IL.10-5

LINDSAY-1

(3)

LINDSAY CHEMICAL COMPANY

INDUSTRIAL HYGIENE SURVEY

PART I

OCCUPATIONAL EXPOSURE TO THORIUM DUST AND THORON

by

Paul B. Klevin
Industrial Hygiene Branch

and

James Fresco
Analytical Branch
Health and Safety Division

Issued: January 21, 1953

Distribution:

1 - File (Health and Safety, NYOO)
2 - Lindsay Chemical Company
3 - Lindsay Chemical Company
4 - Engineering and Construction (Catalytic)
5 - Biology and Medicine, Washington
6 - File (W. B. Harris, Health and Safety)

not complete copy

~~U. S. Atomic Energy~~ Commission
New York Operations Office
Health and Safety Division

INTRODUCTION

The information contained herein comprises the first part of a report in two parts covering a complete industrial hygiene and medical survey of the Lindsay Chemical Company plant in West Chicago, Illinois.

The survey was conducted in order that mutual benefit might accrue both to Lindsay Chemical Company and to the Atomic Energy Commission. To the Lindsay Chemical Company, in order that they might have an accurate definition of the extent of occupational exposures within the plant and also some knowledge of medical history of their present and past employees. To the AEC so that any future plant construction could be made with the maximum toxicological information.

In order to define potential hazards within the operating areas, values have been assigned to airborne concentrations of the primary radioactive components of the materials being processed, thorium and thoron. The values have been chosen as carefully as possible on the basis of information available prior to the writing of the report. The value for thorium has been based on the accepted value for uranium. This concentration, of 70 $d/m/M^3$, presumes that from the radioactivity standpoint both uranium and thorium are equally toxic. The concentration of thoron has been based on the accepted value for radon, of 10^{-11} curies/liter. Here again toxicity had been considered identical on a radioactivity basis.

Whereas by inference these maximum allowable concentration values have considerable validity, it cannot be emphasized too strongly that only through careful epidemiological studies is it possible to establish the maximum concentration to which a worker can be exposed with safety.

Radiation measurements were taken within the plant and outside of the plant but only the Inplant values have been assessed for potential danger. The values taken outside the plant area are presented without interpretation as any possible danger in these areas depends on the use to which these areas will be put.

On the basis of the maximum allowable concentrations which have been used, there are several plant areas in which overexposures were found to exist. Where this is true, an effort has been made to define the source of excessive concentrations and to suggest superficial means for remedying the situation. No effort has been made to provide specific detailed recommendations for the control of atmospheric hazards.

TABLE OF CONTENTS

LIST OF TABLES

Table of Contents - continued

SCOPE

This is a report of a survey performed during the period September 16 through 18, 1952 at the Lindsay Chemical Company, West Chicago, Illinois. The survey was made in anticipation of the construction of a refinery to supply thorium nitrate or other thorium intermediates to the Fernald Area, and covered the health and safety problems existing in the refining of thorium and the concurrent separation of rare earth materials.

PURPOSE

This survey was made with the following objectives in mind:

1. To gather data from which to calculate the daily weighted average exposures of plant employees.

2. To make an intensive study of present and past health experience of all Lindsay workers toward an estimation of the toxicity of thorium and thoron.

3. To suggest to Lindsay, physical and procedural changes which would be needed in the present plant to correct exposures which exceed the interim benchmarks now being used.

4. To provide information on which new thorium facilities can be designed.

RESULTS OF STUDY

Tentative maximum permissible concentrations of 70 $d/m/M^3$ for thorium, and 10^{-11} c/l of thoron have been used as benchmarks in this analysis. Of the eighty-two employees studied, forty-nine (59.8%) were exposed to thorium concentrations exceeding the tentative maximum permissible level; ten of these had exposures of 210 to 2100 alpha disintegrations per minute per cubic meter of air ($d/m/M^3$). The exposures of all plant people exceeded the level of thoron now considered as safe.

1. Thorium

A complete breakdown of the daily weighted exposure to thorium of plant personnel follows:

TABLE I

Summary of Daily Weighted Thorium Exposure

Number of Personnel	84
Average weighted exposure	151 d/m/M^3 *
Maximum weighted exposure	2000 d/m/M^3

	No. Persons
Less than 70 d/m/M^3	35 (41.7%)
70 to 210 d/m/M^3	39 (46.3%)
210 to 350 d/m/M^3	4 (4.8%)
350 to 700 d/m/M^3	2 (2.4%)
over 700 d/m/M^3	4 (4.8%)

* d/m/M^3 = disintegrations per minute per cubic meter of air.

70 d/m/M^3 = maximum allowable concentration (MAC) tentatively used by the New York Operations Office.

2. Thoron

The following table summarizes the calculated weighted thoron exposures as estimated from daughter measurements. (See Method of Study.)

TABLE II

Summary of Estimated Daily Weighted Thoron Exposure

Number of Personnel Studied	84
Average weighted exposure (c/l)*	52 x 10^{-11}
Maximum weighted exposure (c/l)	202 x 10^{-11}

	No. Employees
Less than 10^{-11} c/l	0
1 to 5 x 10^{-11} c/l	0
5 to 10 x 10^{-11} c/l	15 (17.9%)
10 to 20 x 10^{-11} c/l	7 (8.3%)
20 to 40 x 10^{-11} c/l	8 (9.5%)
40 to 80 x 10^{-11} c/l	45 (53.5%)
80 to 160 x 10^{-11} c/l	6 (7.2%)
over 160 x 10^{-11} c/l	3 (3.6%)

* c/l = curies per liter

The maximum allowable concentration (MAC) for the thoron is presently accepted as 10^{-11} c/l.

