a chest x-ray with a risk model of $\frac{200 \text{ excess cancers}}{10^6 \text{ person rem}}$ (14). This can be interpreted as 200 excess cancers in a population of a million when each person has a 1 rem dose, or as a probability of 2 in 10,000 of excess cancer per rem.

200×10^{-6} cancers/person rem $\times 40 \times 10^{-3}$ rem/yr $\times 50$ yr $= 4 \times 10^{-4}$ compared to 4.7×10^{-4}.

Table 4. Risk of Lung Cancer Due to Gypsum Stack Contributions to Radon Progeny Exposure

Location	Annual Average Indoor Concentration, WL[a)]	WLM/WLY[b)]	Annual Cumulative Exposure, WLM/yr	Years at Risk	Lifetime Risk[c)]
2	5.5×10^{-4}	36	1.9×10^{-2}	50	2.9×10^{-4}
6	8.5×10^{-4}	36	3.1×10^{-2}	50	4.7×10^{-4}
9	2.5×10^{-4}	36	9.0×10^{-3}	50	1.4×10^{-4}
12	5.2×10^{-4}	36	1.9×10^{-2}	50	2.9×10^{-4}
14a (school)	1.9×10^{-4}	9	1.7×10^{-3}	6[d)]	3.1×10^{-6}
14b (residences)	1.9×10^{-4}	36	6.8×10^{-3}	50	1.0×10^{-4}

a) Concentration values for the completed pile source have been used as "worst" case values.

b) WLY - "working level year". The factor, WLM/WLY, converts concentration in WL to annual cumulative exposure in WLM/yr.

- For residences, WLM/WLY = 36 is based on the assumption that full time residents breathe three times the air volume as breathed during working hours only.
- For the school, WLM/WLY = 9 is based on the assumption of 40 hr/wk occupancy for 9 months.

c) Risk model used is 3×10^{-4} excess lung cancers per WLM.

d) An upper limit assumption is made here that the school could be used for grades 1-6, although it is currently used for only one grade.

All other areas of interest have an even smaller potential of risk.

Comparison of Radiation Risk to Other Types of Risk

Radiation risk can also be compared to other types of risks which people encounter in their daily lives. For example,

> the theoretical risk associated with living at location 6 nearest the proposed gypsum pile for a lifetime can be compared to smoking three packs of cigarettes per year or driving 160 miles per year in an automobile.**

**Based on risk factors of 1.4 deaths x 10^{-7} per cigarette smoked and 5.6 x 10^{-8} deaths per mile of automobile driving (15).

$$60 \text{ cigarettes} \times 1.4 \times 10^{-7} \text{ deaths/cigarette} = 8.4 \times 10^{-6}$$

$$8.4 \times 10^{-6} \times 50 \text{ yr} = 4.2 \times 10^{-4}$$

$$160 \text{ miles/yr} \times 50 \text{ yr} \times 5.6 \times 10^{-8} \text{ deaths/mile} = 4.5 \times 10^{-4}$$

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APPENDIX A
NATURAL RADIOACTIVITY AND PHOSPHATE MATERIALS

The presence of uranium and its radioactive decay chain in association with Florida phosphate deposits has long been known. It should be pointed out that uranium is ubiquitous on the earth and is concentrated in a variety of minerals, ores and deposits. Some selected average concentrations include:

The earth's crust	1-4 ppm
Florida phosphate matrix	50-150 ppm
Western U.S. uranium ores	1000-5000 ppm
High grade Canadian and African uranium ores	10,000-40,000 ppm

Thus, the uranium content of Florida phosphate matrix is elevated above typical topsoils but considerably less than medium and high grade uranium ores. Elevations in natural radioactivity are not confined to the commercially-mined phosphate deposits. For example, sands with similar uranium concentrations may be found on the dunes and beaches of south west Florida and uranium and thorium may be found in heavy mineral sands in various parts of the state.

Where uranium has remained undisturbed in nature, there are associated several naturally occurring radioactive decay series including the uranium series illustrated in Fig. A-1. In the undisturbed state, the members of the series at least through radium-226 would be expected to be in radioactive equilibrium - that is, all members present in equal quantities of radioactivity. The remaining members of the series would be expected in quantities approaching equilibrium but reduced to whatever extent there is a net loss of the gaseous member, radon-222. In chemical operations, the various members of the series may follow separate pathways determined by their chemical properties.

There are several distinct features and constituents of the uranium series that are of particular significance to this project. Both alpha and beta emitters are represented and some members also emit gamma radiation. Gamma emitters are significant as potential sources of external radiation exposure. While alpha radiation cannot penetrate the skin, alpha emitters are of particular concern if they become deposited inside the body where the radiation is more effective than beta or gamma radiation in producing biological effects.

Gamma Radiation

While a number of the uranium series members are gamma emitters, gamma radiation is most pronounced when radium-226 is present with its daughter products radon-222 through bismith-214. This gamma radiation facilitates detection of uranium ore and of radium, and accumolations of radium and daughter products may consititute a source of external radiation exposure to man.

Radon and Progeny

Radon-222 and the radon progeny through ^{214}Po constitute a significant segment of the series for another reason. Radon is constantly being produced whenever radium is present. Being a noble gas and having a half-life on the order of days, radon may be released from the mineral in which it is formed. diffuse through porous media and liquids and become airborne. Decay of radon in the atmosphere results in the formation of airborne radon progeny which exist either as free-ions or attached to particles. If inhaled, some of the airborne radon progeny deposit in the respiratory system where they irradiate bronchial and lung tissue.

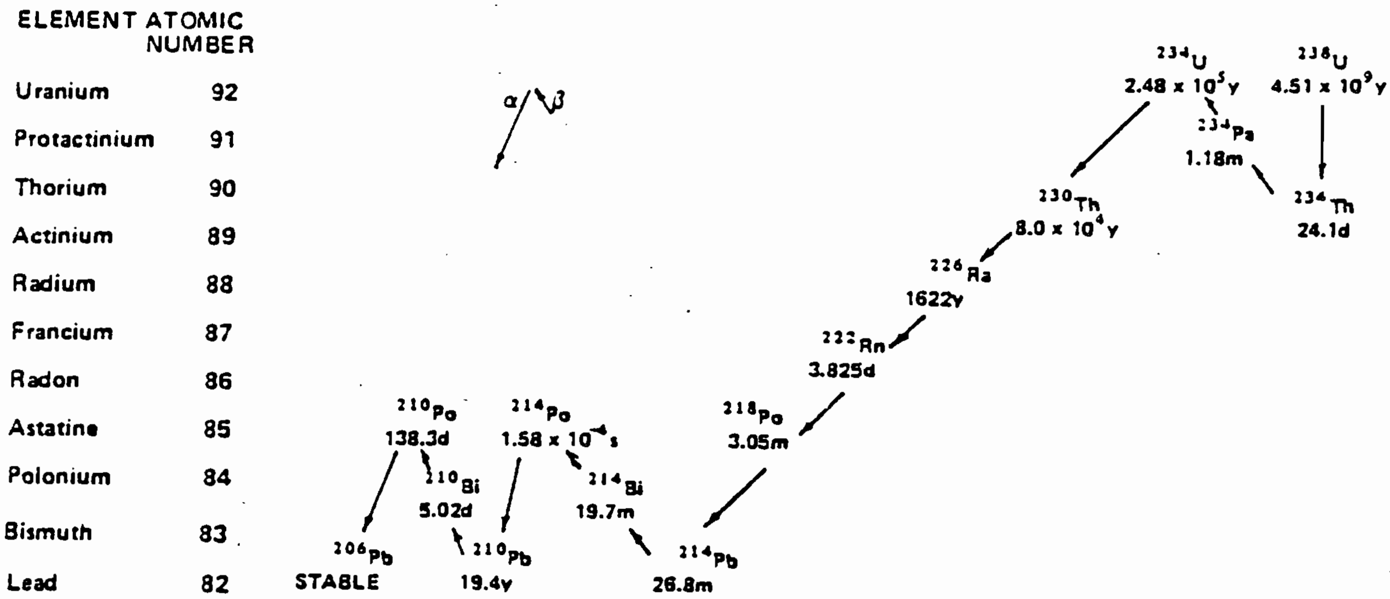

FIGURE A-1. Uranium-238 Decay Series.

Long-lived Alpha Emitters

Other members of the series may become airborne through mechanical processes and thus constitute another route of inhalation exposure in dusty locations. Of particular interest are the long-lived alpha emitters ^{238}U, ^{234}U, ^{230}Th, and ^{226}Ra and the intermediate lived ^{210}Po.

Radium-226 constitutes a potential problem from still another standpoint. It has a sufficiently long half-life (1600 years) so that it may be found occurring independently long after physical and chemical processes have separated it from other members of the decay series. Being chemically similar to the element calcium, following the same chemical and biochemical pathways, and being an alpha emitter, radium is one of the more biologically significant members of the decay chain.

Radioactivity Quantities and Units Used in This Report

A. Activity - The quantity of radioactivity is expressed in terms of the rate at which the nuclei of atoms undergo transformation ("disintegrate"). A traditional special unit of activity is the curie; several fractional units are also in common usage:

curie (Ci) - that quantity of radioactive nuclide disintegrating at the rate of 3.7×10^{10} atoms/second or 2.22×10^{12} atoms/minute.

microcurie (μCi)-one millionth of a curie (3.7×10^{4} dis/sec or 2.22×10^{6} dis/min).

picocurie (pCi) - millionth of a microcurie (3.7×10^{-2} dis/sec or 2.22 dis/min).

B. Concentration - The radioactivity of an environmental medium is usually expressed in terms of activity concentration:

Solid materials such as soil and gypsum - μCi/g, pCi/g, pCi/kg, etc.

Airborne radioactivity - μCi/ml, pCi/liter or pCi/m^3.

$$1\ \mu Ci/ml = 10^{9}\ pCi/liter = 10^{12}\ pCi/m^{3}$$

C. Concentration of Airborne Radon Progeny - Airborne radon progeny concentrations are customarily expressed in units of "Working Level", a unit devised to provide a meaningful expression of airborne radon progeny concentrations independent of the relative proportions of the various individual short-lived radon daughters. One Working Level (WL) is defined as any combination of radon progeny in one liter of air whose ultimate decay through polonium-214 will deliver 1.3×10^{5} MeV of alpha energy. This is the same alpha energy as delivered by short-lived radon progeny in equilibrium with 100 pCi of radon-222. The unit for time-integrated concentration is known as the Working Level Month (WLM). The presence of air containing a radon daughter concentration of one WL for 170 hours (one working month) results in a cumulative concentration of one WLM.

APPENDIX B

REFERENCE RADIOACTIVITY DATA

I. The Radioactivity Source

A. Radium-226 Content of Gypsum

Sampling Date	No. of Samples	Concentration, pCi/g	Data Source
1) Central Florida Phosphoric Acid Plants			
1976-78	10	25.9 (21.1-34.8)	(1)
2) Gardinier Data			
8/73	2	24.5 (21-28)	(2)
8/7/76	1	24.5	(3)
12/78	3	23.4 (22.8-24.4)	(3)
Summary	6	24.0 (21-28)	
	(Use 24 pCi/g for this study)		

B. Radon Flux from Gypsum Piles

EPA data, two central Florida gypsum piles, measured July -Sept. 1978 (4)(5)

Location	Area	Radium, pCi/g	Radon Flux, pCi/m^2-s	Radon Source Ci/yr
Pile A	75.4Ha	25 (19.2-32.2)	--	620
Old Section	--	--	$(0.14-7.2) \times 10^3$	--
New Section	--	--	$(0.17-6.3) \times 10^3$	--
Pile B	81.7Ha	27 (12.8-42.8)	--	680
Old Section	--	--	$(0.11-1.5) \times 10^3$	--
New Section	--	--	$(0.38-8.1) \times 10^3$	--
Summary of Two Piles				
Old Sections	--	--	$(0.11-7.2) \times 10^3$	
New Sections	--	--	$(0.17-8.1) \times 10^3$	
Used for further calculations	--	Avg. = 26	26.7	
		(Use 26 pCi/m^2-s for this report)		

II. Ambient Radon Concentrations

A. Outdoor Radon Concentrations Measured in Florida (6)

Land Type	Location	No. Samples/Sites	Radon-222, pCi/l Site Mean (range)
Unaltered	Alachua Co.	11/8	0.41 (0.11-0.70)
Unaltered	Polk Co.	1/1	0.56
Tailings	Polk	5/5	0.22 (0.07-0.46)
Overburden	Polk	8/7	0.32 (0.07-0.48)
Debris	Polk	10/10	0.32 (0.19-0.73)
Unmined, Radioactive Fill	Polk	6/3	0.60 (0.43-0.80)
Reclaimed, Unknown	Polk	2/2	0.45 (0.31-0.60)
Unknown	Polk	2/1	0.32 (0.10-0.55)
Summary of 37 Sites			0.36 (0.22-0.60)
Range of 45 Samples			(0.07-0.80)

NOTE: No pattern with land type.

B. From NCRP Report # 45 (7)

Avg. for Northern Hemisphere	0.1 pCi/l
Florida (Golden et al.)	0.02-0.3 pCi/l

C. Mean Florida Value from A and B 0.2 pCi/l

III. Airborne Radon Progeny Concentrations Measured Over Gypsum Piles

Short-term grab sample measurements:

Florida Phosphate Industry (8)	4 Measurements 4 Plants	0.0006 (0.0002-0.0013) WL
Gardinier (3)	8/9/76 15:37	0.00034 WL

IV. Standards for Indoor Radon and Radon Progeny Concentrations

At the present time there are no generally applicable airborne radon progeny standards in the U.S. for members of the general public. However, standards are under development and various recommendations have appeared. The National Council on Radiation Protection and Measurements (NCRP) is currently working on a recommendation in response to a request from the State of Florida; this report is expected to appear in the near future.

The current standard for uranium miners and other radiation workers is 4 WLM/yr which is equivalent to a concentration of 0.33 WL under full time occupational exposure of 2000 hrs/yr (40 hrs/wk x 50 wks/yr).

Recommendations for limiting indoor radon progeny concentrations in the non-occupational setting range from 0.005 to 0.05 WL above background. In 1969 guidance issued to the State of Colorado, the U.S. Surgeon General (9) recommended that remedial action was indicated for structures in which the radon progeny concentration exceeded 0.05 WL above background and that it may be warranted in the range of 0.01 to 0.05 WL above background. Recommendations from the Administrator of EPA to the State of Florida in 1979 (10) suggested that remedial action be taken when radon progeny concentrations exceeded 0.02 WL in existing structures. The same document also recommended that building sites be selected and prepared and residences be designed and constructed so that indoor radon progeny concentrations do not exceed the normal indoor background level within the uncertainties of background variation and measurement variability. With measurement uncertainties on the order of 0.005 WL and normal background on the order of 0.004 WL, this translates to a new structure design objective of no more than 0.009 WL ($\sim$0.01 WL). More recently, the Florida state agency Phosphate Related Radiation Task Force is currently preparing an interim model building ordinance having the objective of limiting indoor radon progeny concentrations in residences and occupancy-weighted concentrations in other structures to no more than 0.015 WL (11).

Several other countries of the world have adopted 0.02 WL as an indoor radon progeny standard.

REFERENCES

(1) Roessler, C. E., Z. A. Smith, W. E. Bolch, and R. J. Prince, "Uranium and Radium-226 in Florida Phosphate Materials", Health Physics, Vol. 37, September 1979, pp. 269-277.

(2) U.S. Environmental Protection Agency, Office of Enforcement, Reconnaissance Study of Radiochemical Pollution from Phosphate Rock Mining and Milling, 1973 (revised May 1974).

(3) University of Florida, unpublished data.

(4) Horton, Thomas R., A Preliminary Radiological Assessment of Radon Exhalation from Phosphate Gypsum Piles and Inactive Uranium Mill Tailing Piles, EPA-520/5-79-004, 1979.

(5) Windham, S. T. and T. R. Horton, "Assessment of Radon Exhalation from Phosphate Gypsum", Phosphogypsum, (Proceedings of the International Symposium on Phosphogypsum), 540-553, Florida Institute of Phosphate Research, 1981.

(6) University of Florida, Radioactivity of Lands and Associated Structures, Final Report Volume Four: Data Compilations and Summary Tables, report to Florida Phosphate Council, 1978.

(7) National Council on Radiation Protection and Measurements, Report No. 45, Natural Background Radiation in the United States, 1975 .

(8) Roessler, C. E. and R. J. Prince, Occupational Radiation Exposure in The Florida Phosphate Industry, Final Report to Florida Phosphate Council, December 1978.

(9) Surgeon General of the United States, 1969, "Recommendation of Action for Radiaiton Exposure Levels in Dwellings Constructed on or with Uranium Mill Tailings", Federal Register, Vol. 34, No. 10, pp. 576-577.

(10) Costle, D. M., "Recommendations for Radiation Protection of Persons Residing on Phosphate Lands", contained in letter from Administrator, USEPA, to Governor of Florida, 1979.

(11) State of Florida, Phosphate Related Radiation Task Force, unpublished, February 1982.

