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Books

AMERICAN MEDICAL ASSOCIATION PUBLICATION

The Industrial Hygiene of Uranium Refining

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From the time of the organization of the Atomic Energy Commission until 1954, health protection at all uranium refining operations was supervised by the Health and Safety Laboratory (HASL). Since that time the Laboratory has played an ever-decreasing role in this supervision, acting primarily as a consultant. During the 10-year period 1948 through 1958, HASL conducted 60 complete evaluations of occupational health hazards in seven uranium refining plants.

All of the original plants were activated by the Manhattan Engineering District.

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Under pressure to produce uranium quickly, the project administrators chose as contractors those firms experienced in handling some particular chemical procedure to conduct that portion of the process which involved the use of that type of procedure. No one organization was experienced in all of the chemical techniques utilized in uranium production. Therefore, the production sequence was broken into many segments with portions assigned to different chemical firms. This system of producing materials stepwise in various locations throughout the country resulted in administrative, transportation, and health problems. The intermediate packaging of material for accountability inventory and for shipment

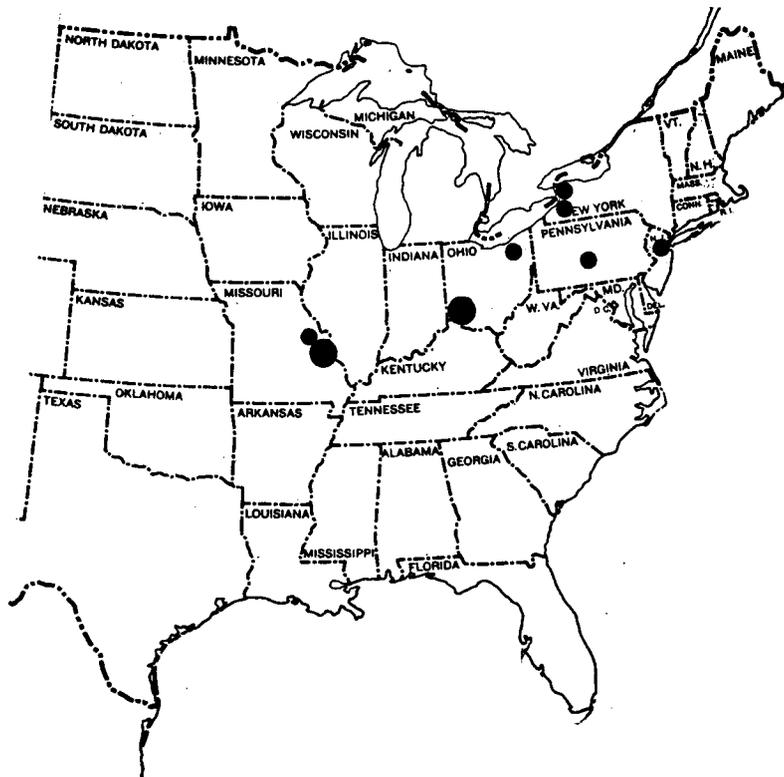


Fig. 1.—Location of early uranium production facilities.

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- DIGES
- DE
- OXIDE
- TETR
- PF
- METAL
- HEXA
- PR
- SCRAF

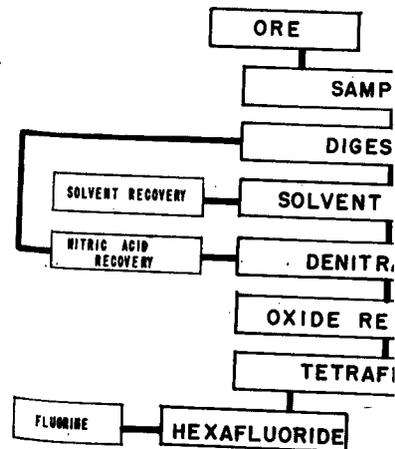
Fig. 2.—Modernization program of various uranium production facilities.

to a succeeding facility was most troublesome source of difficulty. This is a representation of the location of production facilities as of 1955.

By 1955 all of these operations were performed in two parallel, integrated plants. Figure 2 shows the changing pattern as temporary facilities were replaced by more integrated plants.

Where trained industrial hygienists were available, their recommendations were not assigned the priority given to production problems. The periodic industrial hygiene surveys conducted by HASL at each fac-

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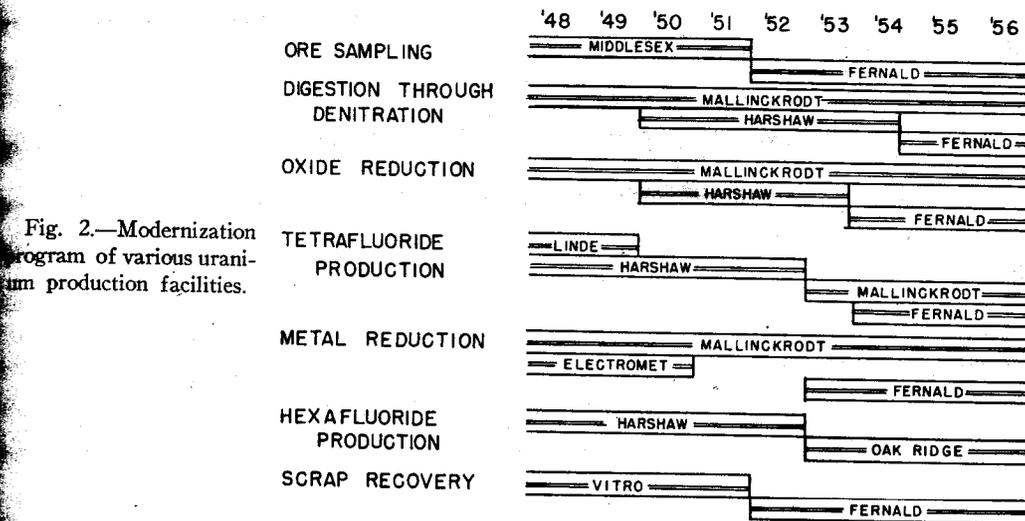


Fig. 2.—Modernization program of various uranium production facilities.

to a succeeding facility was frequently a most troublesome source of dust. Figure 1 is a representation of the location of the production facilities as of 1950.

By 1955 all of these operations were performed in two parallel, integrated plants. Figure 2 shows the changing production pattern as temporary facilities were replaced by more integrated plants.

Where trained industrial hygienists were available, their recommendations for control were not assigned the priority which was given to production problems. After 1948, periodic industrial hygiene surveys were conducted by HASL at each facility for the

purpose of evaluating existing hazards and providing information and recommendations for their control.

Since 1940, uranium production has increased steadily; at present, U.S. purchases of raw material amount to a rate of approximately 30,000 tons of metal per year. In addition to the two integrated units which were mentioned previously, a third refinery, privately financed and operated, has recently been brought into production.