3. Radiation Measurements

a) Smear Samples taken throughout the Lindsay plant area showed removable alpha surface contamination of from 14 to 15000 alpha d/m/sample. The highest contamination (15000 alpha d/m/sample) was found in Building 4 Balcony at the thorium nitrate kettle.

b) External Radiation Measurement - Inplant: Excessive direct radiation was found in the "black mud" and "first gray mud" storage areas located on the Building 3 Balcony. Activity measurements exceeding the highest range of the 2610A Beta-Gamma Survey meter (20 milliroentgens per hour - mr/hr) were found (using a closed window).

c) External Radiation Measurement - Outplant; New plant location, sump, and storage areas: The highest radioactivity measured was in the "black mud" storage area. The reading made in direct contact over the "black mud" pile (approximately 10^6 pounds) was 40 mreps beta, 330 mr/hr gamma and 2×10^6 d/m/100 cm^2 alpha. (Juno readings.)

METHOD OF STUDY

A. Thorium

Dust samples were collected on 1 1/8" Whatman #41 filter paper, employing a Universal air pump at 0.5 cfm as the sampler. The collection period varied from 0.5 minutes to 100 minutes, depending on conditions of operation and dust loading.

The dust samples collected are divided into:

(1) General Air Samples - a sample obtained of a general working area or room atmosphere.

(2) Breathing Zone Samples - a sample obtained in the breathing zone of an operator during the performance of a particular task or operation.

B. Thoron

Because of the decay characteristics of the thorium chain, we have no direct method for measuring thoron gas concentrations with portable field equipment. It is possible, however, to collect thoron daughter products together with an airborne dust sample. The activity of the dust sample may then be used as an indirect means for calculating initial thorium daughter concentration after subtracting the concentration of long-lived alpha emitters. By using the radioactive decay curve of Rn^{220} (thoron) and its daughter products, the thoron concentration may be estimated with reasonable accuracy. The method of analysis of thoron is described in detail under Analytical Method for Thoron. The dust collection medium and the apparatus is the same as described above.

C. Radiation Measurements

Area monitoring for radiation intensity at various plant and outplant locations was done with:

1. Beta-Gamma Survey Meter 2610A - A geiger tube instrument with a shielded window to permit screening out beta particles. This is count rate meter reading intensity in milliroentgens per hour (mr/hr). The instrument has three ranges (0.2, 2.0, 20 mr/hr, full scale).

2. Juno - An ionization chamber instrument for detecting alpha, beta and gamma emitting radioactive materials. The Juno measures radiation intensities in three ranges, 50, 500 and 5000 mr/hr, full scale, and has selective shields to permit distinguishing the three types of radiation.

3. Smears - The removable alpha surface contamination was determined by wiping approximately 150 sq. cm area of a surface with a Whatman #41 filter paper. The alpha contamination adhering to the filter paper was counted on an alpha scintillation counter.

ANALYTICAL METHOD FOR THORON

Rationale

The properties of thoron make it difficult to analyze directly. (See Decay Scheme, Figure 10.) Thoron is, however, the parent of a chain of solid radioactive decay products which can be separated from air by filtration. Neglecting ThA, (0.16 sec half-life) the thoron daughter products will decay with a half-life which is long enough to permit a measurement of their radioactivity within a day or two after collection.

During sampling at a constant rate, decay products will build up on a collector and approach a constant activity. At equilibrium the rate of deposition will equal the rate of decay. However, for the thoron daughter chain this equilibrium will be reached only after 100 hours of sampling. It is therefore neither desirable nor practical to sample to equilibrium. For sampling times less than 100 hours, but more than 8 minutes, it is possible to calculate the percentage of equilibrium activity which will be present on the collector. (For sampling times less than 8 minutes this is not possible, since the decay constants involved are not known to sufficient accuracy.)

The alpha activity of thoron decay products may be converted to thoron concentration by the equation:

$$c/l = \frac{(2)\ (4.5 \times 10^{-16})\ (d/m)}{(F)\ l/m}$$

where

c/l = curies/liter of thoron

2 = empirical correction factor for absorption and incomplete particle retention

d/m = d/m at end sampling period

F = build-up factor

l/m = sampling rate

It is possible that thoron and its daughters may not be in radioactive equilibrium in the sampled air. In this case the above calculation would more correctly represent the concentration of only one of the daughters. From the relative half-lives of the thoron series, however, it is apparent that this can not be a serious discrepancy.

Procedure

The total activity of the samples was measured by a Samson alpha survey meter 7 to 12 hours after collection and the decay of those samples of higher activity was followed. All the filter papers were subsequently re-counted for long-lived activity. After subtracting the second count, the net first count extrapolated to the end of the collection period represents the activity of the daughters. This was then computed by the above equation to equivalent thoron activity.

The lower limit of detection of the Samson meter as used is approximately 250 d/m. This represents 2.0×10^{-11} c/l of thoron in an 8 minute sample measured after 10 hours.

JOB ANALYSIS SHEETS (See Appendix E)

The job analysis sheets give a detailed analysis of the exposure-time relationship of each employee on the project. This consists of a statement of the total time spent on each specific component of the job with the number of times each task is performed per day. The average concentration as obtained from a minimum of three samples per location is also recorded. The time weighted average exposure per full working day is determined by dividing the sum of all products of concentration times time, by the total number of minutes per day. In estimating thoron exposures it was found that only long term samples contained sufficient thoron daughter products in the form of dust to be measurable. In view of the fact that plant operation requires the operators to remain in their work areas almost full time however, the lack of short, breathing zone, thoron samples does not appear important. If anything, exposures which are calculated neglecting breathing zone samples will be somewhat underestimated. Because complete breathing zone coverage was not possible however only General Air information was used to determine the individual daily weighted thoron concentration exposures.