APPENDIX C

METHODOLOGY FOR CALCULATING RADON CONCENTRATIONS

Schaiger (1) has presented a model for predicting airborne radon concentrations over a radon-emanating plane source (see Figure C-1) and at nearby down-wind locations. Consider a thin section of air having dimension Δx in the wind direction, width w normal to the wind direction, and height equal to the mean vertical mixing height, σ_z. This air section has a surface area $w\Delta x$ in contact to the source surface and a volume $w\Delta x\sigma_z$. This air volume moves across the source with the wind velocity u. For a downwind travel distance x over the source, the time available for radon emanation into the volume is x/u. If radon emanates from the surface of the source at a constant rate, ϕ pCi/m^2-s, the radon contributed to the volume during this time is $\phi x/u$ pCi/m^2. Assuming the radon is mixed throughout the volume of the section, the airborne radon concentration as a result of travel for a distance x over the source is:

$$C(\text{pCi}/\ell) = (10^{-3}\ \frac{\text{m}^3}{\ell}) \left[\frac{\phi(\text{pCi}/\text{m}^2\text{-s}) \cdot w\Delta x(\text{m}^2) \cdot \frac{x}{u}\ (\text{s})}{w\Delta x\ \sigma_z\ (\text{m}^3)} \right] = \frac{10^{-3}\ \phi x}{u\sigma_z}\ (\text{pCi}/\ell).$$

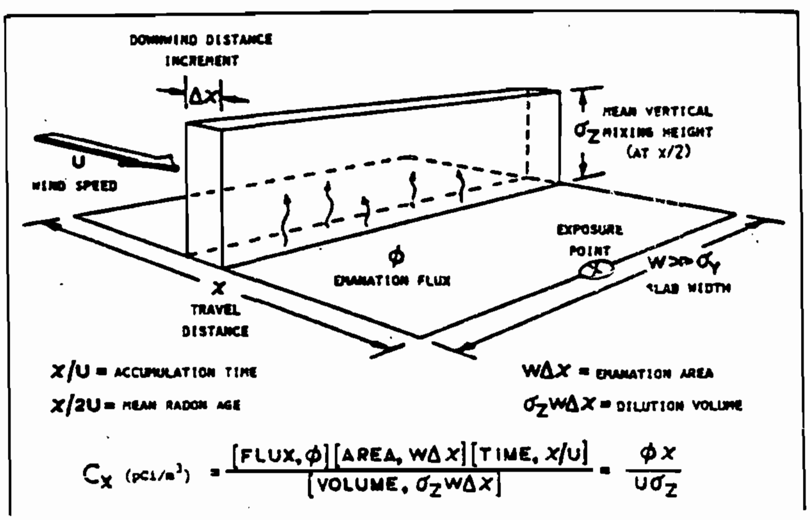

Figure C-1. Radon-Emanating Plane Source Model.

The concentration for a nearby downwind point at distance d beyond the edge of the source can be estimated from:

$$C_{x+d}(pCi/\ell) = C_x(pCi/\ell)\frac{(\sigma_y\ \sigma_z)_x}{(\sigma_y\ \sigma_z)_{x+d}}$$

where x represents the dimension of the source in the direction of the wind and σ_y is the horizontal dispersion coefficient.

While the travel time of the air volume over ths source is u/x the mean age of the radon at the downwind edge of the source is x/2u. The mean radon age at a downwind point distance d beyond the edge of the source would be (d+x/2)/u. If these times are significant relative to the half-life of radon, they can be used to correct the radon concentration for decay during travel to the point of interest.

For this study, the gypsum pile was represented by equivalent rectangles of appropriate dimension x for each wind direction considered.

REFERENCE

(1) Schaiger, K. J., "Analysis of Radiation Exposures on or Near Uranium Mill Tailings Piles", Radiation Data and Reports, Vol. 15, 411-425, July 1974.

APPENDIX D

RADON CALCULATIONS

For the purpose of this study, radon concentrations attributable to the gypsum pile were calculated for the five locations identified in Table 1 and Figure 1 using the methodology described in Appendix C. The meterological input consisted of joint frequency distributions of wind speed, wind direction and stability class as derived from a five-year observation period at the Tampa International Airport. Values of σ_y and σ_z for the various distances and stability classes were taken from Slade (2) and from USNRC Regulatory Guide 1.111 (2).

No corrections were made for radon decay. The greatest travel distance encountered was 2350 meters; this would produce a decay factor of 0.994 for the slowest wind speed considered.

For each receptor location, the contributing wind directions were identified; then for each wind direction, an equivalent source rectangle was specified and the distance from the downwind edge of the source to the receptor location was determined (see Table D-1). Values of σ_z and σ_y for all significantly contributing stability classes were obtained using the downwind dimension of the source rectangle (x) and the source to receptor distance (d).

For each contributing wind direction, the radon-222 concentration contribution at the receptor point was calculated for each significant wind speed within each stability class. Each calculated concentration was then weighted by the joint relative frequency for the wind direction/stability class/wind speed combination. The weighted concentrations were then summed within each wind direction. In turn, the weighted concentration sums for all contributing wind directions were summed to give the total annual average gypsum pile-attributable radon-222 concentration for the receptor location.

Table D-1

Source Geometric Models

Receptor Point	Contributing Wind	Equivalent Rectangle Length (x), Meters	Equivalent Rectangle Width (w), Meters	Distance from Rectangle (d), Meters
2	E	1067	720	274
	ENE	1540	500	300
6	E	1160	500	122
	SSE	1190	850	215
	SE	1190	850	215
	ESE	1190	850	215
9	NW	1280	800	670
	NNW	1280	600	670
12	W	1050	730	490
	WNW	1050	730	425
	NW	1050	730	425
	NNW	1050	730	425
14	WSW	1800	850	550
	SW	1800	850	550
	SSW	1800	850	550

In cases where the equivalent source rectangles for several wind directions within a quadrant were similar (such as for ESE, SE, and SSE) and the relative frequencies within the several directions were similar, the same calculation was used to represent each of the similar wind directions.

A sample calculation is shown below and the complete calculations for the five receptor locations are summarized in Tables D-2 through D-6.

REFERENCES

(1) Slade, D. H., Meteorology and Atomic Energy 1968, U.S. Atomic Energy Commission, Division of Technical Information; available as TID-24190, Clearinghouse for Federal Scientific and Technical Information.

(2) U.S. Nuclear Regulatory Commission, Regulatory Guide 1.111, Method for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water Cooled Reactors, 1977.

SAMPLE CALCULATION:

Consider the early pile (radon flux adjusted for 25% coverage with standing water): $\phi = 0.75\ (26) = 20\ pCi/m^2\text{-}s$

Example Receptor Location - Location 2, housing near SW quadrant of gypsum field.

Example Contributing Wind Direction - from the East

Equivalent source rectangle, w = 720 m, x = 1067 m

Distance downwind source edge to receptor, d = 274 m

Example Stability and Wind Speed - Class A; u = 1.5 kts (0.77 m/s)

From meteorological data set: Relative frequency = 5.5×10^{-5}

Dispersion Coefficients:

Location	Downwind Distance	σ_z	σ_y
Location of mean vertical mixing height	x/2 = 533 m	130 m	--
Downwind edge of source	x = 1067 m	500 m	220 m
Receptor location	x+d = 1341 m	850 m	250 m

Radon-222 concentration at downwind edge of pile:

$$C_x\ (pCi/\ell) = \frac{10^{-3}\ \phi x}{u\ \sigma_z} = \frac{(10^{-3}\ m^3/\ell)(20\ pCi/m^2\text{-}s)(1067\ m)}{(0.77\ m/s)(130\ m)}$$

$$\underline{2.10 \times 10^{-1}\ pCi/\ell}$$

Concentration at receptor point:

$$C_{x+d}\ (pCi/\ell) = C_x \frac{(\sigma_y\ \sigma_x)_x}{(\sigma_y\ \sigma_x)_{x+d}} = 2.10 \times 10^{-1}\ \frac{(500)(220)}{(850)(250)} = \underline{1.10 \times 10^{-1}\ pCi/\ell}$$

Weighted concentration contribution from wind direction E, stability class A, wind speed 0.77 m/s:

$$C_{wt'd} = 1.10 \times 10^{-1} pCi/\ell \times 5.5 \times 10^{-5} = \underline{6.0 \times 10^{-6}\ pCi/\ell}$$

Table D-2

Weighted Radon Concentration Calculations, Receptor Point 2
(Housing near SW quadrant of gypsum field)

Stability Class	Wind Speed (kts)	Wind Origin East: Relative Frequency	Wind Origin East: Radon Concentration (pCi/ℓ)	Wind Origin East: Weighted Concentration (pCi/ℓ)	Wind Origin ENE: Relative Frequency	Wind Origin ENE: Radon Concentration (pCi/ℓ)	Wind Origin ENE: Weighted Concentration (pCi/ℓ)
A	1.5	5.5 E-5	1.10 E-1	6.05 E-6	1.3 E-5	6.88 E-2	8.94 E-7
	5.0	2.0 E-4	3.32 E-2	6.81 E-6	9.1 E-5	2.07 E-2	1.88 E-6
B	1.5	1.5 E-4	3.31 E-1	5.06 E-5	1.1 E-4	2.70 E-1	3.02 E-5
	5.0	1.2 E-3	9.97 E-2	1.23 E-4	8.7 E-4	8.05 E-2	6.99 E-5
	8.5	1.0 E-3	5.86 E-2	5.89 E-5	9.4 E-4	4.76 E-2	4.45 E-5
C	1.5	2.3 E-5	5.28 E-1	1.21 E-5	2.3 E-5	5.47 E-1	1.26 E-5
	5.0	1.7 E-3	1.59 E-1	2.69 E-4	1.7 E-3	1.64 E-1	2.77 E-4
	8.5	5.4 E-3	9.33 E-2	5.03 E-4	5.8 E-3	9.69 E-2	5.66 E-4
	13.5	1.3 E-3	5.87 E-2	7.40 E-5	1.3 E-3	6.09 E-2	7.80 E-5
	19	2.3 E-4	4.17 E-2	9.51 E-6	1.4 E-4	4.34 E-2	5.95 E-6
D	1.5	1.6 E-4	7.23 E-1	1.18 E-4	1.5 E-4	9.48 E-1	1.42 E-4
	5.0	2.2 E-3	2.16 E-1	4.80 E-4	2.5 E-3	2.84 E-1	7.07 E-4
	8.5	1.7 E-2	1.28 E-1	2.12 E-3	1.7 E-2	1.67 E-1	2.87 E-3
	13.5	1.9 E-2	8.04 E-2	1.57 E-3	2.3 E-2	1.06 E-1	2.47 E-3
	19	3.4 E-3	5.71 E-2	1.95 E-4	4.0 E-3	7.50 E-2	3.03 E-4
	21	2.3 E-4	5.16 E-2	1.18 E-5	3.2 E-4	6.78 E-2	2.17 E-5
E	5.0	8.1 E-3	4.02 E-1	3.24 E-3	6.1 E-3	4.93 E-1	3.03 E-3
	8.5	1.4 E-2	2.36 E-1	3.21 E-3	1.5 E-2	2.88 E-1	4.43 E-3
F	1.5	6.9 E-4	2.55	1.75 E-3	5.3 E-4	2.38	1.26 E-3
	5.0	1.2 E-2	7.66 E-1	9.57 E-3	1.2 E-2	7.17 E-1	8.60 E-3
G	1.5	1.1 E-3	4.45	4.90 E-3	8.1 E-4	5.26	4.28 E-3
			Total, E	2.83×10^{-2}		Total, ENE	2.92×10^{-2}

Total for receptor 2 = $(2.83 \times 10^{-2}) + (2.92 \times 10^{-2})$ = 5.8×10^{-2} pCi/ℓ.

Table D-3

Weighted Radon Concentration Calculations, Receptor Point 6
(Housing near NW quadrant of gypsum field)

Stability Class	Wind Speed (kts)	Wind Origin East: Relative Frequency	Wind Origin East: Radon Concentration (pCi/ℓ)	Wind Origin East: Weighted Concentration (pCi/ℓ)	Wind Orgin SE: Relative Frequency	Wind Orgin SE: Radon Concentration (pCi/ℓ)	Wind Orgin SE: Weighted Concentration (pCi/ℓ)
A	1.5	5.5 E-5	1.41 E-1	7.76 E-6	5.2 E-5	1.31 E-1	6.82 E-6
	5.0	2.0 E-4	4.23 E-2	9.70 E-6	1.8 E-4	3.94 E-2	7.21 E-6
B	1.5	1.5 E-4	4.18 E-1	6.40 E-5	1.6 E-4	3.62 E-1	5.61 E-5
	5.0	1.2 E-3	1.26 E-1	1.55 E-4	1.3 E-3	1.08 E-1	1.38 E-4
	8.5	1.0 E-3	7.40 E-2	7.44 E-5	9.6 E-4	6.37 E-2	6.11 E-5
C	1.5	2.3 E-5	6.37 E-1	1.46 E-5	1.2 E-4	6.10 E-1	7.14 E-5
	5.0	1.7 E-3	1.92 E-1	3.24 E-4	1.8 E-3	1.82 E-1	3.24 E-4
	8.5	5.4 E-3	7.13 E-1	6.09 E-4	5.2 E-3	1.08 E-1	5.59 E-4
	13.5	1.3 E-3	7.03 E-2	8.86 E-5	1.3 E-3	6.73 E-2	9.09 E-5
	19	2.3 E-4	5.04 E-2	1.15 E-5	4.6 E-5	4.82 E-2	2.22 E-6
D	1.5	1.6 E-4	1.16	1.89 E-4	2.1 E-4	1.13	2.35 E-4
	5.0	2.2 E-3	3.47 E-1	7.70 E-4	2.1 E-3	3.39 E-1	7.29 E-4
	8.5	1.7 E-2	2.04 E-1	3.39 E-3	1.1 E-2	2.00 E-1	2.26 E-3
	13.5	1.9 E-2	1.49 E-1	2.91 E-3	1.1 E-2	1.25 E-1	1.34 E-3
	19	3.4 E-3	9.13 E-2	3.12 E-4	9.1 E-4	8.92 E-2	8.14 E-5
	21	2.3 E-4	8.27 E-2	1.88 E-5	0	--	--
E	5.0	8.1 E-3	4.67 E-1	3.76 E-3	6.0 E-3	3.98 E-1	2.38 E-3
	8.5	1.4 E-2	2.75 E-1	3.74 E-3	5.3 E-3	2.34 E-1	1.24 E-3
F	1.5	6.9 E-4	2.93	2.01 E-3	4.4 E-4	2.61	1.14 E-3
	5.0	1.2 E-2	8.80 E-1	1.10 E-2	5.4 E-3	7.86 E-1	4.29 E-3
G	1.5	1.1 E-3	4.63	5.09 E-3	7.6 E-4	4.06	3.11 E-3
			Total, E	3.46×10^{-2}		Total, SE	1.81×10^{-2}

Use also for ESE and SSE

Receptor point 6 total = $3.46 \times 10^{-2} + 3(1.81 \times 10^{-2})$ = $\underline{8.9 \times 10^{-2}}$ pCi/ℓ.

Table D-4

Weighted Radon Concentration Calculations, Receptor Point 9
(Housing near SE quadrant of gypsum field)

Stability Class	Wind Speed (kts)	Wind Origin NW Relative Frequency	Radon Concentration (pCi/ℓ)	Weighted Concentration (pCi/ℓ)
A	1.5	4.5 E-5	3.81 E-2	1.71 E-6
	5.0	1.4 E-4	1.14 E-2	1.56 E-6
B	1.5	1.4 E-4	1.76 E-1	2.52 E-5
	5.0	5.0 E-4	5.30 E-2	2.66 E-5
	8.5	4.1 E-4	3.11 E-2	1.28 E-5
C	1.5	3.2 E-5	4.02 E-1	1.29 E-5
	5.0	6.4 E-4	1.21 E-1	7.73 E-5
	8.5	1.9 E-3	7.10 E-2	1.36 E-4
	13.5	8.0 E-4	4.44 E-2	3.55 E-5
	19	1.1 E-4	3.18 E-2	3.62 E-6
	21	6.8 E-5	2.88 E-2	1.96 E-6
D	1.5	1.1 E-4	7.19 E-1	8.12 E-5
	5.0	1.0 E-3	2.15 E-1	2.16 E-4
	8.5	7.2 E-3	1.27 E-1	9.13 E-4
	13.5	1.5 E-2	7.93 E-2	1.19 E-3
	19	5.0 E-3	5.68 E-2	2.81 E-4
	21	1.3 E-3	5.13 E-2	6.78 E-5
E	5.0	2.9 E-3	3.28 E-1	9.51 E-4
	8.5	8.1 E-3	1.93 E-1	1.57 E-3
F	1.5	3.9 E-4	1.89	7.31 E-4
	5.0	6.1 E-3	5.69 E-1	3.49 E-3
G	1.5	1.2 E-3	4.14	5.13 E-3
			Total	1.50×10^{-2}

Use also for NW and NNW

Total for receptor point 9 = $[1 + (50/67)](1.5 \times 10^{-2}) = \underline{2.6 \times 10^{-2}}$ pCi/ℓ.