The first process of choice was one in which the digested raw material was brought to an extreme degree of purity by means of solvent extraction. The purified uranium

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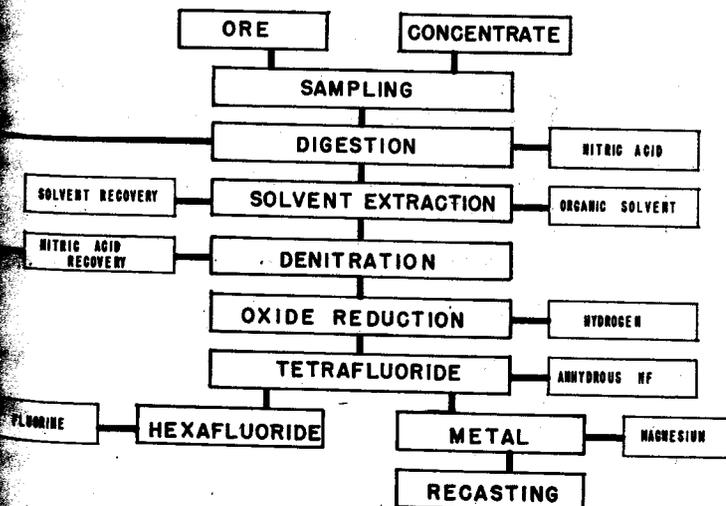


Fig. 3.—Block-flow diagram of uranium refining.

nitrate was then thermally decomposed to UO_3 , reduced by hydrogen to UO_2 , and reacted with HF to form UF_4 . Here a bifurcation in the process stream permitted (a) thermite reduction to metal or (b) fluorination to UF_6 which could be passed through a gaseous diffusion plant for isotopic separation. Figure 3 presents a simplified flow diagram of the various operations involved in uranium refining. For purposes of organizing the presentation of dust-exposure data, the refining process will be considered in nine basic steps: (1) ore handling and sampling; (2) digestion and gangue removal; (3) solvent extraction and stripping; (4) boildown and denitration; (5) oxide reduction; (6) hydrofluorination; (7) fluorination; (8) metal reduction and purification, and (9) scrap recovery. For similar operations conducted at more than one installation, the exposure information for all is averaged, but where there is a major change in an operating step, the occupational exposures are discussed separately.

In 1948, an intensive study was made of all of the operations in the various plants to evaluate the basic problems of continuing operation in the existing facilities. The report resulting from this investigation, dated 1949, comments: "The fact that no definite clinical evidence of persistent damage has been discovered to date in personnel with high uranium dust exposures cannot be taken as evidence that such damage has not been produced or will not occur. We therefore believe that the operating level of exposures to uranium dust which should be used in producing plants for the present should be quite conservative." Since that time only minor clinical evidence of damage has been uncovered, despite a very close medical supervision in all plants. Prior to 1948, permissible levels for exposure to uranium dust in air had been established at $500\mu\text{g}/\text{cu. m.}$ for insoluble salts and $150\mu\text{g}/\text{cu. m.}$ for soluble salts. γ -Radiation levels up to 700 milliroentgens per week were acceptable. The meager records show

that even these liberal levels were sometimes exceeded.

In about 1948 the University of Rochester published its documentation of the toxicity of uranium in experimental animals. This was probably the most extensive toxicity study ever conducted. As a result of it, uranium was classified as a chemical toxin affecting the kidney, not dangerous by any mode of entry other than inhalation. Calculations for human exposure based on the animal studies suggested that the permissible dust-exposure level be set at $50\mu\text{g}/\text{cu. m.}$ for an industrial exposure of 8 hours a day for a working lifetime. For normal uranium this level was interpreted by HASL to be equal to 70 α -disintegrations per minute per cubic meter of air. The maximum permissible concentration published in Title 10 of CFR, Part 20, which is based on NBS Handbook No. 52 sets an industrial exposure level of $5.1 \times 10^{-11} \mu\text{C}/\text{ml.}$, which is equivalent to approximately 110 α -disintegrations per minute per cubic meter. Handbook No. 69 uses a value of $6 \times 10^{-11} \mu\text{C}/\text{ml.}$, but ascribes to the natural uranium curie $4.5 \times 10^{-12} \text{ d}/\text{min}/\text{curie}$. This yields an MPL of $270 \text{ d}/\text{min}/\text{cu. m.}$

As a result of initial plant studies, extensive changes were made in many of the operations. However, it was determined that in many cases sufficient dust control to meet current standards would not be possible without complete process revision. As a result of this decision and mounting pressure from manufacturing personnel to increase production rates, the decision was made between 1948 and 1950 to begin a complete replacement of existing facilities with improved process equipment which would permit the higher production rates while maintaining air concentrations and radiation levels within acceptable limits.

Method of Study

In evaluating the degree of exposure of plant operators to uranium dust, the following two types of air dust samples were collected: (1) general air samples, collected in every normally

occupied area of the plant. (2) personal samples, obtained during the performance of the job. Usually for these samples, the peak exposure is determined and the peak exposure rate is determined. The peak exposure rate may be determined from the samples which were collected during the job. The samples were collected on $1/8$ in. disks on which were returned to the laboratory for α -scintillation counting. The peak exposure rate produces about 100 counts per minute. The collected air samples are analyzed for the time spent in the area. The average exposure rate per day. Protection has been ignored. The report involved individual air dust

In substantial occupational exposures conducted at an installation, the lowest. In reports we have presented also the numeric values made during the

Occupational exposures was studied more hazards in the present that other hazardous occupational hazards in refinery are present in mists and acid vapors, and noise

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occupied area of the plant and (2) breathing zone samples, obtained in the breathing zone of a worker during the performance of a particular task and usually for the duration of the task. Combining these samples, the average concentration in an area and the peak exposures encountered in particular jobs may be evaluated. In each case, replicate samples were drawn. Dust samples, collected on $\frac{1}{8}$ in. disks of Whatman No. 41 filter paper, were returned to the laboratory for analysis by α -scintillation techniques. (Normal uranium decay produces about 1.5 d/min. for each μ g. present.) The collected air concentrations are weighted by the time spent at each operation or area to compute an average weighted exposure for the working day. Protection afforded by dust respirators has been ignored. The 60 surveys reviewed in this report involved the analysis of more than 20,000 individual air dust samples.

In substantially every case, the first survey conducted at any plant disclosed the highest exposures and the most recent measurements were lowest. In reporting occupational dust exposures, we have presented the range of exposures and also the numerical average of all such evaluations made during the 10 years from 1948 through 1957.

Occupational exposure to uranium-bearing dust was studied more thoroughly than other health hazards in the plant, but it should not be inferred that other hazards were insignificant. Some other occupational hazards encountered in the uranium refinery are penetrating radiation, radon gas, acid mists and acid vapors, explosive atmosphere, solvent vapors, and noise.

Presentation

Ore Handling.—Sampling of uranium-bearing (feed) raw material is carried out to determine an assay on which quality control procedures, accountability requirements, and purchase price may be based. Feed material for the refinery was of two general types: high-grade pitchblende of 20% to 50% U_3O_8 content (hot ore) or a product from a concentrating mill where ore containing approximately 0.25% U_3O_8 has been upgraded to 70% to 90% U_3O_8 by chemical purification. In this purification the radium is removed. Because of the extremely long half-life of parent (approximately 10^9 years) uranium, no appreciable quantity of radium is built up before this concentrate is further purified at the refinery. Concentrate material therefore presents no significant hazard from penetrating radiation or

from the accumulation of radon gas, although the first two β -emitting daughters of uranium, UX_1 and UX_2 , are present in substantially equilibrium quantities. Ore material was received at the sampling plant in steel drums welded shut except for a small hole which permitted the escape of radon gas. Enclosed areas for the storage of this material required ventilation to prevent excessive accumulation of radon.

In the very earliest days of ore sampling the only ventilation provided was the air which was drawn through a rotary drying kiln and an exhaust system which removed air from enclosures around the crushers, screens, and elevators. Each of these systems was inadequately designed, both from a standpoint of aerodynamic handling and of air-cleaning equipment. Dryer air was passed first through a multiclone, then through an electrostatic precipitator; yet sampling of the effluent air indicated a loss of approximately 70 pounds of uranium per day during the time of operation of this equipment. The screen exhaust equipment was seriously out of balance, and, as a result, many main exhaust duct lines were found to be as much as three-fourths full of powdered ore.