PROCESS DESCRIPTION

1. Monozite Sand received in 100 pound burlap bags are dumped into a continuous ball mill. The mill discharge is transferred to a sand hopper by buggy, and dumped. Five hundred pound batches of ground sand are reacted with fuming sulfuric acid yielding "pot cake". Unreacted sand is dried, recrushed, and treated as virgin sand.

2. The "pot cake" is leached with water and filtered. The sludge obtained from the filter press is called the first "gray mud".

3. The "first gray mud" is boiled with caustic yielding a crude thorium hydroxide known as "red mud". Upon leaching "red mud" with sulfuric acid, a "black mud" sludge is obtained. This sludge contains mesothorium, thorium and rare earths, and is discarded.

4. "Red mud" is dissolved in sulfuric acid and precipitated with hydrofluoric acid yielding a crude thorium fluoride known as "second gray mud".

5. The "second gray mud" is leached with a soda ash solution and the residue is crude rare earth-thorium carbonate. The carbonate solution is precipitated with caustic yielding an impure thorium hydroxide known as "white mud".

6. Upon dissolving the "white mud" in hydrochloric acid and precipitating with sulfuric acid thorium sulfate crystals are obtained. The crystals are dissolved in water, precipitated again with caustic yielding thorium hydroxide. This is leached with nitric acid to produce a thorium nitrate solution. The thorium nitrate solution is crystallized, centrifuged and recrystallized to produce the purified thorium nitrate tetrahydrate.

7. Thorium nitrate precipitated with oxalic acid yields thorium oxalate, which upon calcining is decomposed to thorium oxide.

A flow sheet of the above operation is included (Figure 1).

DISCUSSION

In order that the data of this report may be interpreted, it is necessary to have some criteria of toxicity. The following maximum allowable concentrations are suggested:

1. Thorium: 70 disintegrations per minute per cubic meter of air.

   Although there is no generally accepted MAC for thorium, the New York Office has tentatively accepted the level which has been in use for some time for insoluble uranium compounds. There is no apparent reason why the radioactive toxicity of these two materials should differ significantly when expressed on an activity basis.

2. Thoron: 10^{-11} curies per liter of air.

   As in the case of thorium, there is as yet no generally accepted MAC but the "American Conference of Governmental Industrial Hygienists" has tentatively proposed the value used in this report. Again this is taken from the accepted value for radon with the same rationale as expressed above.

In this study it was found that forty-nine of the eighty-four plant employees are exposed to thorium concentration exceeding the MAC. The ball mill, rotary drier, pot diggers, thorium oxide preparation, and dissolver operators had exposures ranging from 3 to 12 times the MAC while the rare earth fluoride rotary drier, and pot operators had exposures of 18 to 30 times MAC, respectively. Table III contains the individual daily weighted thorium exposures for all occupations.

The thoron exposures of all Lindsay employees were all found to exceed the tentative MAC of 10^{-11} curies per liter. The range of these exposures was from 8 MAC found for the office personnel to 202 MAC for the

TABLE III

DAILY WEIGHTED AVERAGE EXPOSURE

JOB	No. of Employees	Daily Weighted Concentrations: Thorium (d/m/M^3)	Thoron (x 10^{-11} c/l)
Building 3			
Ball Mill	1	560	64
Rotary Drier	1	870	64
Pot Operator	2	2000	75
Pot Diggers	2	330	75
Pot Baker (small room)	1	54	44
Pot Digger (small room)	1	48	60
HF Operator	1	77	68
Maintenance & Repair - Bldg 3	1	77	48
Press Operators	4	110	52
Working Foreman (Press)	1	90	30
Thorium Oxide Preparation	1	510	59
Thorium Nitrate Crystallization	1	40	28
Building 4			
Rare Earth Fluoride Rotary Drier	1	1300	104
Hydroxide Drier	1	280	105
Thorium Sulphate	1	110	97
Thorium Extraction	1	180	200
Dissolving Operator	1	220	202
Cascade Operator	1	14	160
Thorium Nitrate Mold Crusher	1	18	152
Chemical Operator Foreman	1	150	142
Maintenance & Repair - Bldg 4	1	130	100
Maintenance & Repair - Bldg 2,3,4	7	73	56
Other Personnel (not handling Th)	5	33	39
Building 2			
Plant Superintendant	1	23	20
Production Superintendant	1	69	48
Assistant Superintendant	1	75	47
Maintenance & Repair Supervisor	1	6	13
Receiving and Shipping	1	12	12
Control Laboratory	5	12	19
Labor Crew	20	92	61
Office Personnel	15	6	8
Total Personnel	84		
Average Daily Weighted Concentration		151	52

the dissolving operator. The highest single general air concentration 920×10^{-11} was found at a dissolving kettle #16 on the Building 4 Balcony. It is safe to assume that since the majority of the reported breathing zone thoron concentrations reported in the sample record sheets were about 10^{-9} curies per liter, the estimated individual daily thoron concentrations shown in Table IV are probably on the low side.

From the sample data in Table IV the need for process improvement and control is obvious if the tentative levels are accepted.

Following is a summary of the main points from which a high dust dispersion was noted:

I. Ball Mill

a) During the operation of loading monozite sand into the mill, visible dust was dispersed throughout the area. An average BZ concentration 780 d/m/M^3 was found. This concentration was primarily from:

1. Lack of ventilation at the bag dump hopper.

2. Frequent jamming of sand conveyor.

3. Lack of ventilation between weigh hopper and syntron feeder, and syntron feeder and ball mill.

4. Spread of contamination from

(a) frequently open or leaky monozite sand bags
(b) dust escaping from leaky ball mill
(c) lack of central vacuum cleanup system.

b) Loading a buggy with sand from the discharge of the mill is even dustier. An average breathing zone concentration of 3400 d/m/M^3 was found. Lack of ventilation at the hopper and mill discharge are primarily responsible for the high dust concentrations.