Table D-5

Weighted Radon Concentration Calculations, Receptor Point 12
(Housing near SE quadrant of gypsum field)

Stability Class	Wind Speed (kts)	Wind Origin West: Relative Frequency	Wind Origin West: Radon Concentration (pCi/ℓ)	Wind Origin West: Weighted Concentration (pCi/ℓ)	Wind Origin NNW: Relative Frequency	Wind Origin NNW: Radon Concentration (pCi/ℓ)	Wind Origin NNW: Weighted Concentration (pCi/ℓ)
A	1.5	5.2 E-5	5.41 E-2	2.81 E-6	6.0 E-6	6.11 E-2	3.67 E-7
	5.0	1.8 E-4	1.62 E-2	2.96 E-6	4.6 E-5	1.83 E-2	8.42 E-7
B	1.5	1.5 E-4	2.38 E-1	3.57 E-5	2.8 E-5	2.74 E-1	7.67 E-6
	5.0	1.2 E-3	7.13 E-2	8.27 E-5	5.9 E-4	8.22 E-2	4.88 E-5
	8.5	2.4 E-3	4.20 E-2	1.01 E-4	4.6 E-4	4.84 E-2	2.21 E-5
C	1.5	1.2 E-5	4.68 E-1	5.62 E-6	5.7 E-5	5.18 E-1	2.95 E-5
	5.0	8.7 E-4	1.40 E-1	1.22 E-4	7.5 E-4	1.55 E-1	1.17 E-4
	8.5	7.6 E-3	8.26 E-2	6.32 E-4	2.2 E-3	9.14 E-2	1.98 E-4
	13.5	4.8 E-3	5.16 E-2	2.45 E-4	8.2 E-4	5.71 E-2	4.69 E-5
	19	4.6 E-4	3.70 E-2	1.69 E-5	9.1 E-5	4.09 E-2	3.72 E-6
	21	0	--	--	2.3 E-5	3.70 E-2	8.52 E-7
D	1.5	1.6 E-4	8.37 E-1	1.36 E-4	1.8 E-4	8.77 E-1	1.60 E-4
	5.0	1.0 E-3	2.52 E-1	2.65 E-4	9.8 E-4	2.63 E-1	2.58 E-4
	8.5	8.0 E-3	1.48 E-1	1.18 E-3	7.6 E-3	1.55 E-1	1.18 E-3
	13.5	1.8 E-2	9.25 E-2	1.66 E-3	1.2 E-2	9.68 E-2	1.18 E-3
	19	2.8 E-3	6.62 E-2	1.84 E-4	3.5 E-3	6.92 E-2	2.45 E-4
	21	1.0 E-3	6.00 E-2	6.03 E-5	7.3 E-4	6.27 E-2	4.58 E-5
E	5.0	2.1 E-3	3.13 E-1	6.45 E-4	2.8 E-3	3.32 E-1	9.33 E-4
	8.5	4.2 E-3	1.84 E-1	7.76 E-4	7.4 E-3	1.96 E-1	1.46 E-3
F	1.5	2.1 E-4	2.33	4.92 E-4	3.4 E-4	2.45	8.21 E-4
	5.0	2.9 E-3	7.00 E-1	2.02 E-3	6.0 E-3	7.35 E-1	4.40 E-3
G	1.5	3.8 E-4	4.00	1.53 E-3	8.6 E-4	4.36	3.75 E-3
			Total, W	1.02×10^{-2}		Total, NNW	1.49×10^{-2}

Use also for NW and WNW

Total for receptor point 12 = $(1.02 \times 10^{-2}) + 3(1.49 \times 10^{-2})$ = 5.5×10^{-2} pCi/ℓ.

Table D-6

Weighted Radon Concentration Calculations, Receptor Point 14
(Progress Village and school near NE quadrant of gypsum field)

		Wind Origin WSW		
Stability Class	Wind Speed (kts)	Relative Frequency	Radon Concentration (pCi/ℓ)	Weighted Concentration (pCi/ℓ)
A	1.5	2.3 E-5	8.79 E-2	2.02 E-6
	5.0	1.6 E-4	2.64 E-2	4.22 E-6
B	1.5	8.1 E-5	1.71 E-1	1.38 E-5
	5.0	1.2 E-3	5.14 E-2	6.32 E-5
	8.5	3.8 E-3	3.02 E-2	1.16 E-4
C	1.5	1.0 E-5	4.21 E-1	4.21 E-6
	5.0	7.5 E-4	1.26 E-1	9.49 E-5
	8.5	8.1 E-3	7.43 E-2	5.99 E-4
	13.5	3.7 E-3	4.64 E-2	1.71 E-4
	19	2.3 E-4	3.32 E-2	7.57 E-6
	21	2.3 E-5	3.01 E-2	6.92 E-7
D	1.5	9.6 E-5	8.63 E-1	8.28 E-5
	5.0	1.2 E-3	2.59 E-1	3.11 E-4
	8.5	7.7 E-3	1.52 E-1	1.18 E-3
	13.5	9.8 E-3	9.58 E-2	9.39 E-4
	19	9.6 E-4	6.85 E-2	6.57 E-5
	21	2.5 E-4	6.18 E-2	1.55 E-5
E	5.0	1.4 E-3	3.61 E-1	5.02 E-4
	8.5	3.6 E-3	2.12 E-1	7.65 E-4
F	1.5	1.6 E-4	2.13	3.45 E-4
	5.0	1.4 E-3	6.40 E-1	8.77 E-4
G	1.5	9.6 E-5	5.05	4.85 E-4
			Total	6.63×10^{-3}

Use also for SW and SSW

Total for receptor point 14 = $3(6.63 \times 10^{-3})$ = $\underline{2.0 \times 10^{-2}}$ pCi/ℓ.

RADON FLUX MONITORING PROGRAM
GARDINIER, INC. PHOSPHOGYPSUM FIELD
TAMPA, FLORIDA

Final Report

To:

Gardinier, Inc.
P.O. Box 3269
Tampa, Florida 33601

October 30, 1985

By:

Charles E. Roessler, Ph.D.
Certified Health Physicist
525 N.E. 4th St.
Gainesville, Florida 32601

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RADON FLUX MONITORING PROGRAM
GARDINIER, INC. PHOSPHOGYPSUM FIELD, TAMPA, FLORIDA

SUMMARY

A monitoring program was conducted at the Gardinier, Inc. East Tampa Phosphate Chemical Plant to determine the average radon flux from the existing phosphogypsum storage field. An initial phase, conducted December 1983 through February 1984, included examination of the effect of pile surface conditions and the variability with location on the pile. Conditions were then selected for continued sampling and the program continued with monthly sampling through August, 1985.

Radon flux measurements were made by the charcoal absorber method. Charcoal cartridges were deployed in capped standpipes for 48 hours. The collected radon was measured by gamma counting and the average radon flux for the 48-hr period was calculated from the measured radon. The representative flux for each sampling period was estimated from the average of seven to ten collectors deployed over the pile surface.

Based on 23 sampling periods over the 21-month interval, it is estimated that the average radon flux over the exposed, drained surface of this phosphogypsum field is 22 pCi/m2-s.

The average flux values ranged from 16 to 37 pCi/m2-s over the 23 sampling periods. However, the cumulative average stabilized within one or two pCi/m2-s as the study progressed. Individual sample results were more variable: the results of the 205 samples collected ranged from 2 to 94 pCi/m2-s. This indicates the need to use replicate collectors to determine an average value for the pile surface.

The average radon flux based on sampling over the drained, exposed gypsum is likely to provide an over-estimate of the radon source term for the active pile while much of the surface is wet. The flux measured over the older, grassed areas of the pile appeared to be lower than for the exposed gypsum. Again, the average flux for the drained, exposed gypsum is likely to be an over-estimate of the radon source terms for the portions of an active pile where covering and grassing has begun or for a settled, covered, inactive pile.

RADON FLUX MONITORING PROGRAM
GARDINIER, INC. PHOSPHOGYPSUM FIELD, TAMPA, FLORIDA

INTRODUCTION

A monitoring program was conducted at the Gardinier, Inc. East Tampa Phosphate Chemical Plant to determine the average radon flux from the existing phosphogypsum storage field. An initial phase, conducted December 1983 through February 1984, included examination of the effect of pile surface conditions and the variability with location on the pile. Conditions were then selected for continued sampling and the program continued with monthly sampling through August, 1985.

METHODS

Radon flux measurements were made by the charcoal absorber method. Charcoal cartridges were deployed in capped standpipes for 48 hours. Following the deployment period, the collected radon was measured by gamma counting of the cartridge and the radon flux was calculated from the measured radon.

The method used is the method of Johnson (1983), a modification of the method published by Countess (1976). In a review of radon flux measurements, Colle', et. al (1981) of the National Bureau of Standards state "The charcoal cannister method is probably now the most widely used method for determining radon flux density".

In the method used here, a charcoal cartridge (Mine Safety Appliances Model GMC recirator cartridge) is deployed in a capped standpipe as indicated in Figure 1. The cartridge is elevated above the surface to prevent wetting of the charcoal from a moist surface or from rain and also to avoid disturbing the natural boundary layer at the substrate-air interface.

In field deployment, the sharpened end of the pipe is inserted into the surface, an activated charcoal cartridge is supported by its rim in the upper end of the pipe and the pipe is capped. In a typical gypsum field deployment, the lower surface of the cartridge is supported about 15 cm above the gypsum surface (Figure 2).

A deployment of 48 hours is used as a compromise between a number of competing factors. Long deployment times have the advantage of averaging out short-term temporal variations in actual radon flux. Long collection times also minimize the effect of the temporarily enhanced radon flux stimulated by disturbance of the surface in collector emplacement. On the other hand, if deployment times are too long, radon can migrate through the charcoal bed and be desorbed. Also, with extensive time, the build-up of adsorbed radon at the collection front may reduce collection efficiency.

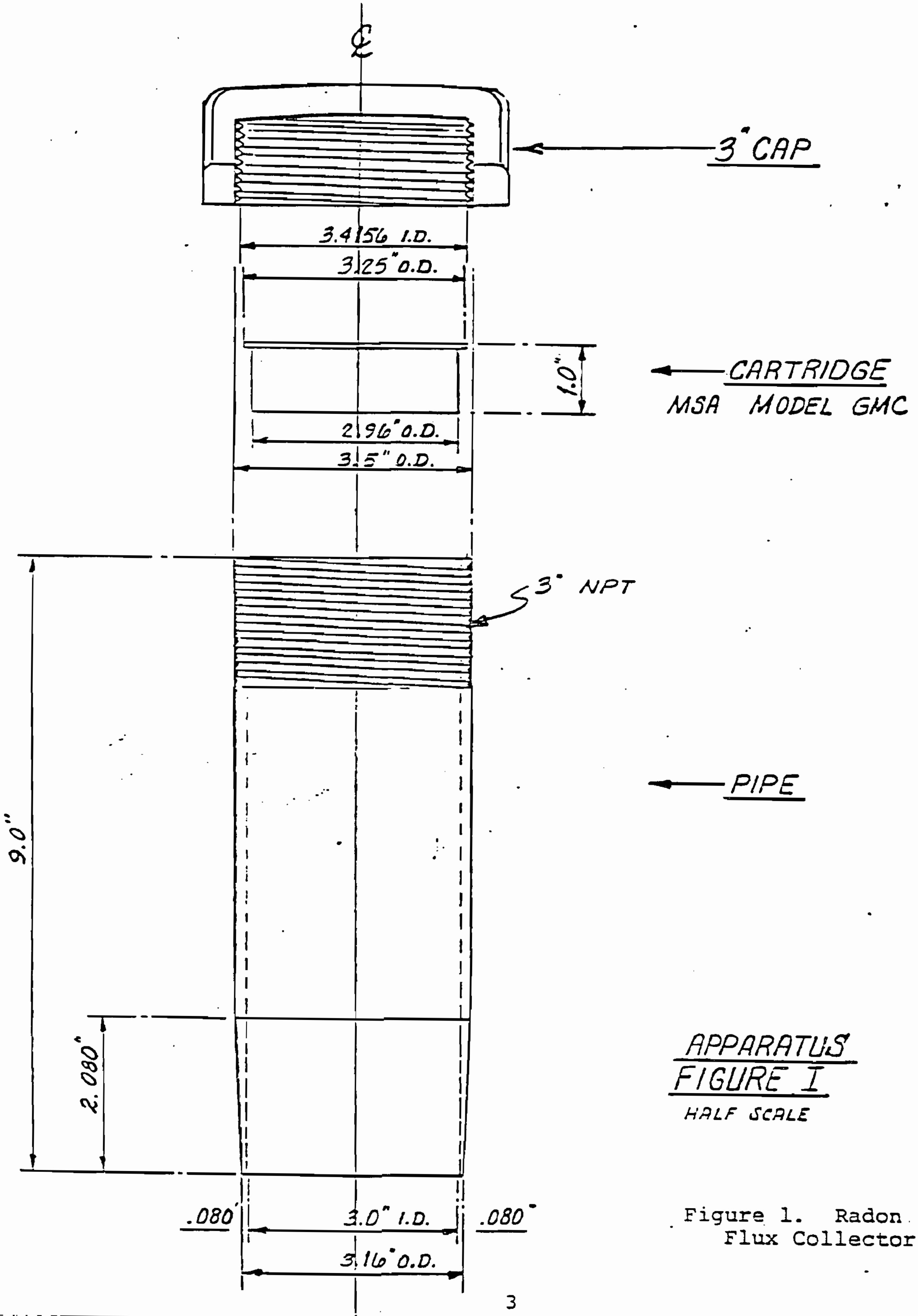


Figure 1. Radon Flux Collector

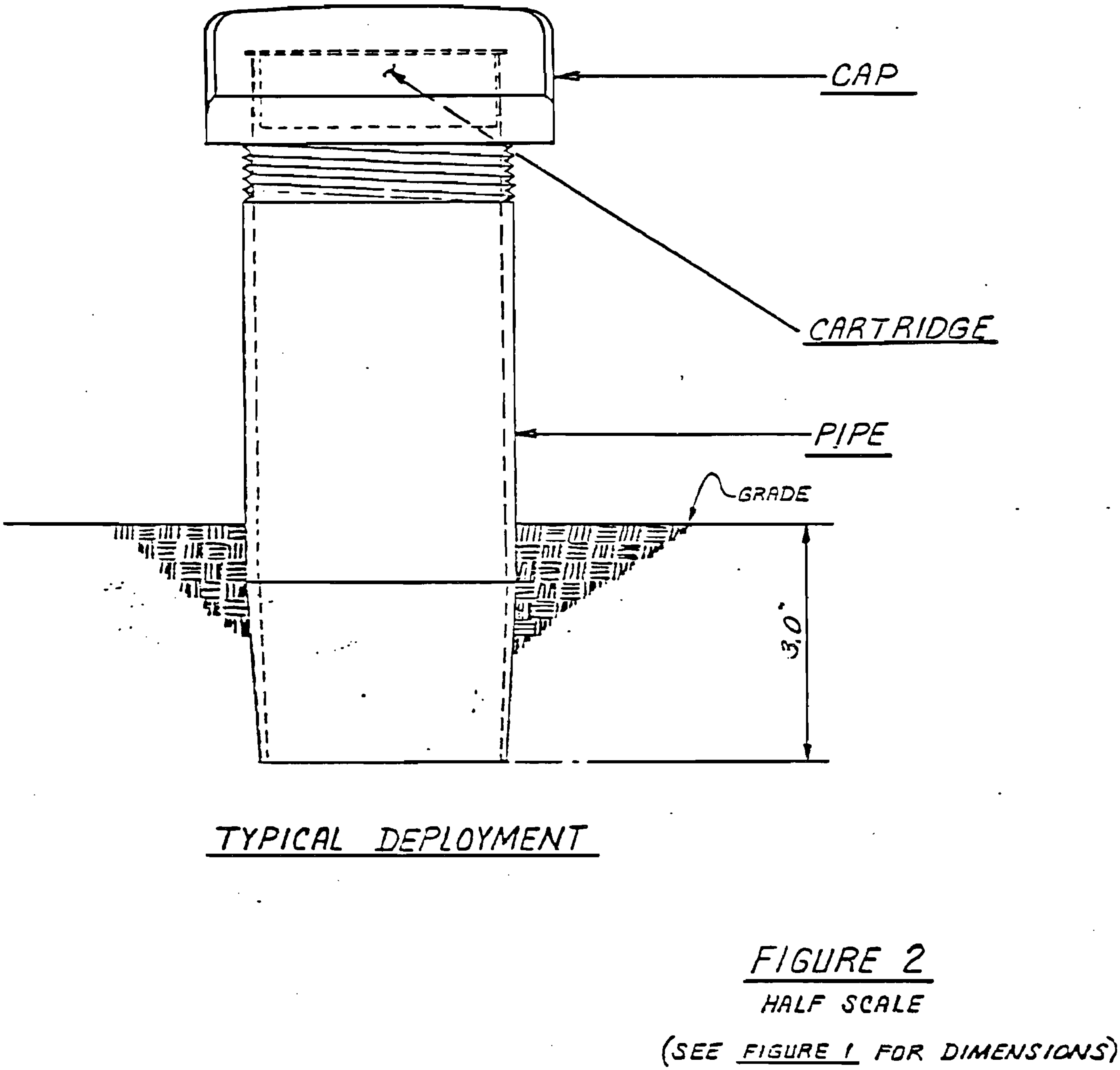


Figure 2. Typical Deployment of Radon Flux Collector

At the end of the collection time, the cartridges are wrapped in plastic wrap and placed in metal cans and the cans are taped and shipped to the laboratory.

The cartridges, in their cans, are counted on a gamma scintillation spectrometer with a 4" x 4" NaI(Tl) crystal. The contained radon-222 is determined from the 609 keV peak of the bismuth-214 radon decay product. The quantity of radon-222 is determined by comparison to a standard consisting of a known quantity of radium-bearing material sealed into an empty cartridge housing. The average radon flux (pCi/m2-s) is calculated from the measured radon (pCi) by assuming a uniform radon exhalation during the collection period, correcting for radon decay during collection, delay, and counting, and accounting for collector area and collection time.

The method is based on the premise that the charcoal has a high efficiency for adsorption of radon at the air-charcoal interface and that the concentration gradient across the air column from the substrate interface to the charcoal interface is an efficient driving force for moving the exhaled radon to the adsorber. The assumption is made that under the deployment configuration and conditions used, the radon collected and retained on the charcoal is proportional to the cumulative exhaled radon and that the collection and retention efficiency for this process is nearly 100%.

Standard operating procedures are presented in Appendix A and the results of an experiment on the effect of collector venting are presented in Appendix B.