The ore material, after drying, crushing, and screening, was passed through a mechanical sampler to obtain a one-drum sample of approximately 1,000 pounds from each lot of ore. In some cases the contents of this drum was further reduced in size by manual coning and quartering in the middle of the sampling plant floor. Over the course of several years of operation of this plant, additional ventilation controls were provided. However, since the output of the plant increased with each successive year, there was no noticeable improvement in the airborne dust concentration.

On the basis of the experience gained in this plant, the integrated facility to be built at Fernald was designed to provide completely automatic ore handling. The drums were to be automatically delidded, dumped by means of a skip hoist into a closed sys-

tem where the ore material was crushed and handled with automatic conveying equipment, and finally deposited in a storage bin. The output from the storage bin was mechanically transferred to the digestion plant where it would be fed directly into the digest equipment. For various reasons of equipment failure and vendor problems, this plant has rarely been used and manual pipe sampling of this material is still performed.

Concentrate materials exhibit little γ -radiation when shipped from the concentrating mill. Radium bearing "hot" ores, on the other hand, contain radioactive equilibrium amounts of all the decay products of the uranium series. These include radium, radon, and the radon daughters. As a result of this dissimilarity in the two different types of refinery feed material, two process streams were provided in the refineries. However, substantially all feed material is concentrate at the present time.

Enclosure of raw ore in process tanks or bins sometimes provides adequate shielding, but more frequently a wall between the operator and the source of radiation is necessary to reduce occupational γ -exposure to permissible levels. Such a shield requires that operations such as drum opening and dumping be performed remotely. Because of this remote handling and the distance from the operator to the material together with ventilation on the enclosures, the operator is not only protected from penetrating radiation but also from α -dust. Exposures

TABLE 1.—Dust Concentrations in Ore Sampling d/m/M³

	Range	Average
BZ * Unload drums to hopper	220- 2,500	1,300
BZ Clean dust collectors	5,000-36,000	20,000
BZ Clean ore drums	370-64,000	30,000
BZ Remove or replace drum lid	92- 1,300	770
GA † Ore room	90- 2,600	1,000
Daily weighted average manual sampling	140- 3,000	800
Daily weighted average automatic sampling	90- 190	140

* BZ-Breathing Zone samples.
† GA-General Air samples.

TABLE 2.—Dust Concentrations-Concentrate Sampling d/m/M³

	Range	Average
BZ Dumping concentrate	700-4,800	1,400
BZ Delidding drum	180-1,300	700
BZ Lidding drum	90-1,300	725
BZ Pipe sampling	60-1,900	900
GA Sampling room	10- 200	60
Daily average exposure	90- 190	140

to dust at ore sampling operations are given in Table 1.

The sampling of concentrates has been conducted at three installations; two of which are in current use, with the third plant in standby.

Average weighted occupational exposures to uranium-bearing dust from the sampling of concentrate materials are summarized in Table 2.

Lidding and delidding of open head drums contributed the major portion of the operators' exposures. Cleaning the sampling equipment between ore lots and emptying the ventilation system dust collectors at the end of each shift also contributed to the over-all exposure at the sampling station.

Radiation measurements in the vicinity of high-grade ore storage indicated γ -radiation in the order of 10 to 100 milliroentgens per hour at a distance of 10 feet from the drums. This dosage limits occupation of such areas to between 3 and 30 hours per week, depending on the actual levels present. This does not constitute a severe restriction for a storage facility, but it does restrict the methods by which these materials may be transported. For example, when it was necessary to transport high active ore by motor trucks the ore was loaded so that no drum of ore was closer to the driver than 8 feet. Had this precaution not been taken, the drivers would have accumulated their weekly permissible radiation dose in less than the 6 hours necessary for one trip.

Radon gas, a decay product of radium, can be a serious hazard if permitted to accumulate; however, the open character of ore-handling facilities usually is sufficient to



limit the activities of this material by rail in close proximity. This practice was applied for the loading of "this purpose" practice, ports each end of for a few minutes opened, and electric fans had been one hour. Radon were as high to 1,000 times

Digestion.—The digestion steps is the material to be in solution. Raw concentrates or hot concentrates -20 mesh particles were fed directly into Skip hoists, but

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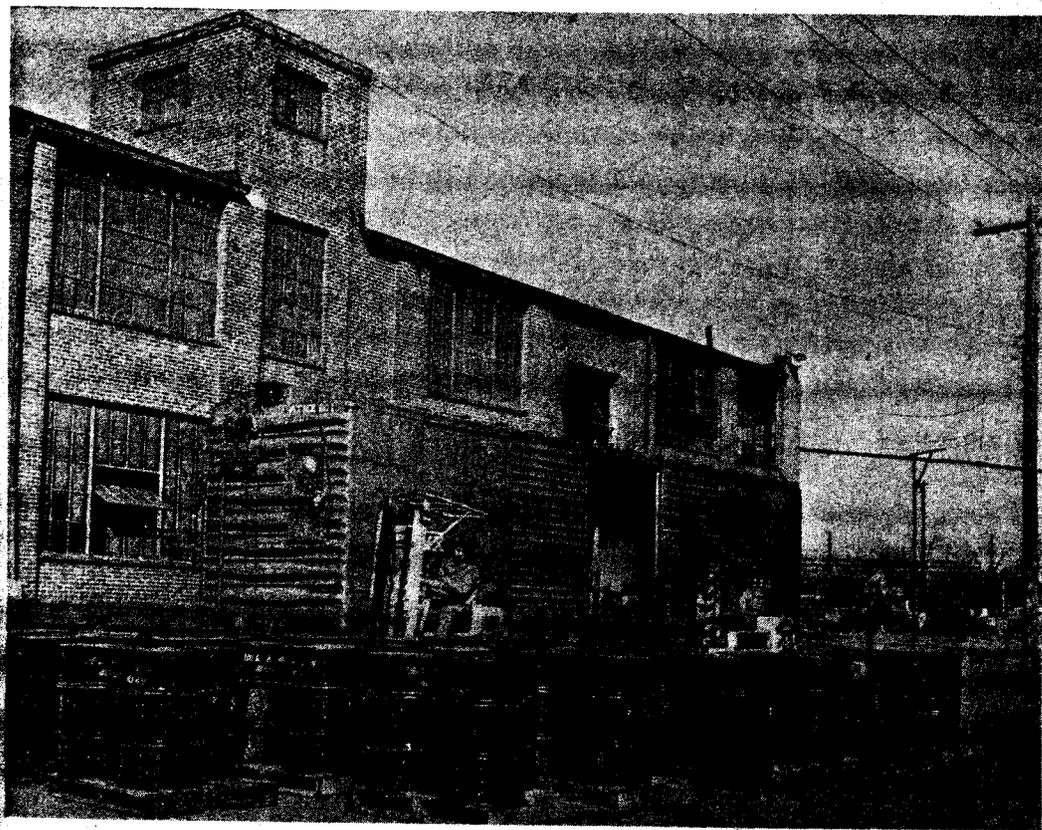


Fig. 4.—Uranium ore shipping car showing forced ventilation.

limit the accumulation of excessive quantities of this material. During transportation by rail in closed box cars some ventilation was applied during car loading and unloading of "hot" ore. A typical car for this purpose is illustrated in Figure 4. In practice, portable electric fans were fitted to each end of the car. They were operated for a few minutes before the car doors were opened, and entry was prohibited until the fans had been running for 20 minutes to one hour. Radon concentrations in ore cars were as high as 10^{-7} to 10^{-8} c/1, or 100 to 1,000 times the MAC.