II. Rotary Drier

Tabulation of this operator's daily tasks are shown in Table IV. The highest average breathing zone concentration (3400 d/m/M^3) was found during the unloading of the sand from the mill discharge onto buggies. This is the same operation as performed by the mill operator.

TABLE IV

TABULATION OF AVERAGE BREATHING ZONE SAMPLES

OPERATION	Concentration (d/m/M3) Average	High	Low	No. of Samples
Rotary Drier				
1. Loads 12 buggies with monozite sand	3400	3900	2800	3
2. Loads Drier with 3 wheel barrel loads of wet monozite sand	100	140	60	2
3. Unloads material from drier into pile in center of area	663	1110	400	3
4. Loads material with truck	132	210	54	2
Ball Mill				
1. Loads one buggy with sand from discharge of mill	3400	3900	2800	3
2. Loads six sacks of monozite sand into mill	785	980	690	3
Pot Operator				
1. Dumping buggy of sand into hopper at center of pot area	9530	14000	3600	3
2. Unloading sand hopper into pot barrel	13200	34000	4800	4
3. Unloading one barrel of sand into pot containing fuming H_2SO_4	3150	8700	5650	4
Pot Diggers				
1. Digging pot cake out of pots	16	32	<1	3
2. Loads buggy with sand from discharge of mill	3400	3900	2800	3
3. Unloading buggy of sand into hopper at center of pot area	9530	14000	3600	3
4. Loads buggy	3400	3900	2800	3
Pot Digger				
1. Digs unreacted sand from pot	-	-	8.0	1
Pot Baker				
1. Charging acid and reclaimed sand into pots	60	190	<1	3
2. Loading sand from hopper into can	93	280	<1	3
Press Operators - Bldg 3				
1. Clean press black mud (mesothorium)	235	260	210	2
2. Loading black mud into drum	280	350	210	2
3. Cleaning first gray mud press	122	170	70	2
4. Loading first gray mud into barrels	70	140	<1	2
5. Cleaning second gray mud press	380	390	370	2

Table IV - continued

OPERATION	Concentration ($d/m/M^3$) Average	High	Low	No. of Samples
6. Loading second gray mud into barrel	150	-	-	1
7. Cleaning red mud press	85	93	78	3
8. Loading red mud into barrels	85	-	-	1
Rare Earth Fluoride Rotary Drier				
1. Shoveling R.E. Fluoride from drum into rotary drier	66	76	52	2
2. Charging grinder hopper with dried R.E. Fluoride	505	680	430	2
3. Discharging R.E. Fluoride from grinder into drum	19000	-	-	1
Hydroxide Drier				
1. Unloads 13 pans R.E. Hydroxide into drum	810	1400	380	3
2. Loads wet R.E. Hydrate into 13 pans	200	300	120	3
3. Loads 13 pans into drier	197	220	160	3
4. Clean up area with sweep	830	-	-	1
Thorium Extraction - Bldg 4				
1. Cleaning second grade thorium mud	185	190	180	2
2. Loads second grade thorium mud into drum	2250	2300	2200	2
Thorium Nitrate Mold Crusher				
1. Crushing $Th(NO_3)_4$ mold in hood	14	16	11	4
Thorium Oxide Preparation Room				
1. Loads trays with thorium oxalate and inserts into furnace after unloading thorium oxide trays from furnace	5000	8200	1800	3
2. Unloads trays ThO_2 from furnace into bottle	52000	160000	107000	3
Thorium Nitrate Crystallization				
1. Scoops thorium nitrate from Fibre Pak carton into mixing kettle	<1	82	41	2

Three other operational samples obtained during loading of the drier, loading monozite sand into trucks and unloading the drier averaged 100, 132 and 663 d/m/M^3, respectively. Direct contributors to the excessive concentrations are:

1. Dumping of unreacted sand on floor in center of area.

2. Crushing large pieces of material with shovel, in open.

3. Frequent handling of material.

4. Lack of ventilation.

III. Pot Area

The pot area is affected by the dust generated during the unloading of milled sand from the sand hopper into the pot barrel, dumping buggy of sand into hopper at center of pot area, and unloading barrel of sand into pot of fuming sulfuric acid. Average breathing zone samples of 13,200, 9500 and 3150 d/m/M^3, respectively, were found for the above operations. Since the average general air concentration in this area is 76 d/m/M^3, it is quite evident that local dust and fume control at the source is desirable. Several practices observed in this area which directly affected the exposure of the individuals were:

1. Frequent spillage of monozite sand and pot cake onto floor.

2. Eating of food and smoking in operating area.

3. Digging out pots with hand scoop exposing operator to dust and fumes.

IV. Rare Earth Fluoride Rotary Drier

Dust creation in this area by far exceeded that created in other operating areas. Fortunately, the rare earth fluoride contains only 0.25% thorium oxide thus the radioactivity content of the collected air samples were not as high as found in other areas. However, a single breathing zone sample taken during the discharging of rare earth fluoride from the grinder into a drum revealed a thorium concentration of 19,000 alpha d/m/M^3. The following violations of good practice were noted:

1. Lack of ventilation at discharge end of Rotary drier.

2. Open system from drier to grinder.

3. Grinder charging hood inadequately ventilated.

4. Entire grinder unit leaks dust.

5. Inadequate ring type exhaust at discharge of grinder.

6. Outlet of Dracco collector recirculates inside the operating area spreading dust throughout the area.

V. Rare Earth Hydroxide Drier

Initially the rare earth hydroxide is dumped onto the floor between the rare earth fluoride rotary drier and the hydrate drier. This fuming pile of hydrate is then transferred to trays and thence to the drier. The entire area between the hydrate drier and pile was covered with a heavy yellow dust. Average breathing zone samples of the four operations performed by this operator ranged from 200 to 830 d/m/M3.