RESULTS

Phase One Experiment

During the interval December 1983 through February 1984, collectors were deployed for five sampling periods at seven sites on the exposed, drained portion of the field, one site over wet gypsum near the hot slurry discharge, and two sites over an older, grassed portion of the pile. Sampling locations are indicated in Figure 3. Results are summarized in Tables 1 and 2 and presented in detail in Appendix C.

Table 1 summarizes the data related to the effect of pile surface conditions. Unfortunately, the collector at the wet gypsum site was disrupted on two occasions and only three samples were obtained. The average flux from these three measurements was about half that observed from the drained gypsum sites; two results were comparable to the lowest values for the drained gypsum sites and one was comparable to the median for those sites. The radon flux values for the two stations on the older, covered portions of the pile were comparable to the lowest values on the newer, exposed portion of the pile. There was only a

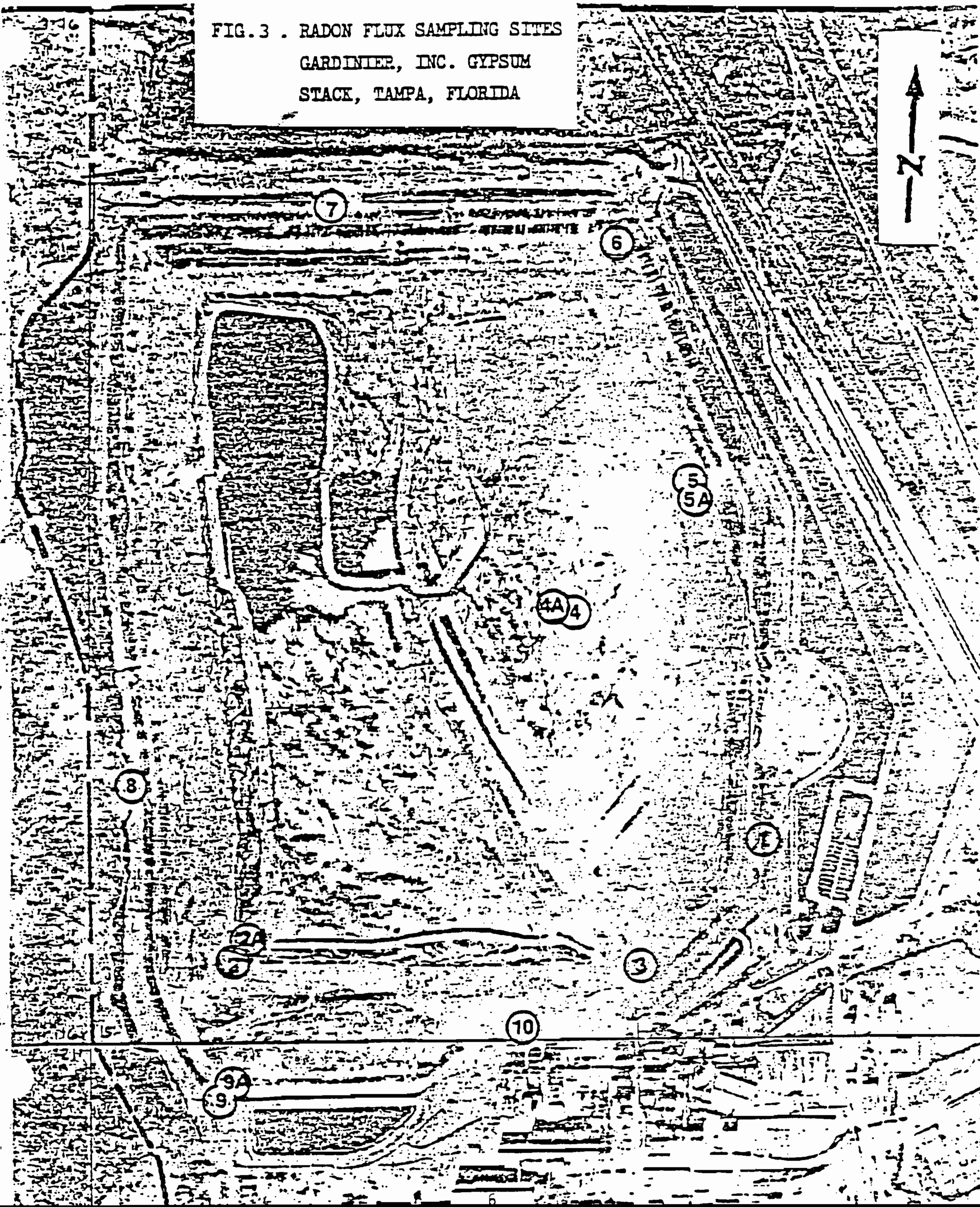


FIG. 3 . RADON FLUX SAMPLING SITES GARDINIER, INC. GYPSUM STACK, TAMPA, FLORIDA

Table 1. Effect of Pile Surface Condition on Radon Flux
(5 sampling periods, 12/83 - 2/84)

Condition	No. of Sites	Total Samples	Radon Flux pCi/m2-s Avg (Range)
Exposed, drained gypsum on top of pile	7	32	23.0 (1.7-63.7)
Wet gypsum near hot slurry discharge	1	3	10.5 (3.0-22.7)
Covered, grassed area	2	10	6.0 (3.4-10.8)

Notes: 48-hour collection periods.
Some samples lost during collection.

small number of samples from two of the surface types, there is considerable variability within all surface types, and apparent differences are not statistically significant. However, the data suggest that the wet gypsum and the covered areas have a lower radon flux than the exposed drained gypsum.

Table 2 summarizes data relating to sample, site, and sampling period variation over the drained, exposed gypsum during the initial sampling experiment. While a detailed statistical analysis was not performed, several things are evident:

1) There was a large variation among samples within sampling periods.
2) The was considerable variation between site averages over continued sampling, and
3) There was a much smaller variation between sampling period averages.

Table 2. Effect of Time and Location on Radon Flux from the Exposed, Drained Phosphogypsum
(7 stations x 5 sampling periods, 12/83 - 2/84)

	Radon Flux pCi/m2-s
Mean of 32 samples	23.0 +/- 2.9*
Ranges:	
5 sampling period averages	15.6 - 31.1
7 site averages	4.5 - 49.2
32 samples	1.7 - 63.7

* +/- one standard error of the mean.

These observations indicated the need to continue to replicate in space (i.e. use multiple sampling sites) to represent the average over the emanating surface. They also indicated the need for some replication in time. However, the average of 7 samples for any single sampling period estimated the 5-period average within a factor of 1.5 and the cumulative average appeared to have stabilized within 1 or 2 pCi/m2-s after the first four sampling periods.

Long-term Measurements

After the initial experiment, long-term measurements were continued on a monthly basis on the exposed, drained portion of the pile. Due to operations on the stack (adding, spreading, reshaping, etc.), it was not possible to continue sampling over the long term in precisely all the same locations. Therefore, the program was modified slightly in March, 1984 to deploy ten collectors over the area of interest with the average value for the sampling period taken as the relevent observation.

Cumulative results through August, 1985 are summarized in Table 3, and presented in detail in Appendix C. These results support the early observations - the between-station variation within sampling periods persists, but the cumulative average has remained relatively stable. The estimated long-term average flux from the exposed, drained gypsum on the newer portions of this pile is 22 +/- 1 pCi/m2-s (one-sigma standard error). Although a detailed statistical analysis was not performed, it appears that the average from any single sampling of 7 to 10 collectors distributed over the pile surface estimates the long-term average within a factor of about 1.7.

Table 3. Average Radon Flux from Exposed, Drained Phosphogypsum (23 sampling periods, 12/83 - 8/85; 7 - 10 stations)

	Radon Flux pCi/m2-s
Mean of 23 sampling periods	21.9 +/- 1.2*
Ranges:	
23 sampling period averages	15.6 - 36.9
203 samples	1.6 - 93.8

* +/- one standard error of the mean.

CONCLUSIONS

Based on 23 sampling periods during the 21-months interval, it is estimated that the average radon flux over the exposed, drained surface of this phosphogypsum field is 22 pCi/m2-s.

The average radon flux based on sampling over the drained, exposed gypsum is likely to be an over-estimate of the radon source term for the active pile while much of the surface is wet.

The flux measured over the older, grassed areas of the pile also appeared to be lower than for the exposed gypsum. This may be due to radon attenuation by the cover, reduced radon transport due to settling and compaction of the gypsum, or other unidentified factors. Again, the average flux for the exposed gypsum is likely to be an over-estimate of the radon source terms for portions of an active pile where covering and grassing has begun or for a settled, covered, inactive pile.

REFERENCES

Colle R., Rubin R.J., Knab L I., and Hutchinson J.M.R., 1981, Radon Transport Through and Exhalation From Building Materials: A Review and Assessment, NBS Technical Note 1139, National Bureau of Standards.

Countess R.J., 1976, "Radon Flux Measurement with a Charcoal Cannister", Health Physics, 31, 455.

Johnson J., 1983, personal communication. Colorado State University, Ft. Collins.

APPENDIX A - PROCEDURES

RADON FLUX MEASUREMENT BY CHARCOAL CARTRIDGE

This is a procedure developed by James Johnson, Western Radiation Consultants, Inc., Ft. Collins. Colorado and is a modification of the procedure published by Countess (1976).

EQUIPMENT:

1. Standpipe - 3-inch inside diameter pipe, sharpened on one end, threaded on the other; with treaded pipe cap.

2. Charcoal cartridges - Mine Safety Applicances Co. (MSA) Chemical Cartridge Part No. 459317. Counted to verify low radium-226 background, activated to remove residual radon-222, and stored for decay of residual radon (twenty-one days decay is preferred: alternatively, cartridges should be counted to verify low background if it is not practical to store between activation and deployment).

3. Counting System - Gamma scintillation counter with NaI(Tl) crystal, 4" x 4" or larger, and multichannel analyzer. (Since interferences are not likely to be present, a single channel analyzer may be used).

PROCEDURES:

1. Selection and preparation of charcoal cartridges.

2. Deployment of cartridges.

3. Counting

4. Calculations

REFERENCE: Countess, R. J. 1976, "Radon Flux Measurement with a Charcoal Cannister", Health Physics, 31, 455.

Written by: C. E. Roessler Date

Reviewed by: C. E. Roessler Date 5/1/84

SELECTION AND PREPARATION OF CHARCOAL CARTRIDGES

A. Regenerating Charcoal (as per telecom. with James Johnson 12/20/83)

- 1) Place in oven @ ~~80°C~~ 110° - 24 hrs. Corrected 1/11/85 CER
- 2) Remove, seal in Saran wrap, place in metal cans
- 3) Hold in storage for additional decay (usually 21 days).

B. Background Counts

If there is a question about the background or storage time was short, count for background -

- 1) Batch count. Count individuals if batch is high, or
- 2) Count cartridge that had the greatest Rn activity during last use.

Written by: C. E. Roessler Date

Reviewed by: C. E. Roessler Date 5/1/84

Revision 1: 1/11/85. C. E. Roessler

RADON FLUX MEASUREMENT BY CHARCOAL CARTRIDGE

Procedure for Deployment of Radon Collectors

EQUIPMENT

1. Standpipe with cap.

2. Charcoal Cartridge - low radium-226 background cartridge. Before deployment, cartridge should be activated to remove radon and should be stored for decay of residual radon or counted to verify low background.

DEPLOYMENT PROCEDURE

1. Select site for delpoyment; do not disturb surface or this will produce a temporary anomaly in flux.

2. Press sharpened end of standpipe into surface being measured, taking care not to disburb the surface crust.

3. Support cannister in top of standpipe by rim on cannister and screw on cap.

4. Record date and time of start of collection.

RETRIEVAL PROCEDURE

1. A suggested collection time is on the order of 24 to 48 hours.

2. Record retrieval date and time.

3. Remove cartridge from standpipe, wrap securely in plastic film (Saran wrap), and place in metal shipping can.

4. Submit cartridges and pertinent data to the laboratory.

Telephone C. E. Roessler to advise of a delivery on the way.

If shipped to arrive Monday-Friday, ship to:

C. E. Roessler 904-392-0836
116 A.P. Black Hall
University of Florida
Gainesville, FL 32611

If shipped to arrive over the weekend, ship to:

C. E. Roessler 904-378-3404
525 N.E. 4th St.
Gainesville, FL 32601

Written by: C. E. Roessler Date

Reviewed by: C. E. Roessler Date 5/1/84

RADON FLUX MEASUREMENT BY CHARCOAL CARTRIDGE

Procedure For Counting Cartridges

I. General - Cartridges are counted on a NaI scintillation crystal connected to a multichannel analyzer. Radon is determined from the area under the 609 keV peak. Blank cartridges from the same batch are counted to determine a background which represents the sum of the counter background and residual radium-226/radon-222/radon daughters in the cartridge. A standard consisting of a known amount of radium-226 sealed into a cannister to prevent radon loss is counted in the same configuration to provide a calibration factor.

Suggested conditions:

Detector: 4" x 4" NaI crystal
MCA: 256 channels, calibrated to 10 keV/channel
609 keV peak in channel 60-61
Sum channels 56 (555 keV) - 67 (675 keV)

Written by: C. E. Roessler Date

Reviewed by: C. E. Roessler Date 5/1/84

Renumbered 6/11/84

RADON FLUX MEASUREMENT BY CHARCOAL CARTRIDGE

Procedure For Counting Cartridges

Pages 2 of 5 through 5 of 5 - Operator Instructions for the Multichannel Spectrometer. Not included here.

RADON FLUX MEASUREMENT BY CHARCOAL CARTRIDGES

Calculation of Radon Flux

A. BACKGROUND AND STANDARD

1. Compute average count rates, cpm, for:

   a) Counter background, BKG
   b) Blank cartridge, BL
   c) Standard, STD

2. Compute calibration factor:

   a) Standard net count, cpm: STDN = STD − BKG
   b) Calibration factor: F (pCi/cpm) = 2164 pCi/STDN (cpm)

B. FOR EACH SAMPLE

1. Compute count rate, SAM (cpm)

2. Compute net count rate: R (cpm) = SAM − BL

3. Compute radon flux:

$$J\ (\text{pCi/m2-s}) = R\ t3\ F\lambda^{2} / 60\ A\ [1-\exp(-\lambda t1)]\exp(-\lambda t2)[1-\exp(-\lambda t3)]$$

where: R = net count rate
λ = radon decay constant
F = calibration factor, pCi/cpm.
60 = sec/min
A = collector area, m2
t1 = collection time
t2 = decay time, end of collection to beginning of counting
t3 = counting time
(t1, t2, t3, R & λ must be in consistent time units)

4. Satisfactory approximations are:

   a) Radon activity at the midpoint of counting:

   $$P2(\text{pCi}) = R\ F$$

   b) Radon activity adjusted to sampling midpoint:

   $$P1\ (\text{pCi}) = P2 \exp(\lambda T) = R\ F \exp(\lambda T)$$

   where T = decay time, midpoint of sampling to midpoint of counting

   c) Radon flux:

   $$J\ (\text{pCi/m2-s}) = P1/A\ t1 = R\ F \exp(\lambda T)/A\ t1$$

APPENDIX B - VENTING EXPERIMENT

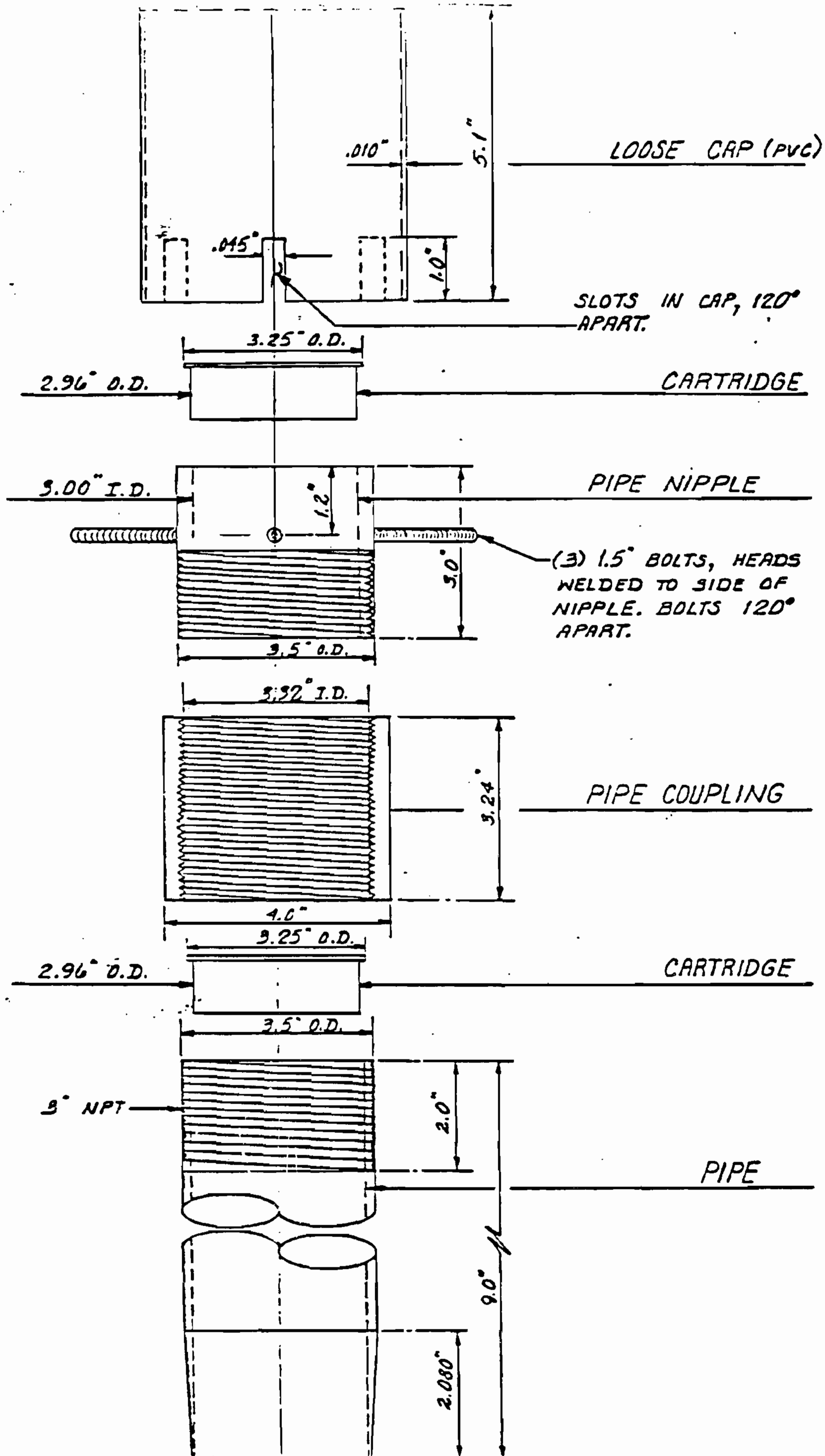
In the technique used in this study, the top of the radon collector is closed by the pipe cap. Some procedures reported in the literature employ a pressure-compensating vent in the collector. An experiment was conducted to test the effect of collector venting on the measured radon flux.