Digestion.—The first of the many refining steps is the nitric acid digestion of raw material to bring the uranium values into solution. Raw ore is fed to the digestion vats or hot concentrated nitric acid as a -20 mesh powder. Other feed materials were fed directly without prior processing. Skip hoists, bucket elevators, vibratory and

screw feeders were used in the slow, careful feeding of the raw material to the reaction vessels. The feed material had to be added to the digest liquor at such a rate that the reaction would proceed without unusual violence. If the feed device permits "slugging" of the material, the reaction may be violent, with subsequent flooding of the area with uranium-laden nitric fumes. The reaction vessels are maintained under a slight negative pressure by water-sealed vacuum pumps which take the collected dust, mist, and nitric oxide fume from the reaction through a nitric acid recovery system. This system can be balanced with reasonable accuracy against the rate of fume evolution caused by the rate of raw material feed.

In the plant designed to handle both pitchblende ore and concentrated materials, the sampling, digestion, and solvent extraction sections were duplicated in parallel

TABLE 3.—Digestion

	Ore d/m/M*		Concentrate d/m/M*	
	Range	Average	Range	Average
BZ reaming ore chute	350-8,000	1,000	1,000-6,000	2,400
BZ drum dumping				
Uncontrolled			0- 220	90
Ventilated		2,500	6- 44	30
Remote				
BZ lidding & delidding drums	600-1,700	1,200		
GA digest area	6- 330	150		
GA ore room	90-2,600	1,000	0- 75	30
Average daily exposure	7- 350	110	17- 100	40

process streams, the "hot" stream requiring shielding and some remote operation. As shielding was added to the early pitchblende refinery operations, it was found that it was not possible to reduce the radiation level below a certain minimum. It was determined that sufficient γ -emitting mate-

rial had been collected in the overhead process piping as an interior coating to produce radiation levels exceeding 300 milliroentgens per week in the operating areas. Modification of the refinery to reduce radiation to acceptable levels was considered uneconomical. For this reason, rotation of per-

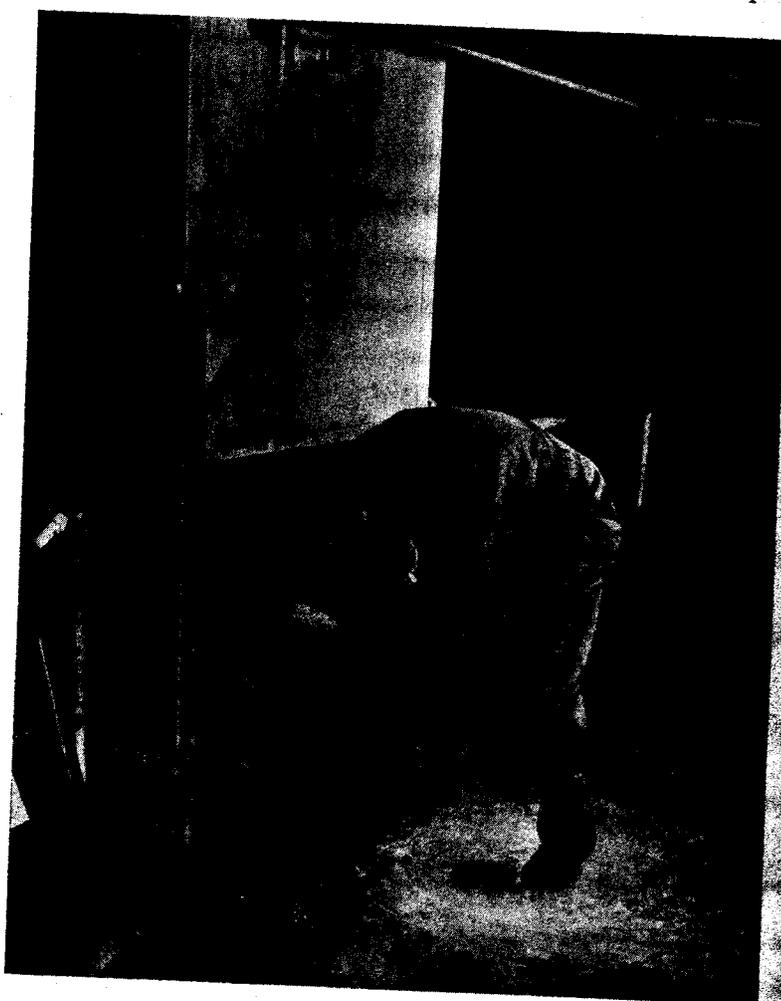


Fig. 5.—Ventilated U_3O_8 drum-dumping station.

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sonnel was used as a temporary control of radiation exposures while engineering efforts were directed toward a redesign of the refinery.

The average exposures encountered in the digestion of refinery feed materials during the years from 1948 to 1956 are contained in Table 3.

In some of the temporary plants, the digesters were fed manually by dumping the contents of open top drums of concentrate through a hole in the floor above the tanks. Dust concentrations at the operator's breathing zone ranged from 1,000 to 6,000 d/min/cu. m. for these uncontrolled conditions. When a ventilated enclosure was constructed around this drum dumping station (Fig. 5) the breathing zone concentration was reduced to 100 to 300 d/min/cu. m. and the operator's exposure averaged about 100 d/min/cu. m. With the introduction of remote automatic drum dumping into hoppers, which in turn led to the digestion tanks, the operator's exposure was reduced to about 10 to 30 d/min/cu. m.

When ground ore was fed from a hopper by automatic conveyor to the digesters, bridging of the ore occasionally interrupted the flow. The operator would then ream the chute with a rod and be exposed to high concentrations of dust. This bridging could be prevented by thoroughly drying the ore. Other operators whose duties were allied to digestion were exposed as follows:

	d/m/M ^a	
	Range	Average
Weighted exposure nitric acid recovery	10-240	75
Weighted exposure silica filtration	6-800	220

Ventilation in the acid recovery areas is reflected in the relatively low average exposures. Separation of uranium solution from the silica gangue led to the highest dust and γ -exposures of all operations associated with digestion. A string discharge filter was used in the early installation for sand removal. Any operation associated with maintenance of this string filter resulted in high external γ -radiation dose of the operator. At the newer facilities it has been possible

to run a slurry containing all of the gangue material directly through the solvent extraction. This modification has precluded the necessity for prior filtration of the silica with the high radiation doses which accompanied it.

During the early years of AEC interest, only the uranium content of the ore was purchased. All of the other mineral values remained the property of the vendor. Each lot of ore was therefore processed separately and all residues were collected and repackaged for storage and eventual disposition at the discretion of the vendor. These residues were made up of two basic materials: (1) the radium cake which was a barium sulfate coprecipitation of the radium materials and (2) the raffinate material which was the residuum after solvent extraction. The radium cake was the most concentrated γ -emitter in the refinery. Considerable care was necessary to insure adequate limitation of γ -radiation dosage from this material. At the surface of a 55-gallon steel drum of radium cake, radiation levels ran approximately 100 to 300 milliroentgens per hour. Measurements taken 10 feet from a stacked tier of drums showed levels from 50 to 100 milliroentgens per hour.

The only ventilation which was provided for these operations was around a centrifuge which was used to separate the radium cake. Here the centrifuge was enclosed in a booth from which air was drawn primarily for the removal of radon gas. Radon concentrations in this area were approximately at the maximum permissible level of 10^{-10} curies Rn/l.