The surveyors noted the following violations of good industrial hygiene procedures:

1. Storage of rare earth hydroxide (often fuming) in an open area between the rare earth fluoride and drier.

2. Loading of hydroxide into pans in open area.

3. Conveying of dust laden pans in open.

4. Contamination of entire floor area with dried hydrate and tracking of material to adjacent areas.

5. Unloading of hydrate from pans into drums was performed in open, creating a dusty atmosphere.

6. Drums filled with dried hydrate were left unlidded.

VI. Press Areas

Cleaning and loading of the various press cakes exposed the operators to average BZ concentrations ranging from 70 to 380 d/m/M3. The highest concentrations found were at the "second gray mud" presses.

Such operations as hand cleaning of the presses with scrapers, shoveling the cake into barrels or into tanks and cleanup of area after press dumping contributed to the average general air concentration of 125 alpha d/m/M^3 found on the Building 3 Balcony. In addition, a direct radiation exposure to beta and gamma or both exists during the cleaning of the presses. A lack of gloves on many of the press operators was noted.

VII. Thorium Oxide Preparation Room

During the operation of loading trays with thorium oxalate and inserting into calciner, the operator was exposed to an average Breathing Zone concentration of 5000 d/m/M^3. While unloading the trays of thorium oxide from calciner into a bottle in the open, an average breathing zone concentration of 52,000 d/m/M^3 was found.

The lack of adequate hooding facilities for loading and unloading of thorium oxalate and thorium oxide, and the general spread of contamination were primarily responsible for the excessive dust concentration.

Table V which contains a tabulation of the average general air samples shows the major concentration of both thorium and thoron in Building 4. The average thorium concentration was found to be 245 d/m/M^3 and the average thoron concentration 263 x 10^{-11} curies per liter.

VIII. Radiation

A. Inplant

1. Table VI contains the results of a complete radiation survey of thorium production, office and laboratory, areas at the Lindsay Chemical Company. The highest readings obtained were found on the Building 4 Balcony the location of high thorium and thoron concentrations. Three foot level (waist high) measurements near the thorium nitrate kettles, hydroxide filter, cascade and thorium nitrate crushing hood averaged 2 mreps beta and 4.5 mr/hr gamma. Readings exceeding the capacity of the 2610A for both beta and gamma were found in direct contact with top and sides of thorium nitrate tub.

2. Smears - The highest removable contamination (a 15,000 alpha d/m/sample, smear taken over an area of 150 cm^2) was found at the thorium nitrate kettle located on the balcony of Plant 4. The site also of the highest thoron and thorium dust concentration.

B. Outplant

1. Table VII and Figures 2 and 3 contain the results of direct radiation measurements made in outdoor storage areas and of the waste liquors from the process. The

TABLE V

TABULATION OF AVERAGE GENERAL AIR SAMPLES

LOCATION	Average Concentration Thorium ($d/m/M^3$)	Average Concentration Thoron (10^{-11} c/l)
Building 3		
Mill and Drier Area	220	64
Pot Area	76	77
Balcony	125	48
Main Floor under Presses	66	64
Small Pot Room	53	43
Building 4		
Main Floor	129	111
White Mud Filter Press Area	69	115
White Mud Tank Area	78	73
Balcony	245	263
Cascade Room (Evaporation)	14	164
Main Floor North of Thorium Production Area	34	39
Building 2		
Thorium Oxide Preparation Room	32	36
Thorium Crystallization Area	48	20
Receiving and Shipping Area	12	14
Control Laboratory	13	19
Machine Shop	5	20
Old Mantle Production Area	5	36
Locker Room	5	22
Main Office Area	6	8

TABLE VI

SMEAR SAMPLE RESULTS

LOCATION	RESULTS (d/m/sample)
Building 3 - Mill Drier Area	
Floor, Ball Mill Changing End	330
Sample, Monozite Sand	1200
Floor, Unreacted Wet Sand	860
Floor, Charging End Drier	650
Sample, Unreacted Wet Sand	1500
Sample, Dry Unreacted Sand	1400
Sample, Top of Monozite Sand Burlap Bags	14
Floor, Discharge End Drier	460
Building 3 - Pot Area #2	
Side Sand Hopper	540
Pot Cake	250
Crud on Top of Pot	440
Platform - Pot Cake Discharge Tank	450
Floor, Front of Sand Hopper	510
Glove of E. Kramp	670
Building 2 - Small Pot Room	
Side Sand Hopper	150
Crud Top Pot	50
Pot Cake 2nd Baking	240
Floor Front Pot	120
Floor in Front Sand Hopper	140
Building 2 - Men's Locker Room	
Top of Locker	230
Floor	180
Building 4 - Rare Earth Fluoride Area	
Floor, R. E. Fluoride Drier	520
Dust on R. E. Fluoride Hopper	350
Floor, Discharge of R. E. Fluoride Hopper	750
Top R. E. Fluoride Drier, Feed End	1600
Building 4 - Rare Earth Fluoride Area	
Floor, Feed End R. E. Fluoride Drier	670
Floor, R. E. Hydrate Bin	150
Floor, R. E. Hydrate Drier	170
Building 4 - Process Area	
Floor, Front Cerox Sifter	680
Platform Cerox Hyd. Filter	2000
Floor, 15 ft. South Elevator	700
Top Thorium Hydride Filter Press	960
Floor Under Thorium Hydride Filter Press	3300
Floor Elevator	1200