To test the effect of venting, a special collector, referred to as a "tandem collector" was constructed as indicated in Figure B-1. The lower portion of the collector with the charcoal cartridge is identical to the regular collector. Instead of the pipe cap, this special collector has 1) an extension, 2) a second cartridge to prevent the contact of ambient radon with the lower cartridge, and 3) an open top with a weather cover.

Five vented collectors were deployed in parallel with regular collectors on each of two occasions, December 11-13, 1984 and February 12-14, 1985. Data are presented in the attached reports.

In the December sampling, the average for the five vented collectors (lower cartridge), 15.0 pCi/m2-s, did not differ statistically from 14.1 pCi/m2-s, the average for the five corresponding regular collectors. In the February sampling, the vented collector (lower cartridge) average, 7.7, was significantly less than 14.8, the regular collector five-sample average. The reason for the difference between the two sampling episodes is not known. It was observed that there was a very strong wind blowing at the time of the February deployment, but it is not clear whether this had any relationship to the observed difference between the closed and vented collectors.

From this experiment it appears that the usual practice of using a closed collector does not result in a lower reported flux than if the collector were vented.



SPECIAL STUDY APPARATUS
VENTED COLLECTION WITH
TANDEM CARTRIDGE
FIGURE #1

Charles E. Roessler, Ph.D.
Certified Health Physicist

Genevieve S. Roessler, Ph.D.
Health Physicist

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: December 11-13, 1984

Special Study, Regular and Tandem Collectors

Station	Radon Flux, pCi/m2-s *		
	Regular	Tandem	
		Lower	Upper
1	9.1	12.8	5.2
2	20.2		
3	20.6	11.5	2.5
4	18.9		
5	5.1	18.9	10.3
6	27.9		
7	20.8	18.0	4.6
8	16.2		
9	14.8	13.6	4.6
10	11.4		
Average of 10	16.5	---	---
Five Parallel Stations:			
Average	14.1	15.0	5.5
Standard error	3.1	1.5	1.3

* Using a collection efficiency factor of 100%. Based on the averages of two counts.

COMMENTS:

1. Three of the lower cannisters in the vented collector accumulated less radon than those in the standard, closed collector; two collected more radon. No. 5 is an unusual data set compared to the others.

2. The vented collector average, 15.0, does not differ statistically from 14.1, the regular collector average.

3. The average for the five lower cannisters in the vented collector, 15.0, is less than 16.5, the average for the ten in the standard, closed collector, but this difference is not statistically significant.

Preliminary report based on initial count:	December 17, 1984
Second count and flux calculations completed:	December 20, 1984
Revised report prepared:	March 12, 1985

C. E. Roessler

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R

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: February 12-14, 1985

Special Study, Regular and Tandem Collectors

Station	Radon Flux, pCi/m2-s * Regular	Tandem Lower	Tandem Upper
1	3.6	2.4	0.4
2	4.4		
3	11.6	14.8	2.4
4	13.7		
5	15.7	2.5	0.8
6	26.3		
7	22.9	3.7	0.6
8	16.9		
9	20.4	15.2	2.3
10	36.1		
Average of 10	17.2	---	---
Five Parallel Stations:			
Average	14.8	7.7	1.3
Standard error	3.4	3.0	0.4

* Using a collection efficiency factor of 100%.

COMMENTS:

1. Four of the lower cannisters in the vented collector accumulated less radon than those in the standard, closed collector; one collected more radon.

2. The vented collector average, 7.7, is less than 14.8, the regular collector average.

3. The average for the five lower cannisters in the vented collector, 7.7 is less than 17.2, the average for the ten in the standard, closed collector.

C. E. Roessler
February 23, 1984

APPENDIX C - DATA REPORTS, DECEMBER, 1983 - AUGUST 1985

RADON FLUX SAMPLING
GARDINIER PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Site	Radon Flux, pCi/m2-s, for Indicated Sampling Period					
	12/3-5/83	12/5-7/83	12/27-29/83	1/16-19/84	2/14-16/84	Average
A. Exposed Gypsum on Top of Stack:						
1.	5.6	6.9	4.0	1.7	4.3	4.5
2.	24.2	22.8	—	—	—	
2A.*	—	—	35.4	43.8	6.5	26.5
3.	45.4	lost	63.7	55.7	32.2	49.2
5.	13.2	14.2	—	—	—	
5A.	—	—	28.7	38.4	38.8	26.7
6.	3.6	11.8	10.2	18.7	lost	11.1
7.	27.0	30.0	27.9	33.9	34.6	30.7
8.	6.4	7.7	11.8	25.2	lost	12.8
Avg	17.9	15.6	26.0	31.1	23.3	23.0
Cumulative:						
Samples	(7)	(13)	(20)	(27)	(32)	
Avg	17.9	16.8	20.0	22.9	23.0	
Std Error	5.8	3.4	3.5	3.2	2.9	
B. Wet Gypsum, near Hot Slurry Discharge:						
4.	5.9	3.0	—	—	—	
4A.	—	—	22.7	lost	lost	10.5
C. Grassed Areas:						
9.	3.4	3.8	—	—	—	
9A.	—	—	4.3	4.3	3.8	3.9
10.	5.6	6.4	10.8	8.6	9.3	8.1
Avg	4.5	5.1	7.6	6.4	6.6	6.0

* "A" indicates sampling in same general vicinity on stack but not at same exact location.

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...d Health Physicist

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RADON FLUX
GARDINIER PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Station No.	Radon Flux, pCi/m^2-s for Indicated Deployment Period		
	3/20-22/84	5/1-3/84	5/23-25/84*
1	66.1	28.0	33.0
2	16.9	11.9	43.8
3	22.7	14.3	8.8
4	18.0	9.6	6.2
5	29.4	35.3	27.2
6	27.9	28.8	3.3
7	28.7	19.1	1.6
8	15.7	19.1	25.2
9	24.1	33.1	1.6
10	--	4.0	11.2
Avg.	27.7 ± 5.1	20.3 ± 3.3	16.2 ± 4.7
Range	15.7 - 66.1	4.0 - 35.6	1.6 - 43.8

*5/23-25/84 cartridges shipped in individual cans taped but not individually wrapped in plastic.

Summary

	Radon flux, pCi/m^2-s Avg.	Range
From Previous Sampling (12/83-2/84)		
32 samples	23.0 ± 2.9*	1.7-63.7
5 sampling period means	22.8	15.6-31.1
Cumulative (12/83-5/84)		
61 Samples	22.1 ± 1.9	1.6-66.1
8 Sampling period means	22.3	15.6-31.1

* ± values indicate one std error of mean

NOTE: All values are for exposed gypsum on the top of the stack. Sampling stations were reassigned beginning with the 3/10-22/84 sampling period. Stations were distributed around the top of the stack but station numbers do not correspond to same locations as for 12/83-2/84 sampling periods.

C E Roessler 6/1/84

C. E. Roessler

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: July 18-20, 1984

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s
1	34.2
2	66.7
3	93.8
4	47.3
5	33.4
6	15.3
7	5.7
8	24.5
9	16.8
10	45.5
No. of Samples	(10)
Avg.	36.9 +/- 8.9
Range	5.7 - 93.8

CUMULATIVE SUMMARY, 12/83- 7/84

	Previous	Current
Summary of Period averages:		
No. of periods	9	10
Mean (pCi/m2-s)	21.9	23.4
Range (pCi/m2-s)	15.6-31.1	15.6-36.9
Summary of Individual Samples:		
No. of samples	70	80
Mean (pCi/m2-s)	21.7	23.6
Range (pCi/m2-s)	1.6-66.1	1.6-93.8

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C. E. Roessler
September 23, 1984

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: August 27-29,1984

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s
1	42.4
2	9.0
3	26.3
4	34.8
5	19.5
6	13.4
7	20.1
8	19.0
9	18.8
10	12.2
No. of Samples	(10)
Avg.	21.5 +/- 3.3
Range	9.0 - 42.4

CUMULATIVE SUMMARY, 12/83- 8/84

	Previous	Current
Summary of Period averages:		
No. of periods	10	11
Mean (pCi/m2-s)	23.4	23.3
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	80	90
Mean (pCi/m2-s)	23.6	23.4
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: September 11-13, 1984

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s
1	12.5
2	35.0
3	34.5
4	42.0
5	18.6
6	4.6
7	16.6
8	18.8
9	7.1
10	3.5
No. of Samples	(10)
Avg.	19.3 +/- 4.3
Range	3.5 - 42.0

CUMULATIVE SUMMARY, 12/83- 9/84

	Previous	Current
Summary of Period averages:		
No. of periods	11	12
Mean (pCi/m2-s)	23.3	23.0
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	90	100
Mean (pCi/m2-s)	23.4	23.0
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

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September 23, 1984

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: June 19-21, 1984

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s
1	no sample
2	12.9
3	24.7
4	3.7
5	27.4
6	21.4
7	31.9
8	11.4
9	33.8
10	2.3
No. of Samples	(9)
Avg.	18.8 +/- 3.9
Range	2.3 - 33.8

CUMULATIVE SUMMARY, 12/83- 6/84

	Previous	Current
Summary of Period averages:		
No. of periods	8	9
Mean (pCi/m2-s)	22.3	21.9
Range (pCi/m2-s)	15.6-31.1	15.6-31.1
Summary of Individual Samples:		
No. of samples	61	70
Mean (pCi/m2-s)	22.1	21.7
Range (pCi/m2-s)	1.6-66.1	1.6-66.1

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September 23, 1984

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: October 9-11, 1984

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s
1	26.5
2	10.7
3	15.1
(4	15.0 ** dislodged by dozer)
5	8.2
6	16.6
7	20.3
8	36.5
9	29.8
10	11.5
No. of Samples	(9) (No. 4 not included)
Avg.	18.6 +/- 3.7
Range	8.2 - 36.5

CUMULATIVE SUMMARY, 12/83-10/84

	Previous	Current
Summary of Period averages:		
No. of periods	12	13
Mean (pCi/m2-s)	23.0	22.7
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	100	109
Mean (pCi/m2-s)	23.0	22.6
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

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October 28, 1984

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: November 13-15, 1984

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s
1	24.6
2	47.9
3	17.8
4	17.5
5	18.3
6	8.3
7	33.4
8	20.2
9	86.9
10	13.5
No. of Samples	(10)
Avg.	28.8 +/- 7.4
Range	8.3 - 86.9

CUMULATIVE SUMMARY, 12/83-10/84

	Previous	Current
Summary of Period averages:		
No. of periods	13	14
Mean (pCi/m2-s)	22.7	23.1
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	109	119
Mean (pCi/m2-s)	22.6	23.1
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

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C. E. Roessler
November 18, 1984

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: December 11-13, 1984

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s
1	9.2
2	19.9
3	19.4
4	18.9
5	4.8
6	27.5
7	19.4
8	15.9
9	14.3
10	11.1
No. of Samples	(10)
Avg.	16.0 +/- 2.0
Range	4.8 - 27.5

CUMULATIVE SUMMARY, 12/83-12/84

	Previous	Current
Summary of Period averages:		
No. of periods	14	15
Mean (pCi/m2-s)	23.1	22.6
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	119	129
Mean (pCi/m2-s)	23.1	22.6
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

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December 17, 1984

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: January 29-31, 1985

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s*
1	19.2
2	21.0
3	17.3
4	8.9
5	17.4
6	37.7
7	18.1
8	19.8
9	15.2
10	9.3
No. of Samples	(10)
Avg..	18.4 +/- 2.5
Range	8.9 - 37.7

CUMULATIVE SUMMARY, 12/83-~~12/84~~ 1/85 CER

	Previous	Current
Summary of Period averages:		
No. of periods	15	16
Mean (pCi/m2-s)	22.6	22.3
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	129	139
Mean (pCi/m2-s)	22.6	22.3
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

* Using a collection efficiency factor of 100%.

C. E. Roessler
C. E. Roessler
February 10, 1985

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: February 12-14, 1985

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s*
1	3.6
2	4.4
3	11.6
4	13.7
5	15.7
6	26.3
7	22.9
8	16.9
9	20.4
10	36.1
No. of Samples	(10)
Avg.	17.2 +/- 3.1
Range	3.6 - 36.1

CUMULATIVE SUMMARY, 12/83 - 2/84

	Previous	Current
Summary of Period averages:		
No. of periods	16	17
Mean (pCi/m2-s)	22.3	22.0
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	139	149
Mean (pCi/m2-s)	22.3	22.0
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

* Using a collection efficiency factor of 100%.

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: March 26-28, 1985

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s*
1	6.4
2	18.1
3	20.8
4	16.5
5	12.1
6	Lost
7	21.1
8	13.3
9	36.6
10	17.3
No. of Samples	(9)
Avg.	18.0 +/- 2.8
Range	6.4 - 36.6

CUMULATIVE SUMMARY, 12/83 - 3/85

	Previous	Current
Summary of Period averages:		
No. of periods	17	18
Mean (pCi/m2-s)	22.0	21.8
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	149	158
Mean (pCi/m2-s)	22.0	21.8
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

* Using a collection efficiency factor of 100%.

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C. E. Roessler
April 2, 1985

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: April 23-25, 1985

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s*
1	11.1
2	20.6
3	25.7
4	(22.0) partially dislodged
5	6.7
6	19.4
7	20.9
8	lost
9	27.0
10	overturned
No. of Samples	(7)
Avg.	18.8 +/- 2.8
Range	6.7 - 27.0

CUMULATIVE SUMMARY, 12/83 - 4/85

	Previous	Current
Summary of Period averages:		
No. of periods	18	19
Mean (pCi/m2-s)	21.8	21.6
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	158	165
Mean (pCi/m2-s)	21.8	21.7
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

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* Using a collection efficiency factor of 100%.

C E Roessler

C. E. Roessler

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: May 27-29, 1985

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s*
1	22.5
2	25.8
3	19.7
4	16.7
5	14.2
6	19.4
7	27.7
8	20.1
9	22.6
10	5.5
No. of Samples	(10)
Avg.	19.4 +/- 2.0
Range	5.5 - 25.8

CUMULATIVE SUMMARY, 12/83 - 5/85

	Previous	Current
Summary of Period averages:		
No. of periods	19	20
Mean (pCi/m2-s)	21.6	21.5
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	165	175
Mean (pCi/m2-s)	21.7	21.6
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

---

* Using a collection efficiency factor of 100%.

C. E. Roessler
June 11, 1985

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See Consultant Report

REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: July 1-3, 1985 (June sampling)

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s*
1	23.7
2	28.5
3	39.3
4	10.0
5	45.2
6	19.5
7	27.7
8	16.6
9	~~9.96~~ 9.9
10	3.0
No. of Samples	(10)
Avg.	22.3 +/- 4.2
Range	3.0 - 45.2

CUMULATIVE SUMMARY, 12/83 - 6/85

	Previous	Current
Summary of Period averages:		
No. of periods	20	21
Mean (pCi/m2-s)	21.5	21.5
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	175	185
Mean (pCi/m2-s)	21.6	21.6
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

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* Using a collection efficiency factor of 100%.

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CORRECTED REPORT

REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: July 1-3,1985 (June sampling)

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s*
1	23.7
2	28.5
3	39.3
4	10.0
5	45.2
6	19.5
7	27.7
8	16.6
9	9.9
10	3.0
No. of Samples	(10)
Avg.	22.3 +/- 4.2
Range	3.0 - 45.2

CUMULATIVE SUMMARY, 12/83 - 6/85

	Previous	Current
Summary of Period averages:		
No. of periods	20	21
Mean (pCi/m2-s)	21.5	21.5
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	175	185
Mean (pCi/m2-s)	21.6	21.6
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

* Using a collection efficiency factor of 100%.

C. E. Roessler

C. E. Roessler

Original report July 24, 1985; corrected August 29, 1985

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: July 29-31, 1985

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s*
1	17.8
2	lost
3	16.2
4	37.0
5	31.5
6	21.2
7	42.7
8	30.5
9	18.7
10	61.6
No. of Samples	(9)
Avg:	30.8 +/- 4.9
Range	16.2 - 61.6

CUMULATIVE SUMMARY, 12/83 - 7/85

	Previous	Current
Summary of Period averages:		
No. of periods	21	22
Mean (pCi/m2-s)	21.5	21.9
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	185	194
Mean (pCi/m2-s)	21.6	22.0
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

* Using a collection efficiency factor of 100%.