Solvent Extraction.—The early methods of solvent extraction utilized ethyl ether for the selective extraction of uranium values; more recently, tributyl phosphate in kerosene has been used. In either case the uranium-bearing aqueous material was fed to the top of extraction columns while the organic solvent, which forms the continuous phase, is let into the bottom. During the extraction of slurry the columns are me-

chanically pulsed to improve contact between phases.

Columns, similar to those used in extraction, are utilized in scrubbing the organic extract with hot demineralized water. In solvent extraction, solutions or slurries are handled in what is an essentially sealed system. Because of the possible fire hazard in using ether, the extraction and stripping section were isolated from the remainder of the refinery. This isolation limits the possibility of cross contamination from major dust-producing operations. Since the system is continuous, sealed, and utilizes only liquid material, the occupational exposure to uranium is minimal. The extraction operations led to average exposures which ranged from 7% to 50% of current permissible levels. The solvent extraction areas represent the lowest air contamination levels found in any refining operation.

The potential fire hazards associated with ether extraction far outweigh any dust-inhalation hazards. In fact, because of the possibility of initiating an explosion with a spark from their pumps, the HASL survey teams at no time obtained samples from the ether solvent extraction areas. Whenever the contractor collected air samples from this area, by use of explosion proof equipment, the ether content was below the explosive limits and the uranium-bearing dust was well below permissible levels.

One serious explosion resulted from this use of large quantities of ether solvent. It was attributed to an inadvertent mixing of concentrated nitric acid and ethyl ether. In no instance over the 10-year period was a fire caused by accidental ignition of ether vapor.

After contacting the digest solution with the organic solvent, the material remaining in the aqueous phase contains nitrates of all of the undesirable metals, including the UX_1 and UX_2 radioactive components. The liquor may either be concentrated and calcined to recover nitric acid or it may be discarded directly. This concentrate material is called raffinate and presents a prob-

lem of waste storage. The raffinate material was either put in drums and stored on the plant site or conveyed to storage lagoons.

Boildown and Denitration.—The product from solvent extraction is the purest form of uranium in the refinery. From this point on, contamination from process equipment reduces the purity of the product. This dilute solution of highly purified uranium nitrate is concentrated in multiple-effect evaporators and boildown tanks to a solution of uranyl nitrate hexahydrate (UNH).

When the final product is to be metal, batchwise denitration in gas-fired pots is the routine method of reduction to UO_2 . The conditions of the reaction are indicated by the temperature and the rate of rise of the temperature during heating of the pot contents. As heat is added, first water vapor is evolved, then oxides of nitrogen are driven off (to be collected in the acid recovery system). The mass is continuously agitated until all the material has been converted to uranium trioxide. The final product, dry, lumpy, and very dusty, is removed from the denitration pots from above. At one time orange oxide was scraped and shoveled from the pots; a later innovation (Fig. 6) incorporated a pneumatic conveying device called a gulping tool to transport this material to a packaging station or to the next step in the process. Before pneumatic conveying was introduced, the operators' exposures were 30,000 to 80,000 d/min/cu. m. for scraping and emptying the denitration pots. With pneumatic conveying this has been reduced to an average of 560 d/min/cu. m.

The reaction and the product are very sensitive to temperature and possibly other physical and chemical factors. For reasons not clearly understood, the product sometimes builds up in the pots to a hard, lumpy mass, sticking to the sides and the agitator blades. In this case it must be chopped out (Fig. 7), resulting in air concentrations similar to the high ones mentioned above. Continuous rotary-kiln denitration equipment has been used where the product is

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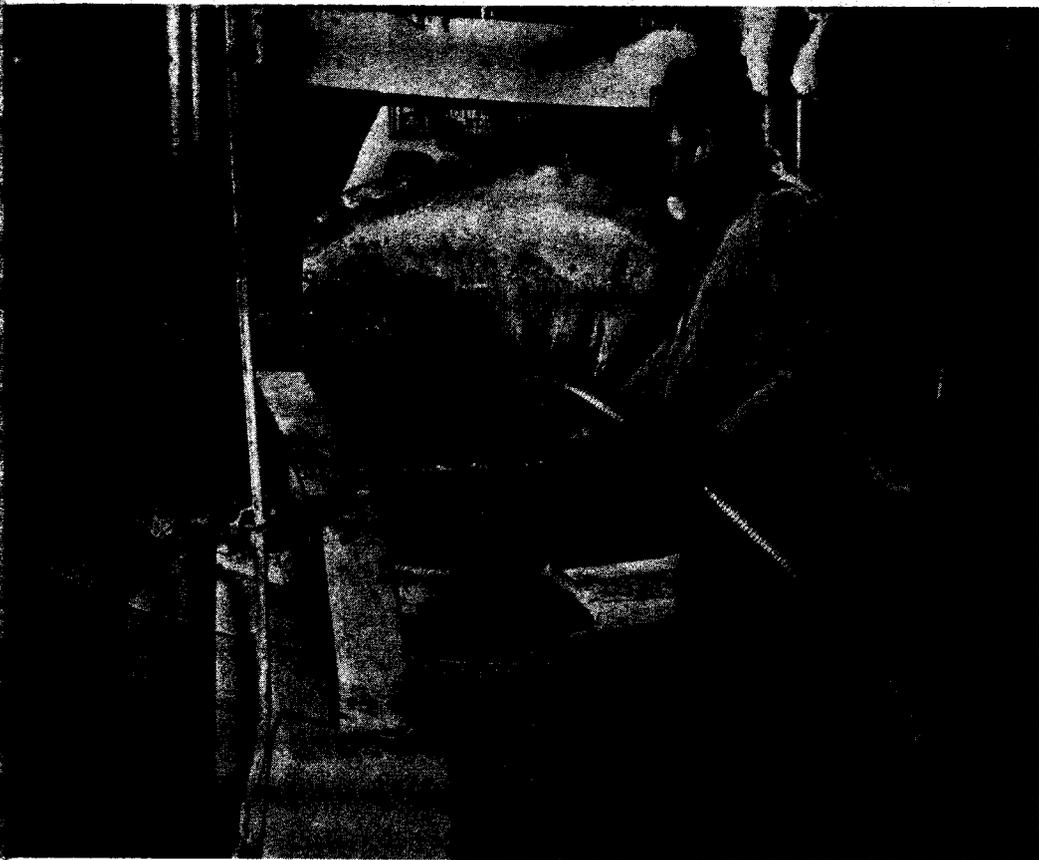
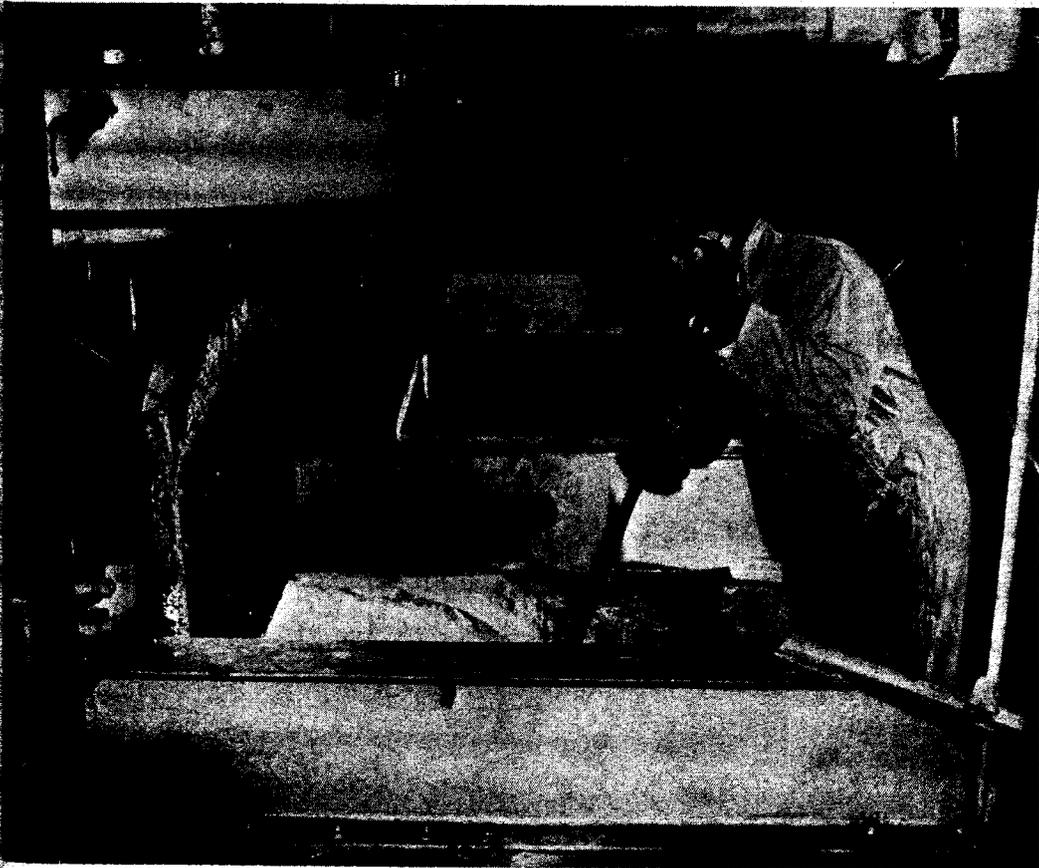