Table VI - continued

LOCATION	RESULTS (d/m/sample)
Building 4 - Balcony	
Floor, Front Elevator Balcony	1900
Floor in Front $ThNO_3$ Kettles	930
Side of $ThNO_3$ Kettle	8700
Liquid $ThNO_3$ Kettle	15000
Floor, Front Cascade	1700
Dust on Top - Cascade Hood	480
Wall South End on Top Cascade Hood Near Breaker	270
Floor, Front Breaking Table	4000

TABLE VII

DIRECT RADIATION MEASUREMENTS - INPLANT

LOCATION	β mreps/hr	γ mr/hr	α d/m/100 cm^2
Building 2			
Passageway, N.E. Corner - Floor Level	0.23	0.12	25000
Passageway, N.E. Corner - 3' Level	0.2	0.05	
BBL. Rare Earth Fluoride, Stored N. End - Top	0.05	2.5	8000
BBL. R.E. Fluoride, Stored N. End - Side, Contact	0.05	2.5	
BBL. R.E. Fluoride, Stored N. End - " , 6" "	0	0.08	
Drum Cerox Oxalate, Top Contact	0.05	0.5	2000
Drum Cerox Oxalate - Side Contact	0.15	0.25	
Drum Cerox Oxalate - Side 6" Contact	0.1	0.2	
Drum R.E. Hydrate - Top Contact	0.05	1.1	3000
Drum R.E. Hydrate - Side Contact	0.05	1.1	
Drum R.E. Hydrate - Side 6" Contact	0	0.7	
Drum Cerox - Side 6"	0	2.5	
Opposite Shipping Door - Contact - Floor Level	0.5	2.5	14000
Drums, $ThNO_3$ (24 Drums, 190 lbs. each)			
Top of Drum - Contact	3	20	5000
Side of Drum - Contact	8	40	
Side of Drum - 1/2'	6	31	
Side of Drum - 1'	5	22	
Drum, ThO_2 - Top Contact	1	7	
Drum, ThO_2 - Side Contact	0.5	16	
Drum, ThO_2 - Side 1/2'	0.5	7.5	
Drum, ThO_2 - Side 1'	0.5	5.5	
Near Shipping Door - Floor Level	0	2	10000
Old Mantle Plant			
Bastnasite Storage	0.25	0.2	
Old Webbing, N. End - Contact	3	1.5	
Old Webbing, N. End - 3'	0.9	0.3	
Middle Room - 3' Level	0.1	0.2	
Work Tables - Contact	0.12	0	5000
Asbestos String Box - Contact	0.25	0.75	17000
Mantle Shelf, N.W. Corner			3000
Storage Bin, N.W. Corner	3	1.5	40000
N. End Center - Contact - Floor Level	0.25	0.5	16000
Center - Contact - Floor Level	0.1	0	8000
South End - Contact - Floor Level	0.5	0.1	8000
Machine Shop			
Electric Shop Area - Work Bench	0.03	0.02	2000
Aisleway	0.05	0.1	10000
Stockroom - Counter	0.06	-	Neg.
Front of Stockroom - Floor Level	0.06	0.08	9000
Machine Area - Bench	0.05	0.1	5000
Machine Area - Floor Level	0.04	0.06	7000
Center Machine Shop - 3' Level	0.025	0.05	

Table VII - continued

LOCATION	READINGS		
	β mreps/hr	γ mr/hr	α d/m/100 cm^2
$ThNO_3$ Drums, Near BJB Office - Top Contact	1	20	7000
$ThNO_3$ Drums, Near BJB Office - Side Contact	3	30	
$ThNO_3$ Drums, Near BJB Office - Side 1/2'	2.5	20	
$ThNO_3$ Drums, Near BJB Office - Side 1'	2	14	
La Treating Room			
Table Top - Contact	0.03	1.1	3000
Center of Room - 3' Level	0	1.4	
On Scale by ThO_2 Bottle, 1/5 Full	0	12	
Furnace Room			
Front of Furnace Door, 1'	2.5	0.8	350000
Center of Room - Floor Level	1	1.5	140000
Center of Room - 3' Level	0.3	0.7	
Table Top by Trays	0.9	0.75	120000
Asbestos Gloves	1.8	0.7	130000
R.E. Carbonate Drum - Top Contact	0	2	
R.E. Carbonate Drum - Side Contact	0	0.7	
Drum, Barnesite (Re_2O_3) - Side	0	0.5	
Center of Middle Room in Front of $ThNO_3$ Kettle			
3' Level	0.4	0.7	
Floor Level	1.0	0.45	50000
Men's Locker Room, Center - 3' Level	0.04	0.1	
Men's Locker Room, Center - Floor Level	0.3	1.5	20000
Control Laboratory			
West Center - 3' Level	0.1	0.3	
Table Near Hood	0.1	0.3	
Polishing Room Center Table - Top	0.5	0.2	Neg.
West Center - 3' Level	0.1	0.2	
Building 3			
Passageway, N. End - 3' Level	0.1	0.25	
Passageway, N. End - Floor Level	1	3	11000
Passageway, Center - 3' Level	0	2.5	
2nd Gray PPT'N. Tank (Full) - Side Contact	0	10	
Red Mud, Cone Bottom Tank, Washing - Contact	0	4	28000
Red Mud Filter Press in Operation	0.5	1.5	
Red Mud Filter Press in Operation - Floor Level	5	3	120000
Passage Between Ball Mill & Pots - 3' Level	0.3	1.2	
Passage Between Ball Mill & Pots - Floor Level	1.8	2	22000
Pot Area			
Bucket Pot Cak - Top Contact	1	3	3000
Near Bucket - Floor Level	0.5	2.0	8000
Pot Cake Dissolving Tank - Side	0	2.5	
Sand Hopper - Side Contact	0	4.5	
Front of Sand Hopper - Floor Level	1	2.5	29000
Front of Sand Hopper - 3' Level	0.1	1.6	