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C. E. Roessler
August 29,1985

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REPORT OF RADON FLUX MEASUREMENT

GARDINIER, INC. PHOSPHOGYPSUM STACK, TAMPA, FLORIDA

Collection Period: August 20-22, 1985

THIS COLLECTION PERIOD

Station	Radon Flux, pCi/m2-s*
1	21.2
2	6.0
3	47.5
4	28.4
5	18.6
6	8.2
7	9.3
8	38.0
9	13.7
10	lost
No. of Samples	(9)
Avg.	21.2 +/- 4.2
Range	6.0 - 47.5

CUMULATIVE SUMMARY, 12/83 - 8/85

	Previous	Current
Summary of Period averages:		
No. of periods	22	23
Mean (pCi/m2-s)	21.9	21.9
Range (pCi/m2-s)	15.6-36.9	15.6-36.9
Summary of Individual Samples:		
No. of samples	194	203
Mean (pCi/m2-s)	22.0	22.0
Range (pCi/m2-s)	1.6-93.8	1.6-93.8

* Using a collection efficiency factor of 100%.

C E Roessler

C. E. Roessler
August 29,1985

cc: GEW

GARDINIER INC.

Post Office Box 3269 • Tampa, Florida 33601 • Telephone 813-677-9111 • TWX 810-876-0648 • Telex 52666 • Cable - Gardinphos

March 15, 1985

Mr. Harlan Keaton
Office of Radiation
Florida Department of Health & Rehabilitative Services
P.O. Box 15490
Orlando, Florida 32858

Subject: Radon Emanation Program

Dear Mr. Keaton:

Gardinier requests the approval of its Radon Emanation Program as described in the attached report.

The values reported are higher than the average for the entire Gypsum Field as all readings used in determining the average were taken from dry exposed areas. Emissions would be somewhat lower on the sides of the field which are covered with topsoil and grass and considerably lower in the wet areas.

The results from the two-cannister test show good agreement with the standard method.

As the results of this study show good agreement, Gardinier requests permission to terminate testing after 18 months of data have been obtained.

If you have any questions, please contact Mr. Steve Boswell

Yours very truly,

G. E. W.

G. E. Wilkinson

GEW:rw
Enclosure
cc: Mr. Rudy J. Cabina
Mr. Steve Boswell

STATE OF FLORIDA
DEPARTMENT OF HEALTH AND REHABILITATIVE SERVICES

May 17, 1985

Mr. G. E. Wilkinson
Gardinier, Inc.
P.O. Box 3269
Tampa, FL 33601

Attn: Mr. Steven T. Boswell

Dear Mr. Wilkinson:

We have reviewed your proposed radiation monitoring program for radon around Gardinier's new phosphogypsum field. In general, we concur with your program of study.

We do have four suggestions:

1. In order to avoid further delays, the program should commence 9/1/85 or when all approvals are received, whichever is the earlier.

2. We suggest you might combine sites 9 and 10 into one site, located between current sites 9 and 10, and then add a new site (a 10th site) northeast of the storage field, toward Progress Village, but located 500 to 1000 feet from the stack boundary.

3. For quality control purposes, we suggest that Track Etch detectors be employed in triplicate at any two sites.

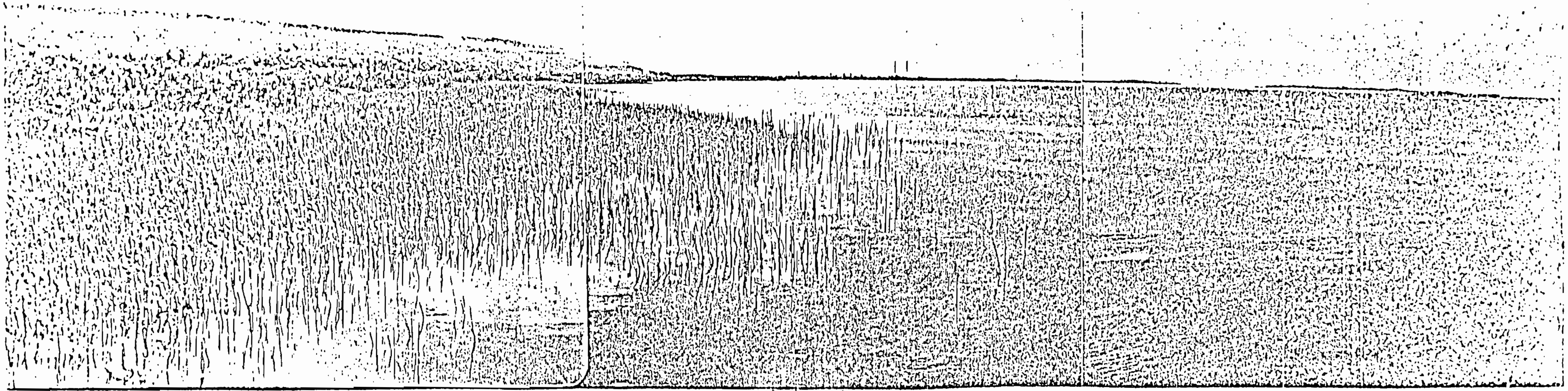
4. In order to evaluate fugitive airborne dust emissions from the stack, and in particular the radium content of the dust, we suggest that at least two high-volume air samplers be operated off-site from the stack. At least one should be located in the direction of Progress Village, and one to the west of the new stack. Each should be operated for 24 hours, every eighth day. Filters should be analyzed for total suspended particulate material and for sulfate. From analyses of average radium-to-sulfate ratio in the bulk phosphogypsum, radium content in the airborne dust can be calculated. As a quality control measure, every twentieth filter should be analyzed for radium.

In regard to your request concerning termination of radon emanation testing on the present gypsum stack, we have no problems with your phase-out of this program. The testing that will be performed by the U.S. Environmental Protection Agency will provide additional data for evaluating the characteristics of the stack.

Sincerely,

Lyle E. Jerrett
Director
Office of Radiation Control

Copy to: Harlan Keaton



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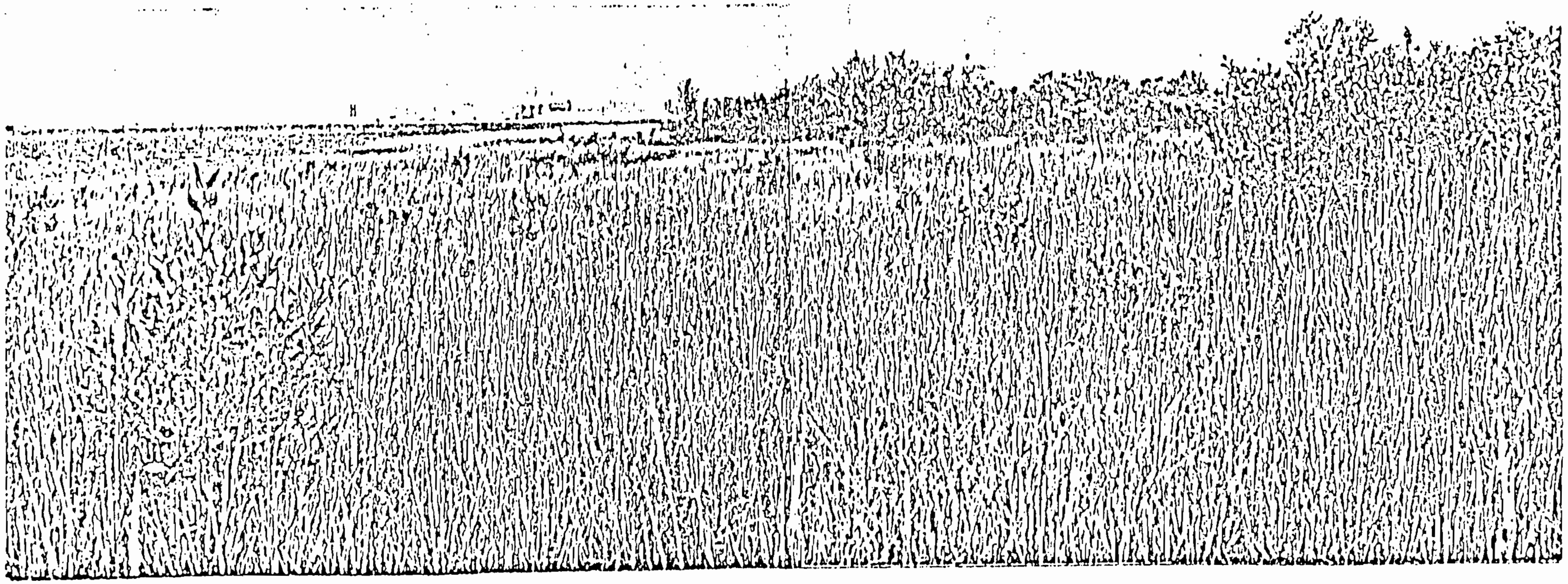

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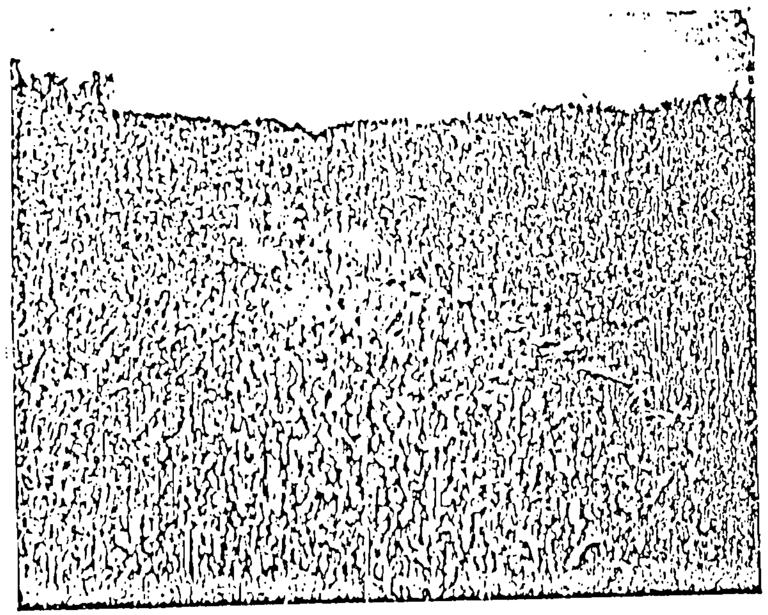

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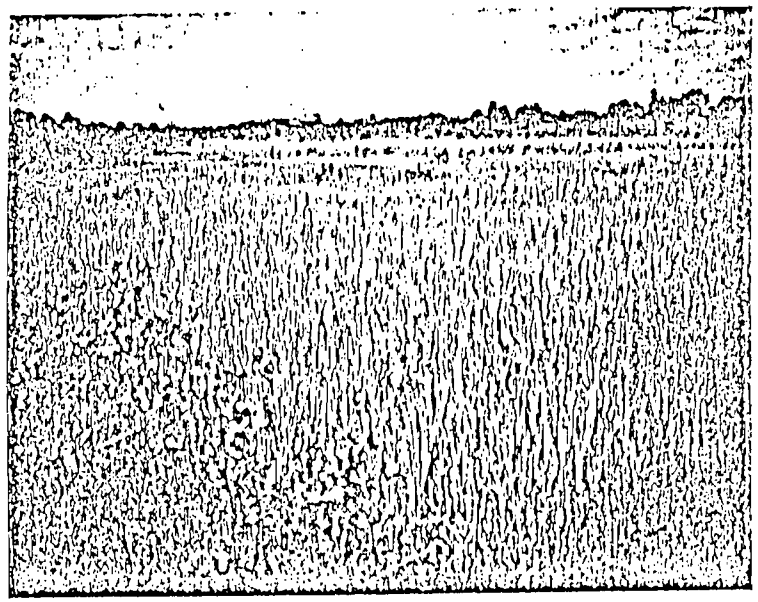

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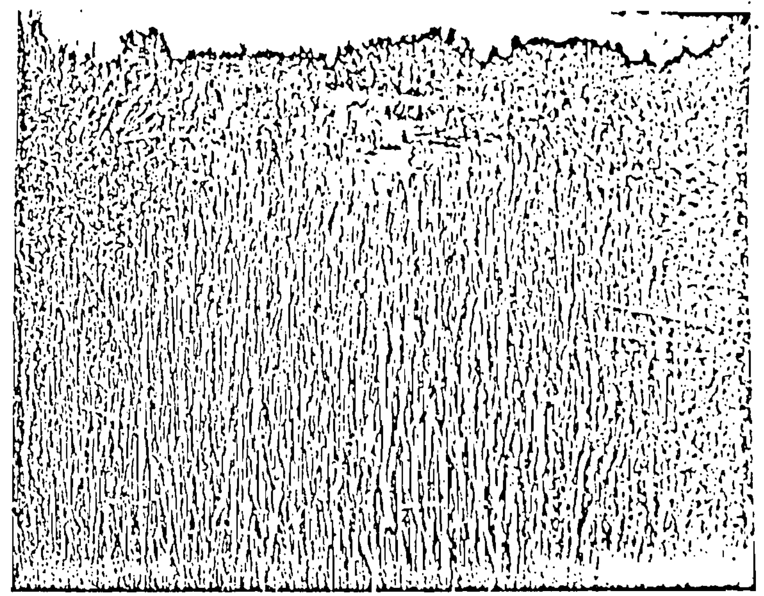

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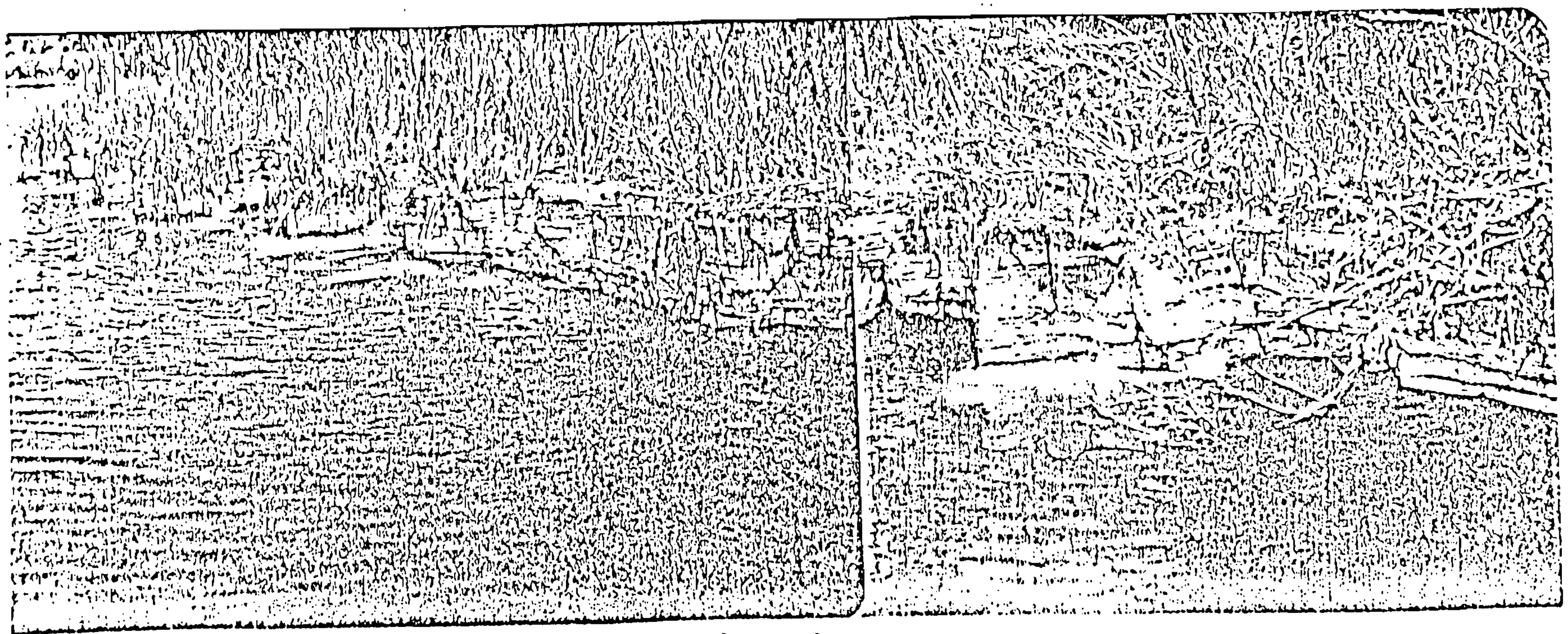