Fig. 6.—Pneumatic UO_3 pot unloading.
Fig. 7.—Chipping UO_3 cake in denitration pot.



to be converted to UF_6 , but for some reason too contaminated to be converted efficiently this product is unsufficiently reactive and to metal. Here too, a packaging step is incorporated to facilitate accountability of UO_3 and to permit transport to the succeeding facility for further processing.

An operation auxiliary to denitration is the recovery of vapors evolved in the decomposition of uranyl nitrate. In only one survey was the dustiness found to be excessive. This was probably the result of cross contamination from adjacent areas. Later surveys failed to detect concentrations above 100 d/min/cu. m. The operators of nitric acid recovery units were exposed to an average concentration of 67 d/min/cu. m. with a range from 20 to 240 d/min/cu. m.

TABLE 4.—Denitration

	d/m/M ^a Range	d/m/M ^a Average
GA denitration area	7- 750	140
GA UO_3 packaging area	15- 180	63
BZ scrape and shovel UO_3 from pots	29,000-82,000	48,000
BZ pneumatically empty UO_3 pot	70- 1,800	560
BZ pour UNH liquor into pots	45- 63	56
Average weighted exposure up to 1949	4,200-32,000	15,000
Average weighted exposure since 1949	31- 234	130

Table 4 summarizes the denitration pot operators' exposures.

Denitration has also been performed continuously in a moving bed reactor at AEC installations in Paducah and Oak Ridge. The product from this continuous operation is not as uniform in composition

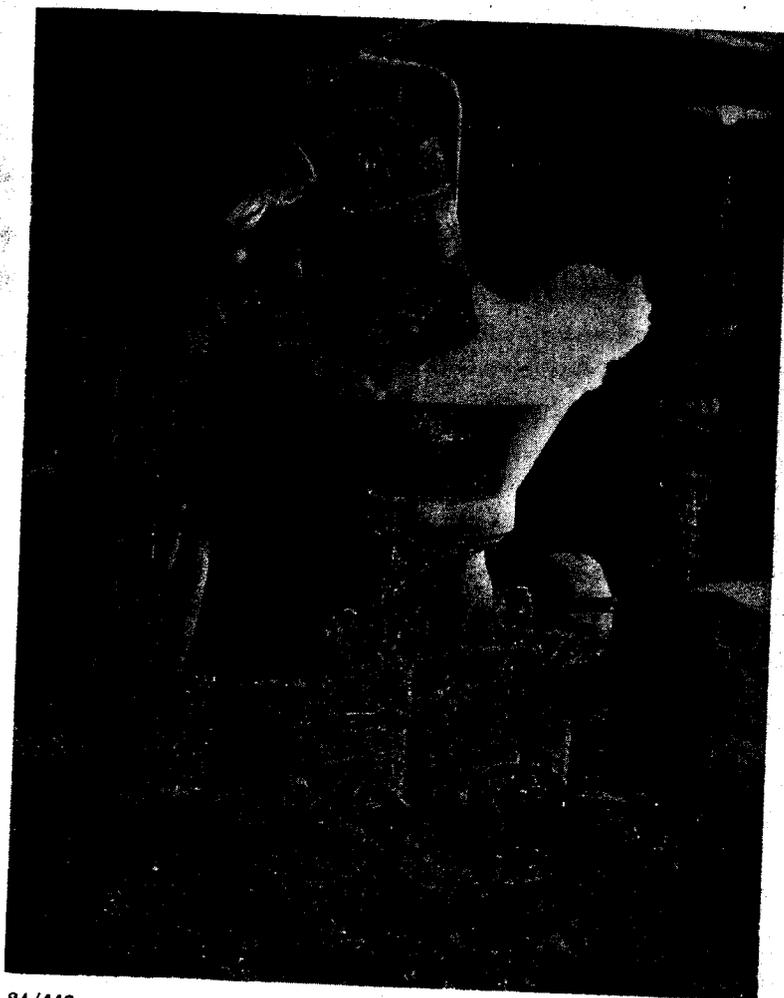


Fig. 8.—Loading lump U_3O_8 into crusher.

and reactive operations air data are of person systems. C stallations clude not ventilation enclosures which in t use of pne the beds, i concentrati maximum trol proced be effective air respira

Oxide R tween solid essary to the solid c reaction to reduction, solid urar



URANIUM REFINING

Year	d/m/M Average
1950	140
1951	63
1952	48,000
1953	560
1954	56
1955	15,000
1956	130