Table VII - continued

LOCATION	READINGS		
	β mreps/hr	γ mr/hr	α d/m/100 cm^2
Bucket of Sand - Side Contact	0.5	4	8000
Bucket of Sand - Side 1/2'	1	2.5	
Bucket of Sand - Side 1'	0.5	2	
Glove, E. Kramp - Palm Side	0.6	1.5	15000
Small Pot Area			
Platform in Front of Pots	0	1	5000
In Front of Pots - 3' Away - 3' Level	0.15	0.6	
Pot Cake from Unreacted Sand (Baked 2nd Time)	0.5	3	17000
Center of Room - Floor Level	0.15	0.1	22000
Front of Unreacted Sand Hopper - Floor Level	2	1.4	15000
Bucket of Unreacted Sand - Side Contact	0.5	3	
Platform Just South of Hopper	0.5	0.75	5000
Work Table	0	0.25	3000
HF Operator's Cabinet	0.06	0.1	4000
Around Black Mud Press - Floor Level	off scale	9	
Bottom Pan under Black Mud Press	off scale	10	
Around Second Gray Mud Press - Floor Level	5	3	
Beside Second Gray Mud Press	1.5	2.5	
BBL. First Gray Mud - Top Contact	3.5	9	
BBL. First Gray Mud - Side Contact	2.5	10	
BBL. First Gray Mud - Side 6"	0	7	
Red Mud Dissolving Tank - Side Contact	2	7.5	
Red Mud Dissolving Tank - Side 6"	1.5	6.5	
Red Mud Boiling Tank - Side Contact	0.5	7	
Red Mud Boiling Tank - Side 6"	0.5	6	
Between Red Mud Boiling & Dissolving Tanks			
Floor Level	4	4.5	
3' Level	1	4.5	
BBLS. First Gray Mud From Yard - Top Contact	off scale	off scale	
BBLS. First Gray Mud From Yard - Side Contact	1	20	
BBLS. First Gray Mud From Yard - Side 6"	1.5	11.5	
Front of Red Mud Boiling Tank - Floor Level	1	6.5	
Building 4			
Passage Between Bldgs 2 & 4 - 3' Level	0.1	0.3	18000
Passage Between Bldgs 2 & 4 - Floor Level	0.17	0.3	
Just West of Hydrate Driers (S. End) - Floor Level	0.1	0.3	11000
Between Driers - 3' Level	0.1	0.6	
Between Driers - Floor Level	0.35	0.55	12000
Damp Rare Earth Hydrate in Tray	0.2	1.2	90000
Front of Feed End of R.E. Fluoride Drier - Floor Level	0.3	0.25	15000
Discharge End of R.E. Fluoride Drier - Floor Level	0.18	0.4	15000

Table VII - continued

LOCATION	READINGS β mreps/hr	γ mr/hr	α d/m/100 cm^2
Just W. of Th Centrifugal - Floor Level	0.5	1	38000
BBL. $ThNO_3$ - Top Contact	0	5.5	
BBL. $ThNO_3$ - Side 1/2'	0	3	
BBL. $ThNO_3$ - Side 1'	0	1.8	
West of Centrifugal - 3' Level	0.25	1	
BBL. R.E. Hydrate - Side Contact	0.05	1.75	
Front of Cerox Sifters - Floor Level	0.6	0.75	70000
Th Hydroxide Filter Press, 3"	0.3	1.2	
Elevator - Floor Level	1	2	150000
Front of Elevator on Balcony - Floor Level	0	2	
Front of Elevator on Balcony - 3' Level	0	1.8	
$ThNO_3$ Kettle - Side Contact	3	15	
$ThNO_3$ Kettle - Side 1/2'	1	12	
$ThNO_3$ Kettle - Side 1'	0	7.5	
Front of $ThNO_3$ Kettles - Floor Level	6	5.5	
Front of $ThNO_3$ Kettles - 3' Level - 3' Away	1	4	
Th Hydroxide Filter, 3' South - 3' Level	0.5	4.5	
Front of Cascade - 3' Level	2.5	4.5	
Table at End of Cascade	4	2.5	
Tub of $ThNO_3$ - Top Contact	> 20	> 20	
Tub of $ThNO_3$ - Side Contact	> 20	> 20	
Tub of $ThNO_3$ - Side 6"	1	11.5	
Pan of $ThNO_3$ - Top Contact	off scale	17.5	
Pan of $ThNO_3$ - Side Contact	3	15	
Pan of $ThNO_3$ - Side 6"	1	5	
Front of Crusher - Floor Level	4	4	
Front of Hood - 2' Away - 3' Level	2	3	
Th Extraction Filter Press - Top	3	2	
Th Extraction Filter Press - Floor Level	5.5	4	
Front of Elevator - Floor Level	5.5	3.5	
First Gray Mud Spilled on Floor	2.5	5	
Black Mud Storage	off scale	off scale	
Between Black & 1st Gray Mud Storage - 3' Level	0.5	10.5	
2 1/2 Feet From Black Mud BBLS.	off scale	20	
3 Feet From Black Mud BBLS.	3	17	
4 Feet From Black Mud BBLS.	4	11	