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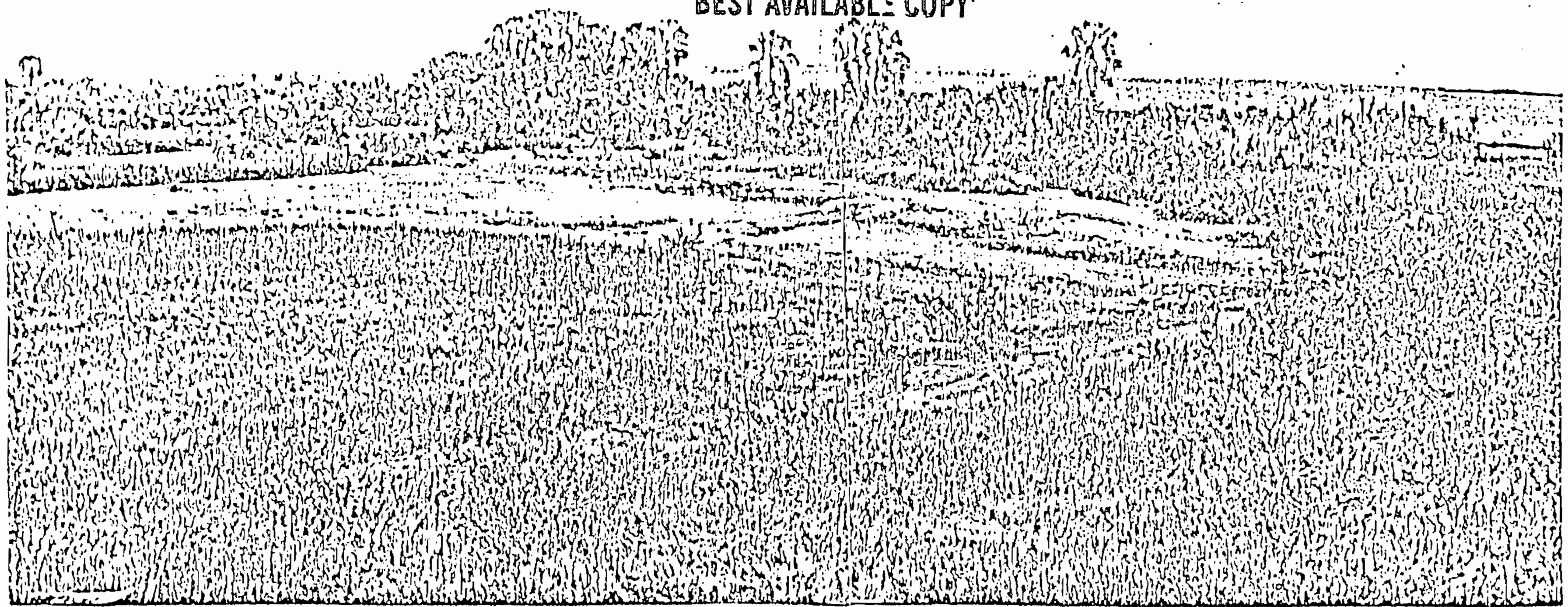

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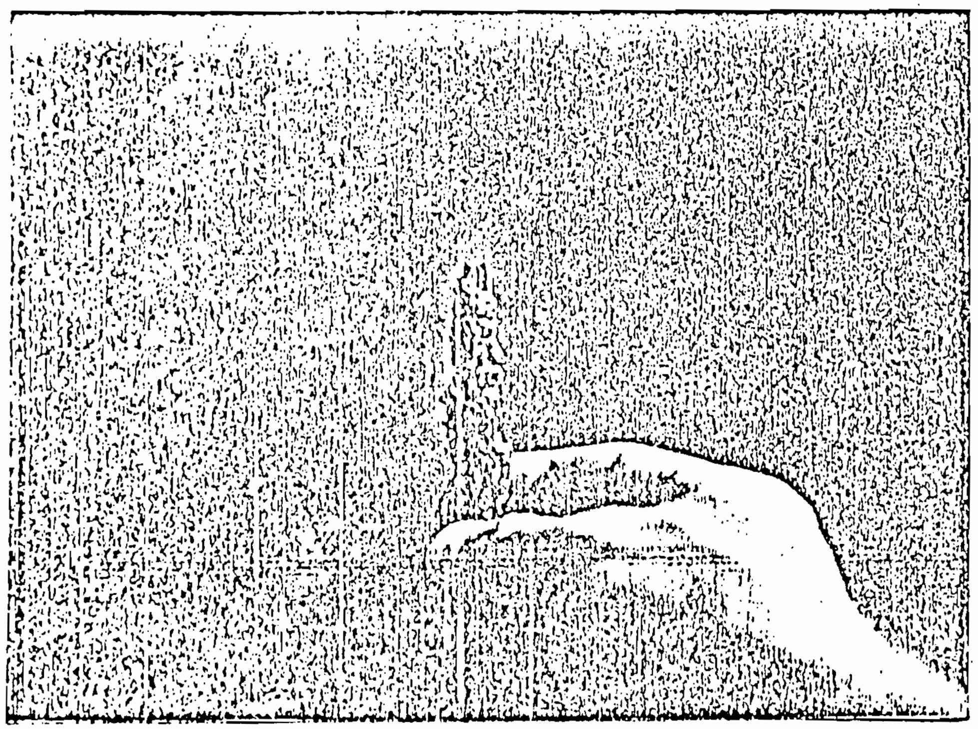

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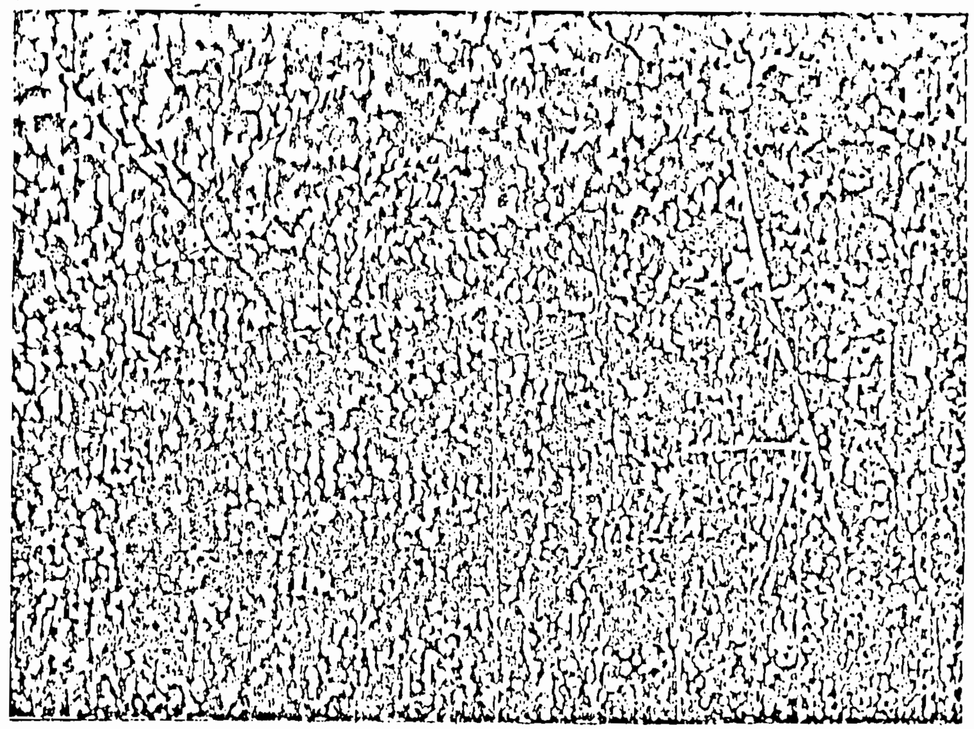

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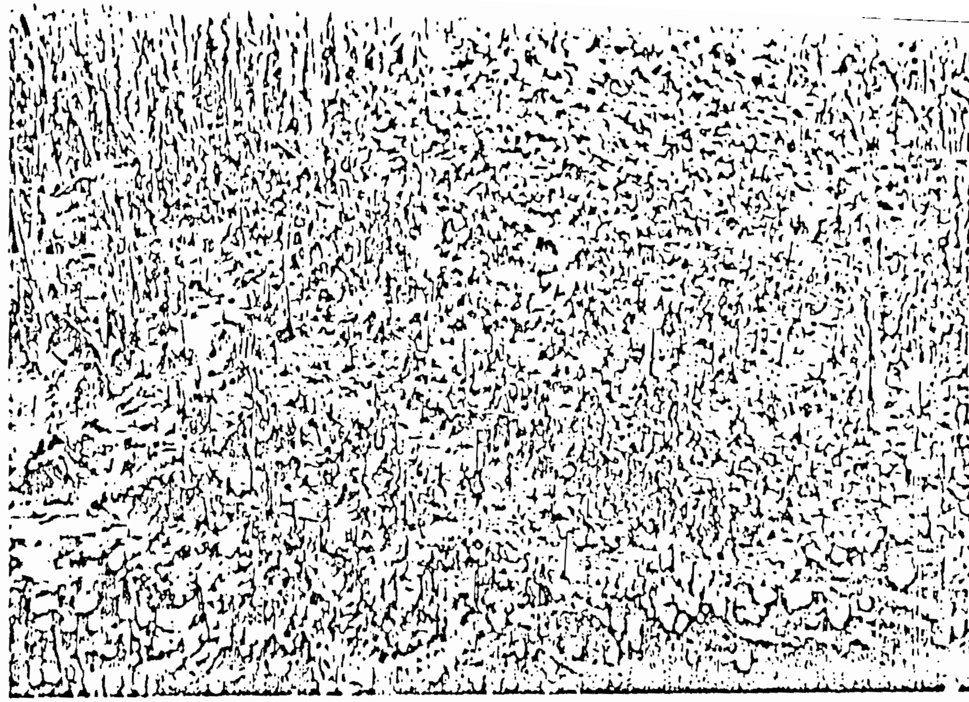

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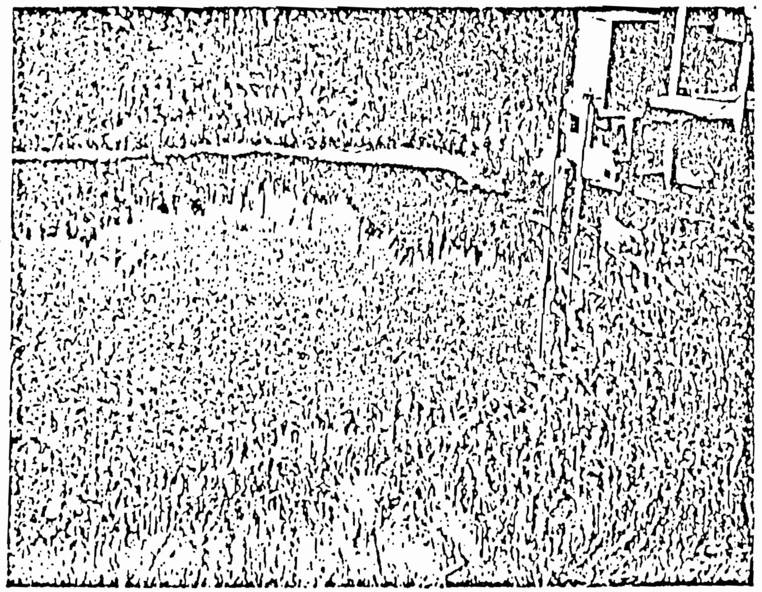

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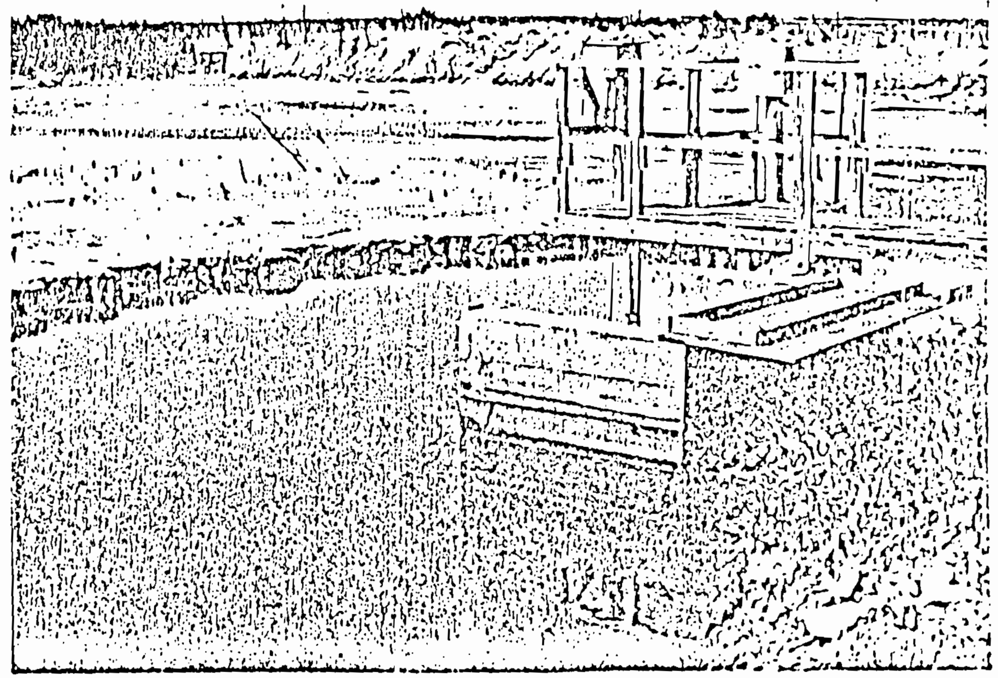

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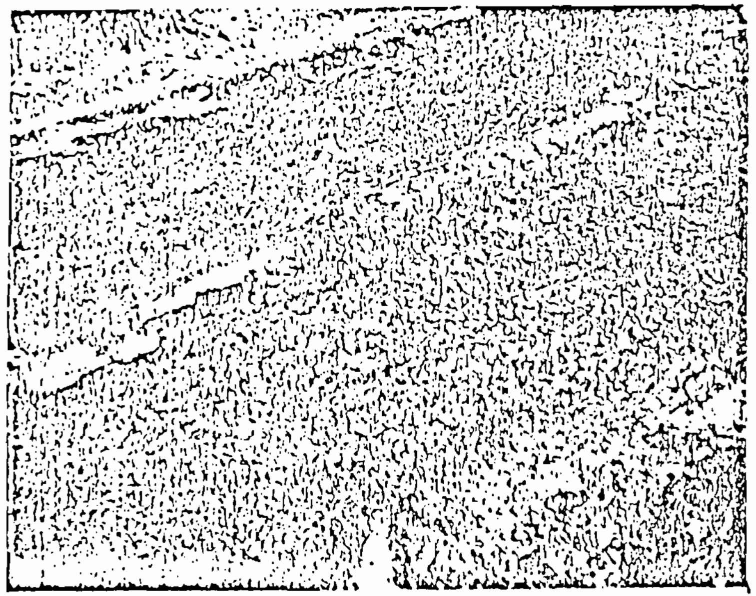

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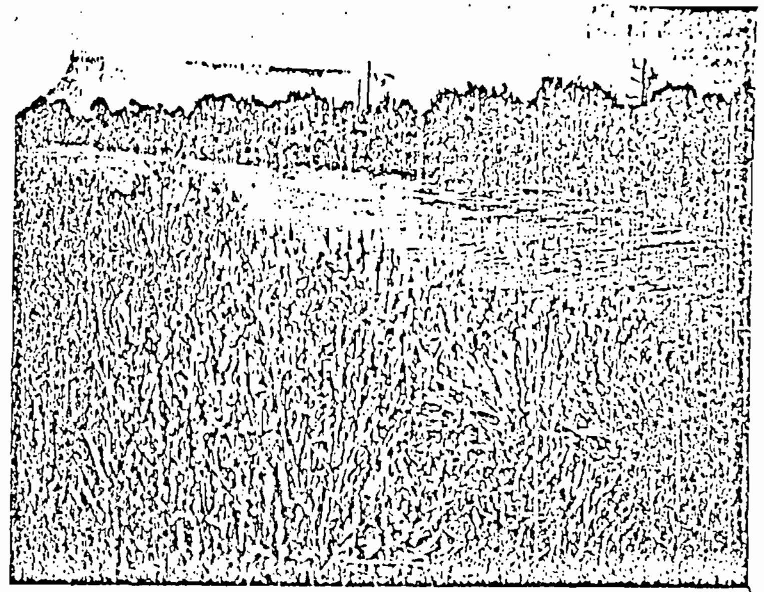

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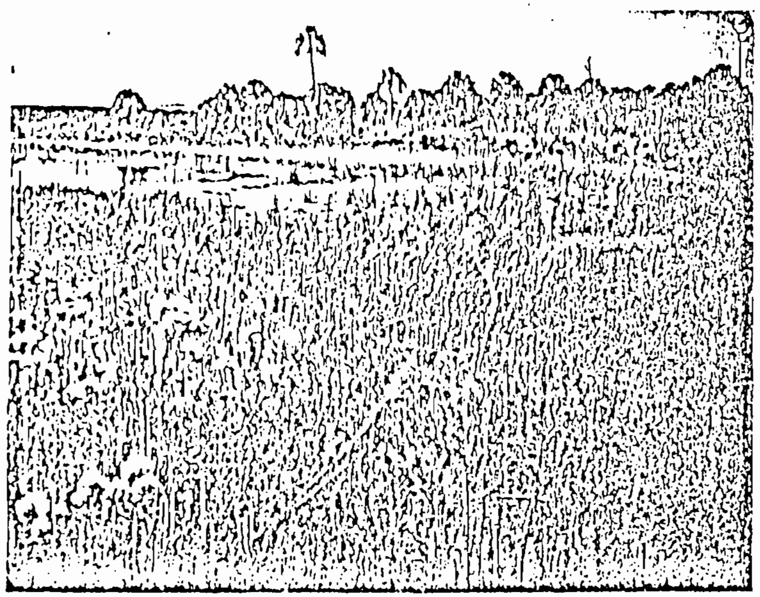

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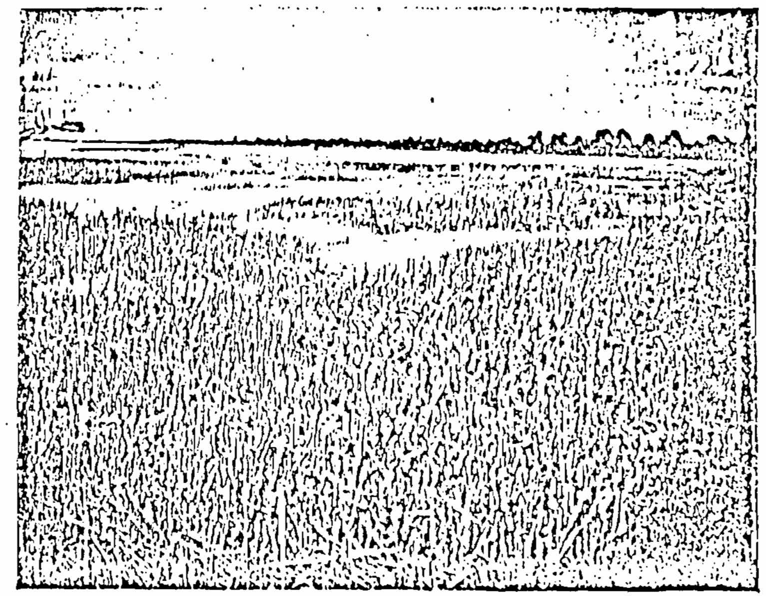