ration pot

performed reactor at and Oak continuous composition

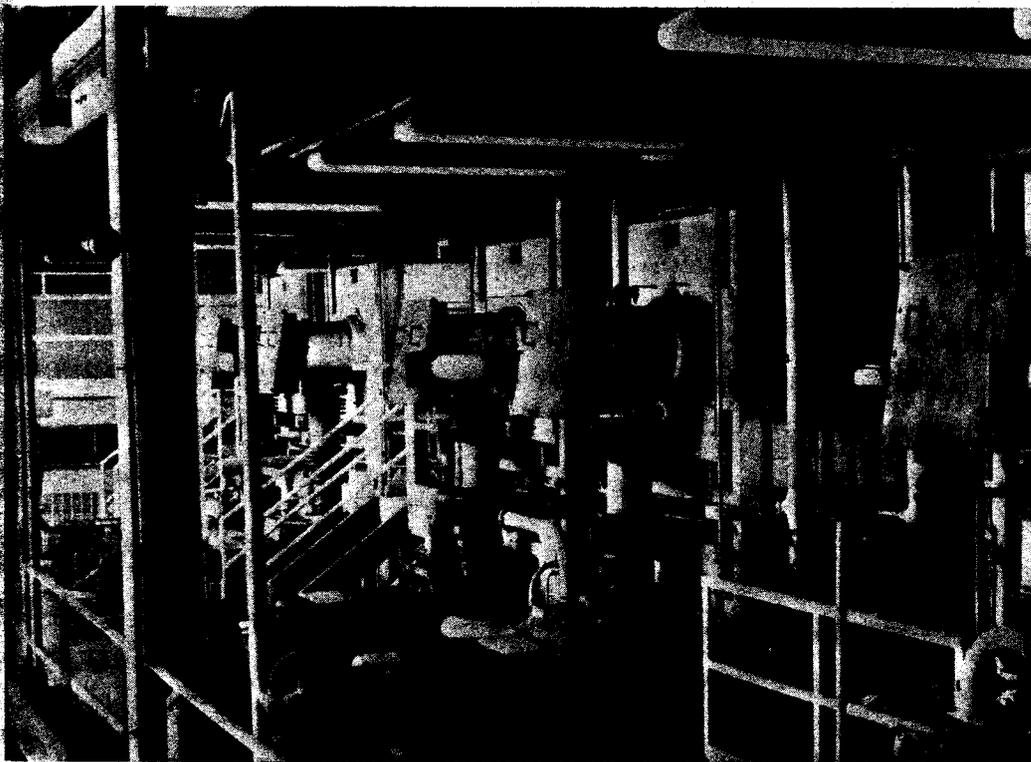
and reactivity as that produced in the batch operations conducted in gas-fired pots. No air data are presented on the dust exposure of personnel at the continuous denitration systems. Control of these most recent installations of moving denitration beds include not only large quantities of general ventilation from the bedroom area but also enclosures around the individual beds, which in turn are exhausted. Despite the use of pneumatic unloading equipment for the beds, it has been difficult to maintain concentrations in the remote areas at the maximum permissible level. The only control procedures which have been found to be effective in this area have been supplied air respirators and rotation of personnel.

Oxide Reduction.—In most reactions between solid and gaseous materials it is necessary to change the contacting surface of the solid continuously in order to drive the reaction toward completion. In the oxide reduction, hydrogen is utilized to reduce solid uranium trioxide to solid uranium

dioxide with the evolution of water. When the UO_3 is removed from the denitration pots as a hard, lumpy material, it is first necessary to pulverize the orange oxide product. An early method of performing this operation is illustrated in Figure 8. The operator dumped a drum of UO_3 into a mill in which it was comminuted to a fine powder.

Three methods have been used in the reduction step. In the first, shallow nickel trays were filled to about 1 in. depth with UO_3 and then introduced to a furnace. H_2 was caused to flow over the trays. In the second method, oxide was introduced to a multiple hearth furnace in which rakes continuously agitated the solid reactants. Upon heating, gaseous hydrogen reduced the trioxide to a dioxide. Water vapor and excess hydrogen from the reaction were led to an area where combustible gases could be safely burned. Finely divided UO_2 formed by each of these methods was packaged for

Fig. 9.—Bank of horizontal reactors, UO_3 to UF_4 .



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ading lump sher.

transportation to the succeeding facility for further processing.

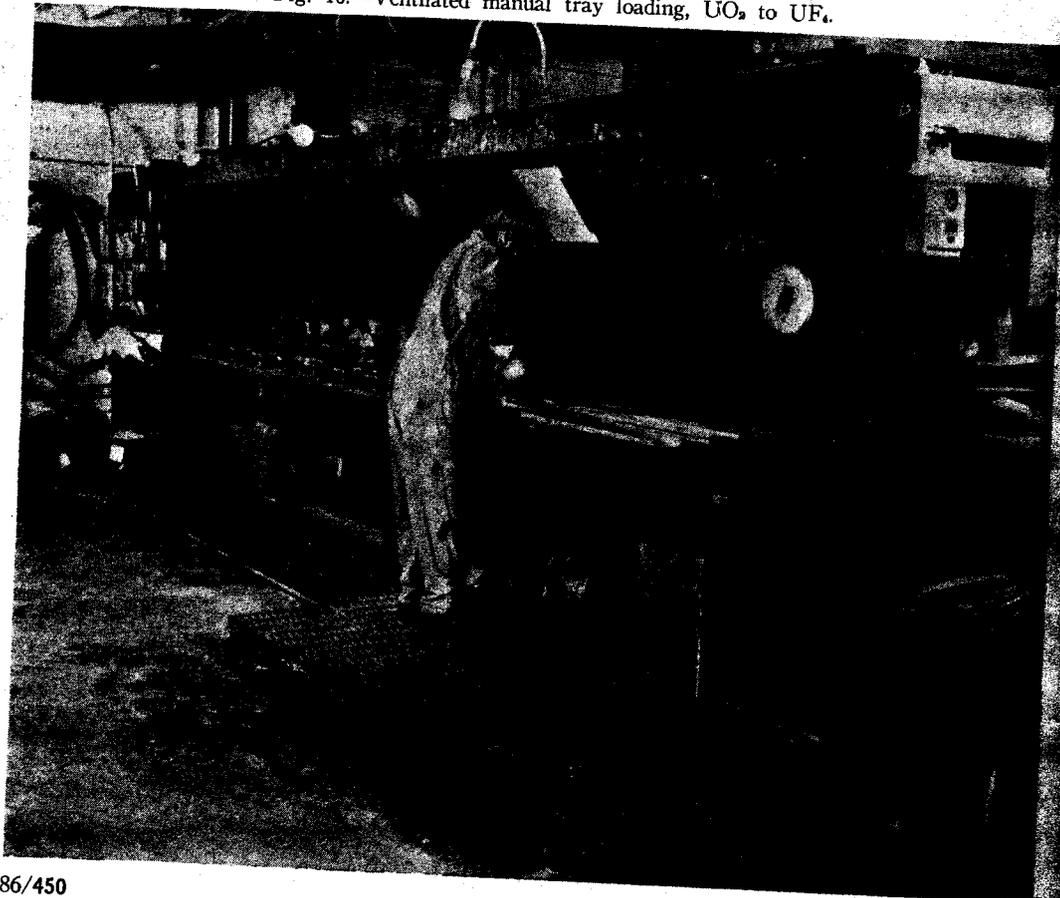
A later innovation in this step provided a continuous process stream by the use of horizontal reactors similar to helical screw conveyors. Screw flites moved trioxide countercurrent to the hydrogen stream with continuous feed and discharge. A series of these reactors is illustrated in Figure 9. Purified hydrogen necessary for this reaction is obtained from the decomposition of pure anhydrous ammonia, since ammonia can be handled more safely and at lower pressures than hydrogen alone. Again, the off-gases are burned. In this system there is a significant evolution of uranium salts as fine hot dust. These salts must be filtered from the burned hydrogen stream. Similar reactors are utilized in the ensuing steps for the production of UF_4 and UF_6 . A summary of occupational exposures during oxide reduction is contained in Table 5.

In converting from batch to continuous operation the operators' average exposures were reduced by approximately two orders of magnitude. In packaging and feed

TABLE 5.—Dust Concentrations—Oxide Reduction (UO_2-UO_3)

	d/m/M*	
	Range	Average
BZ Load UO_2 -trays	3,200- 61,000	26,000
BZ Load UO_2 -horizontal reactor	70- 240	170
BZ Load UO_2 -multiple hearth furnace	160- 2,700	1,400
BZ Unload UO_2 from trays	4,000-125,000	60,000
BZ Package UO_2 from trays	25,000-115,000	80,000
BZ Package UO_2 from multiple hearth	16,500- 35,000	23,000
GA Tray furnace area	78- 3,300	1,800
GA Multiple hearth furnace area	245- 440	340
GA Horizontal reactor area	33- 120	60
DWA Tray furnace operations	9,800- 32,000	20,000
DWA Multiple heart operations	31- 4,200	700
DWA Horizontal reactor operations	45- 234	140

Fig. 10.—Ventilated manual tray loading, UO_2 to UF_4 .