Ball Mill

LOCATION	β mreps/hr	γ mr/hr	α d/m/100 cm^2
Bags of Monozite Sand - Top	3.0	10	
Near Bags of Sand - Floor Level	1.5	2	
Between Large Pile (6" Between)	4.0	15	
Pile of Bags - Side Contact	1.0	10	
Pile of Bags - Side 1/2'	1.0	6.5	
Pile of Bags - Side 1'	1.0	5	
Pile of Bags - Side 3'	0.5	4	

Table VII - Continued

LOCATION	READINGS		
	β mreps/hr	γ mr/hr	α d/m/100 cm^2
Discharge of Unreacted Monozite Sand Drier -			
Top Contact	1.0	7.0	
Side Contact	1.0	3.0	
Piles of Spilled Monozite Sand - Top	2.5	5.5	
Center of Room - Floor Level	1.5	1.0	
Pile of Wet Unreacted Monozite Sand - Top	1.5	5.0	
Discharge Ball Mill Monozite Sand - Top Contact	1.0	6.5	
Discharge Ball Mill Monozite Sand - Side 6"	1.0	4.5	
Near Ball Mill Discharge - Floor Level	1.0	1.0	
Ball Mill Charger Hopper	0.5	4.5	
Charger Drier	1.0	1.5	
Center of Area - Floor Level	1.0	1.0	

liquid waste of approximately 180,000 fluid gallons per day from Plant 2, 3, and 4 contains approximately 0.4% solids by volume. The liquor discharges through an underground sewer to a sump area located a 1/4 mile south of the plant. The highest measurement obtained (1.5 mreps/hr beta, 7.5 mr/hr gamma and 110,000 d/m/100 cm^2 alpha) was on direct contact with a pile of material dredged from the sumps. Evidence of contamination was found at the site of the excavation for a new thorium plant. 0.9 mr/hr gamma and 8,000 d/m/100 cm^2 alpha was found.

2. Solid Sludge which includes "black mud", thorium extraction residue, "first gray mud" and "second unreacted sand" are stored within a cyclone fenced enclosure located 200 yards south of the sump area. Waste materials are trucked from the plant to this storage area several times a day. The highest reading found in direct contact with the road at several locations between the sump area and the storage area was 0.6 mreps/hr beta, 1.3 mr/hr gamma and 160,000 alpha d/m/100 cm^2. A 480 ton pile of "black mud" located at the extreme north east corner of the enclosure provided the highest radiation readings. 40 mreps beta, 330 mr/hr gamma and 2×10^6 d/m/100 cm^2 alpha was found using a Juno instrument.

CONCLUSION

Daily weighted thorium and thoron concentrations exceeding the presently accepted preferred levels have been found for a majority of the Lindsay plant employees.

If the departures from good industrial hygiene practices noted in the Discussion are corrected, it is our belief that the airborne dust exposures of all plant personnel can be substantially reduced.

TABLE VIII

DIRECT RADIATION MEASUREMENTS - OUTPLANT

LOCATION	READINGS		
	β mreps/hr	γ mr/hr	α d/m/100 cm^2
I. Site of New Building 50' S. of Bldg 3			
3' Level	0	0.5	
Contact Ground		0.9	8000
On Street 150 yds S. Plant			
3' Level		0.16	
Contact Ground		0.5	
II. Sump Area 150 yds S. of Plant			
Inside Gate (30') - 3' Level	0.05	0.15	
Inside Gate (30') - Contact Ground	0.5	0.45	
Unreacted Sand Pile	1.5	4.0	
1 ft. above liquor in North Sump		0.15	
Ground at S.E. Corner of N. Sump	2.0	0.5	100000
Pile of Sump Sludge - Contact	2.0	4.0	85000
Hole East of South Sump - 1st	2.0	2.0	45000
Hole East of South Sump - 2nd	1.5	4.0	150000
Material Dredged from Sump	1.5	7.5	110000
Road inside Sump Area - 3' Level	0.05	0.25	
III. Mud Storage Area 1/4 mile S. of Plant			
Road into area at corner - 3' Level	0	0.4	
Road into area at corner - Contact	0.7	0.55	40000
Road into area 50 yds W. corner	0.6	1.3	160000
Fill from new plant site - graded	0	0.2	10000
Pile of mud from Sump 50' away from fence			
3' Level	0	1.5	
Contact	2.0	5.0	47000
Pile of Old India 1st Gray Mud			
Contact	0.5	2.5	
Top of Pile - Contact	off scale	17.5	
Top of Pile - 1' away	6.0	10.5	60000
2nd Unreacted Sand - Contact	2.0	6.0	
Background Between 2nd Unreacted Sand and Extraction Residue		5.0	
Idaho 1st Gray Mud - Contact	5.0	14.0	250000
Road - 3' Level	1	5.5	
India 1st Gray Mud - Contact	12	48	200000
India 1st Gray Mud - 3' Level		20	
India 1st Gray Mud - Contact in hole where sifted	20	120	800000
India 1st Gray Mud - 3' Level		off scale	

Table VIII - continued

LOCATION	READINGS		
	β mrcps/hr	γ mr/hr	α d/m/100 cm^2
III. (continued)			
Roadway 7' From Pile	2	10	
Scrapings - Contact	5	30	130000
Between Unreacted Sand and Scrapings	1	6.5	
Thorium Extraction Residue - Contact	off scale	19	110000
Thorium Extraction Residue - 6"	20	15	
Black Mud Pile - With 2610 beta-gamma			
12' From Pile at Fence	19.5	17	
11' From Pile	off scale	18.5	
10' From Pile	off scale	19.5	
9' From Pile	off scale	off scale	
Black Mud Pile - With Juno			
12' Away		22	
10' Away	21	29	
9' Away		40	
8' Away		40	
7' Away		40	
4' Away	10	70	
3' Away	15	85	
1' Away	15	85	
Contact Over Pile	25	210	
Over Pile	40	330	2000000