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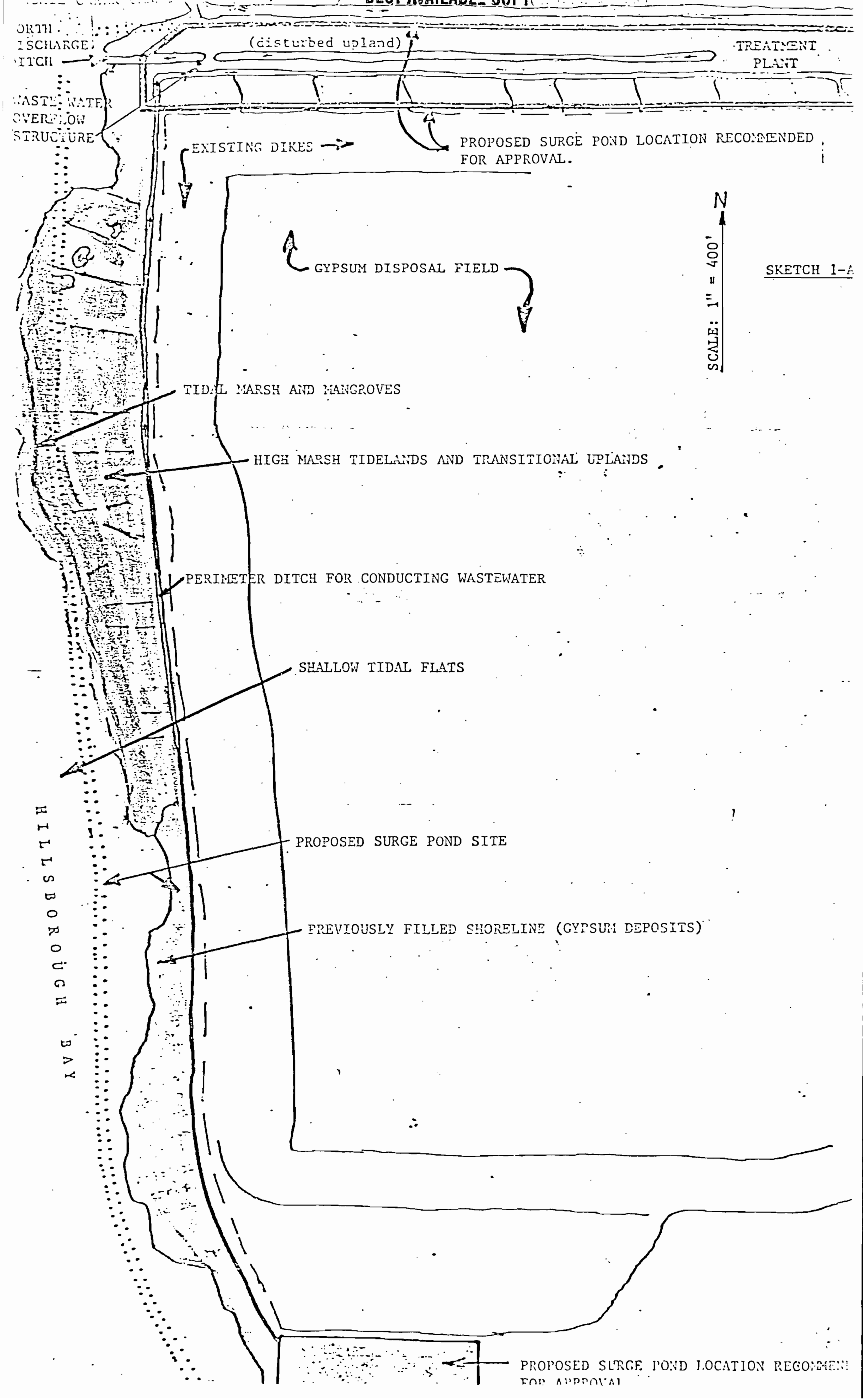
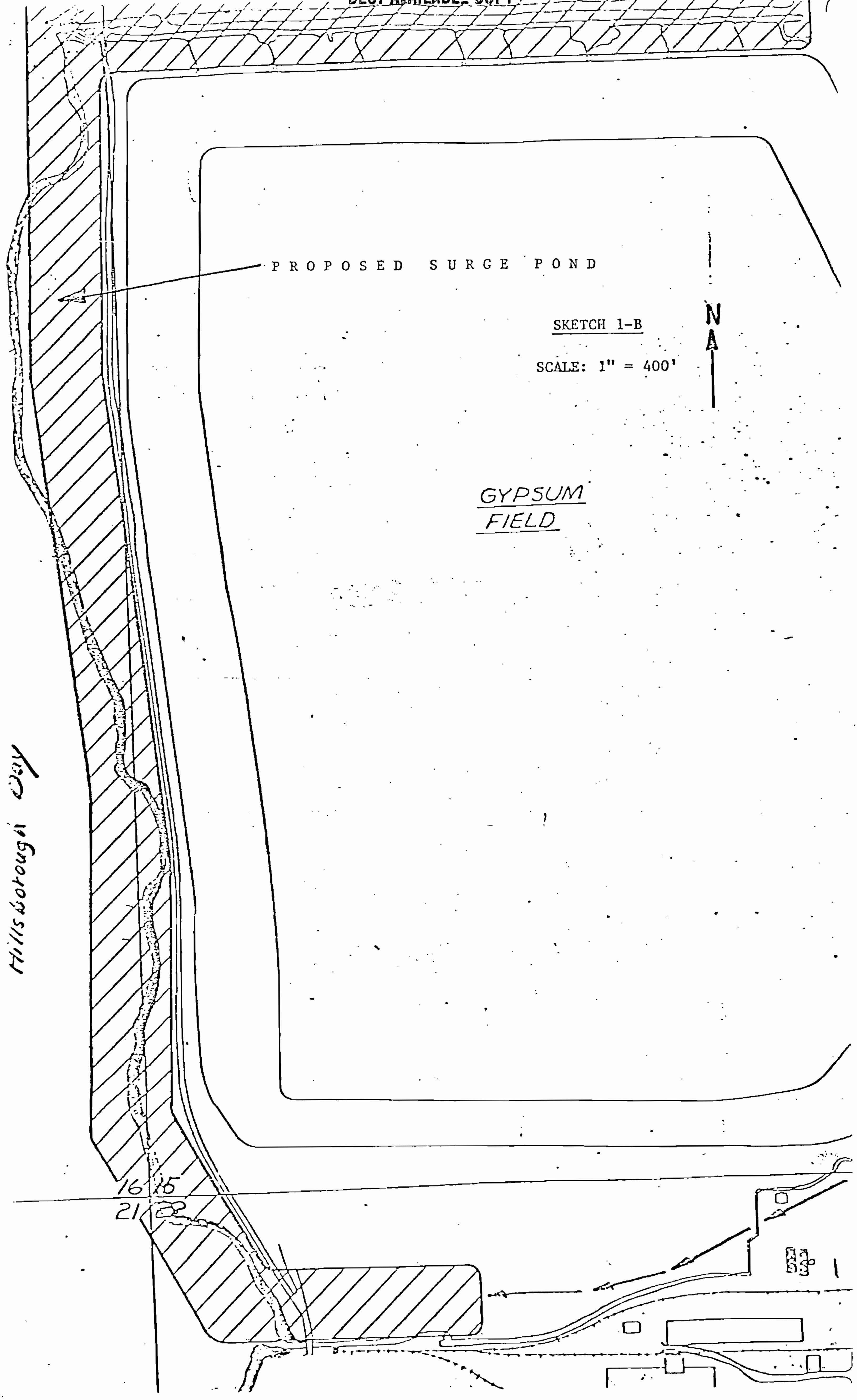
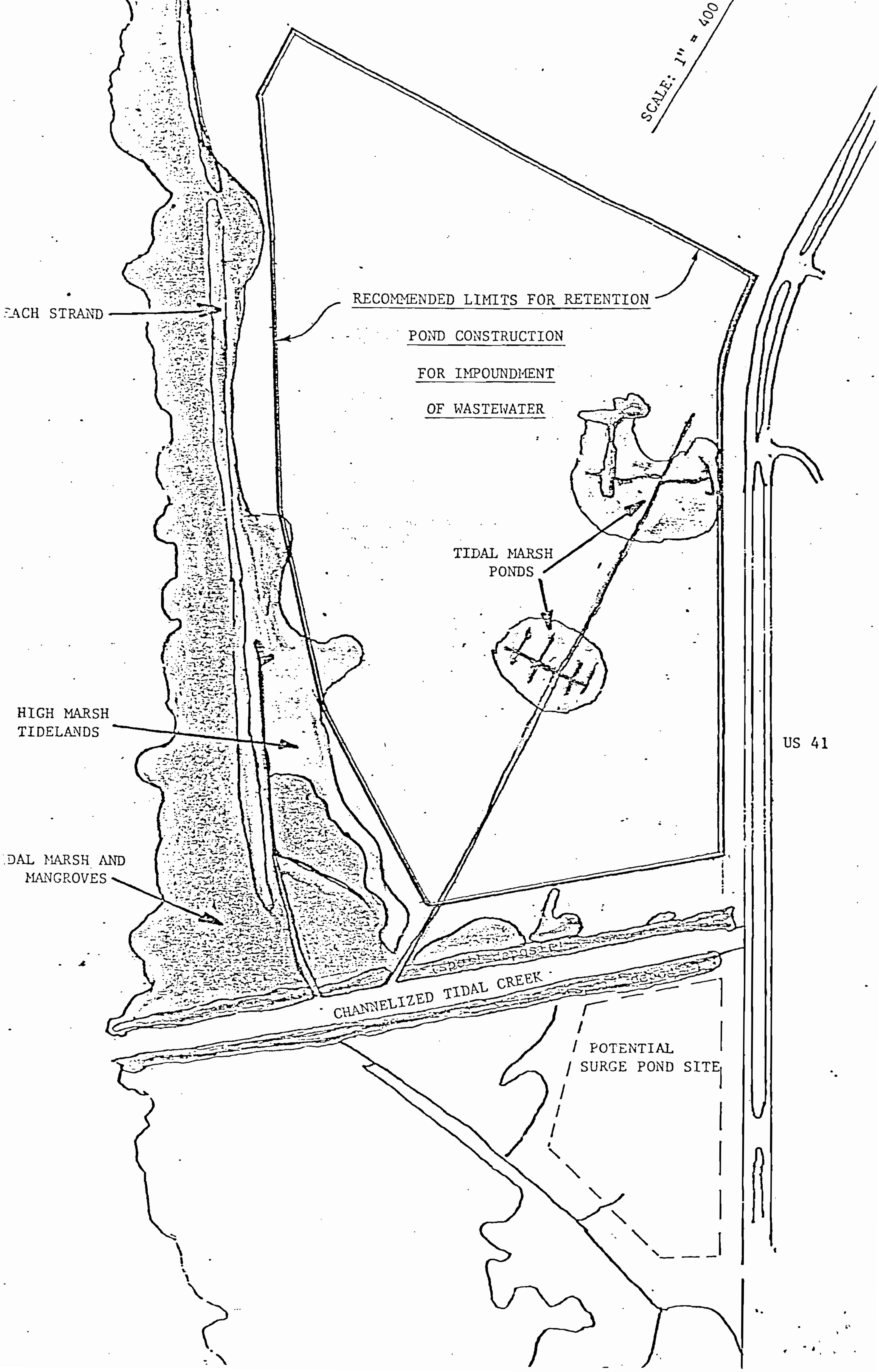
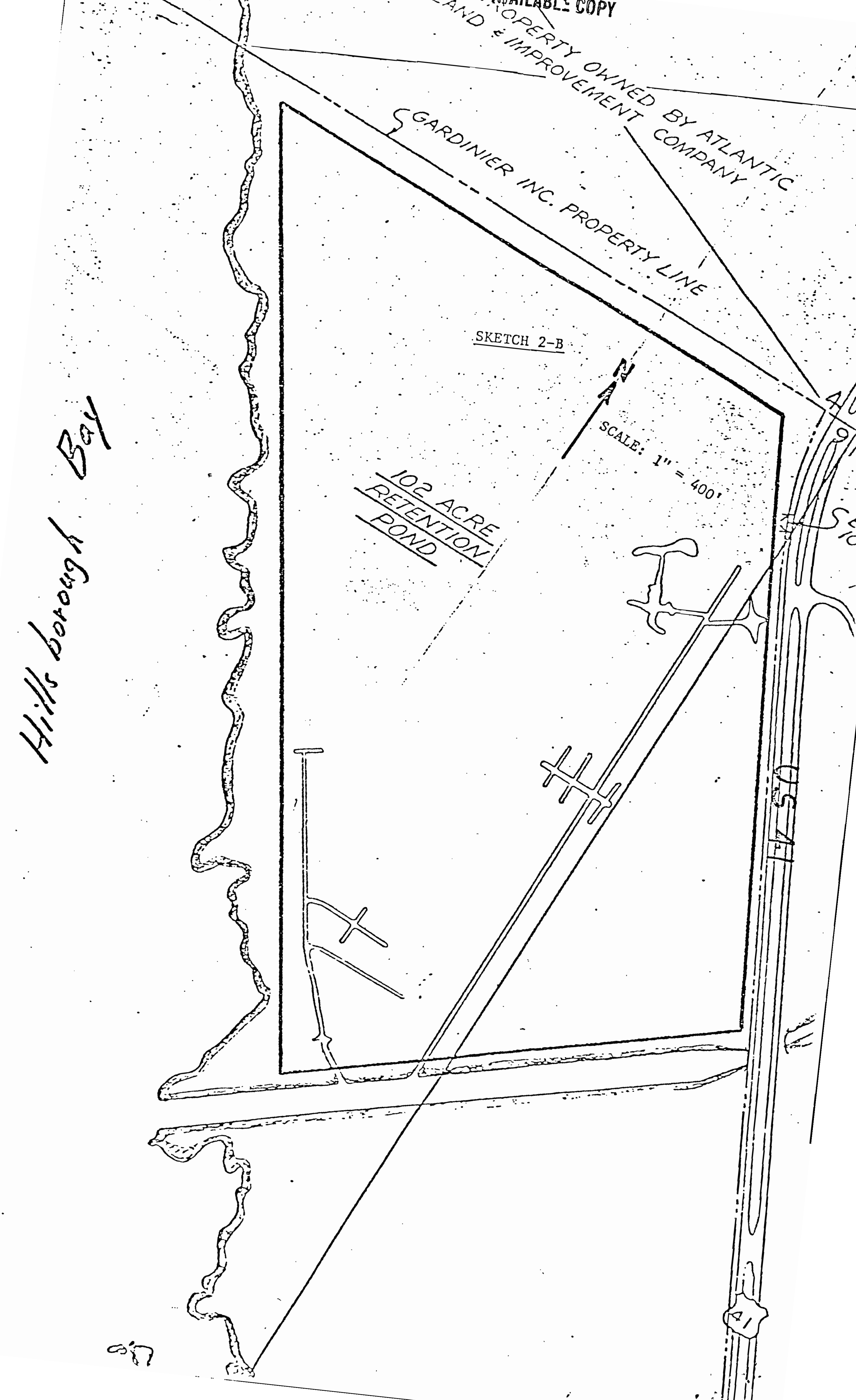


ORTH
ISCHARGE
ITCH
(disturbed upland)
TREATMENT
PLANT
WASTE WATER
OVERFLOW
STRUCTURE
EXISTING DIKES
PROPOSED SURGE POND LOCATION RECOMMENDED
FOR APPROVAL.
N
GYPSUM DISPOSAL FIELD
SCALE: 1" = 400'
SKETCH 1-A
TIDAL MARSH AND MANGROVES
HIGH MARSH TIDELANDS AND TRANSITIONAL UPLANDS
PERIMETER DITCH FOR CONDUCTING WASTEWATER
SHALLOW TIDAL FLATS
HILLSBOROUGH BAY
PROPOSED SURGE POND SITE
PREVIOUSLY FILLED SHORELINE (GYPSUM DEPOSITS)
PROPOSED SURGE POND LOCATION RECOMMEN


PROPOSED SURGE POND
SKETCH 1-B
SCALE: 1" = 400'
N
GYPSUM
FIELD
Hillsborough Bay
16
15
21

SKETCH 2-A


SCALE: 1" = 400'
N
RECOMMENDED LIMITS FOR RETENTION
POND CONSTRUCTION
FOR IMPOUNDMENT
OF WASTEWATER
ACH STRAND
TIDAL MARSH
PONDS
HIGH MARSH
TIDELANDS
DAL MARSH AND
MANGROVES
US 41
CHANNELIZED TIDAL CREEK
POTENTIAL
SURGE POND SITE


PROPERTY OWNED BY ATLANTIC
LAND & IMPROVEMENT COMPANY
GARDINIER INC. PROPERTY LINE
SKETCH 2-B
N
SCALE: 1" = 400'
102 ACRE
RETENTION
POND
Hillsborough Bay
US 41
41