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Hydrofluor tion convertin ride, a gaseou solid, produci again the pro surface of the ing with anhy one time the trays over w vated tempera cess HF wer units.

At first the UO_2 to UF_4 formed in the table (Fig. 10) dumped from into steel dr Sugar scoops out of the la trays. The n this operation

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xide Reduction

d/m/M*	
Range	Average
11,000 240	26,000 170
2,700	1,400
15,000 15,000	60,000 80,000
15,000	23,000
3,300 440 120	1,800 340 60
12,000 4,200 234	20,000 700 140



umping operations the operators had been exposed to breathing zone concentrations as high as 100,000 d/min/cu. m. or 1,000 times the present permissible levels. Since the advent of continuous operation, packaging of UO₂ was conducted only intermittently when there was a need for brown oxide as a ceramic or when the material did not meet purity specifications.

During the period of extremely high exposures, the primary dust control measure in effect was the provision of half-face respirators used at the operator's discretion. More recently, processing equipment has been completely enclosed and ventilated.

Hydrofluorination.—Again, in the reaction converting UO₂ to uranium tetrafluoride, a gaseous material is reacted with a solid, producing a solid and water vapor; again the problem is to renew the reacting surface of the solid continually while bathing with anhydrous hydrogen fluoride. At the time the solid was spread in shallow trays over which HF was passed at elevated temperatures. Water vapor and excess HF were collected in acid recovery units.

At first the loading and unloading of the UO₂ to UF₄ conversion trays was performed in the open; later on a perforated table (Fig. 10). The green salt (UF₄) was dumped from the trays and permitted to fall into steel drums located below the table. Sugar scoops were used to scoop the UF₄ out of the larger drums and to load the trays. The most effective dust control for this operation was the enclosure of this

grated table to form a hood and the exhausting of air from this hood. This resulted in a reduction in airborne concentration by about a factor of 7, from a weighted average exposure of about 10,000 d/min/cu. m. to 1,500 d/min/cu. m.

Presently this operation is carried out inside sealed horizontal reactor tubes identical to those used in preparing UO₂. It is possible to prepare UF₄ from UO₃ continuously by utilizing a series of such horizontal spiral flite reactors in a vertical stacked array. Uranium trioxide, fed to the uppermost reactor, is transported countercurrent to a hydrogen atmosphere by slowly rotating helical screw flites. As the dry powdered reactant is moved to the end of a reactor it is permitted to drop to the next lower one through a rotary valve which effectively seals one reactor from the next. At the completion of the reduction of UO₃ to UO₂ the solid reactant is next contacted with HF in a similar series of reactors located directly below those used in the reduction. Provision is made for packaging either of UO₂ or UF₄. During normal operation of these reactors the dust levels in the vicinity are negligible. During maintenance on the flites and the bearings which support them, however, the long helices present a serious dust hazard to the maintenance mechanics. The long screws are withdrawn slowly into a long cylinder called a "coffin." The salt is removed from the reactor tube and the flite by vacuuming as the flite is withdrawn. This has been done by use of respiratory protection. The

TABLE 6.—Hydrofluorination

	d/m/M* Trays		d/m/M* Reactor	
	Range	Average	Range	Average
Weighted average exposures				
UO ₂ loaders	260- 8,900	3,300	--	--
Furnace operator	50- 1,200	500	30-40	30
UF ₄ package	110- 4,400	1,300	1-57	20
Breathing Zone operations				
Loading UO ₂	730- 15,000	5,000	--	--
Unload UF ₄	400- 53,000	14,000	--	--
Interchanging trays	70- 3,300	1,000	--	--
Package UF ₄	500-115,000	23,000	10-360	110

hydrofluorination operators' exposures are summarized in Table 6.

Since uranium tetrafluoride may be utilized as a raw material for reduction to metal or for conversion to hexafluoride, most frequently it is packaged as tetrafluoride at the discharge of the hydrofluorination reactor.

It might be worth while at this point to discuss the packaging of uranium powders. This operation has resulted in high occupational exposures whenever it has been performed, and a great deal of effort has been put into the design of suitable engineering control equipment to minimize these exposures. The most successful of these has been the provision of a circular exhaust hood which makes an effective shield with the chime of the container and goes around the lip of the container into which the material is being poured. High-velocity exhaust air is drawn from outside and at the same time across the top of the drum. In addition to this local exhaust hood, the entire operation was placed inside of a complete enclosure with swinging door entrance and exit. This enclosure in turn was also ventilated. The drum traveled through the enclosure on a roller conveyor in which a section attached to a weighing device permitted the operator to achieve full weight without the necessity for viewing the level. Despite these precautions, excessive airborne concentrations have frequently been found in the breathing zone of the operator. Typical exposures encountered during drumming operations are listed in Table 7.

Whenever materials are transported from location to location in drums, the empty drum creates an intense source of airborne activity. Most modern uranium drum dumping stations are provided with automatic can washing and drying equipment which removes substantially all of the uranium salt contamination.

Reduction to Metal.—Metal is produced by thermite reduction of halide salt with magnesium in refractory lined steel

TABLE 7.—Dust Concentrations at Drum Transfer Operations

	d/m/M*	
	Range	Average
BZ Fill uranyl nitrate drum	300- 2,000	1,100
BZ Fill UO ₂ drums from pots	31- 29,000	600
BZ Fill UO ₂ drums-manual	170- 20,000	10,000
BZ Fill UO ₂ drums-remote	26- 950	220
BZ Fill UO ₂ cartons	1,000-175,000	36,000
BZ Empty UO ₂ cartons-manual	3,800- 40,000	21,000
BZ Empty UO ₂ cartons-remote	120- 980	400
BZ Open UO ₂ cartons for remote dump	3,300- 31,000	11,000
Package UF ₄		
BZ Weigh and seal full drum	110-115,000	21,000
BZ Adjust final drumweight	100- 6,400	1,800
GA Packaging area before 1950	110- 960	500
GA Packaging area since 1950	1- 180	43

"bombs." Uranium tetrafluoride is mixed with magnesium chips in the appropriate proportions and blended. Refractory lining of the bombs is prepared by introducing a mandrel into a steel cylinder, then tamping the annulus between mandrel and cylinder with a powdered refractory lining (Fig. 11). The mandrel is withdrawn and the space occupied by it is filled with the prepared charge (Fig. 12). More lining is then placed over the charge, and finally the reduction bomb is sealed by bolting a lid in place. It is heated to initiate the highly exothermic reaction, during which the temperature inside the bomb exceeds the melting point of uranium. Because of its high specific gravity, the uranium collects at the bottom of the bomb, with MgF slag floating to the top. Upon completion of the reaction the bomb is permitted to cool; it is opened, and the charge is broken out. It is not possible to dislodge the uranium from the lining, slag, and unreacted components without breaking the lining. This breakout is the primary dust-producing operation in metal reduction.

In the early days of the project, the bomb liner was made from fused dolomite which was compacted by jolting. The particle size of this material was such that it formed a dense contact liner which could then be

Fig. 12.—I reduction ft with UF₄-M₁

Concentrations
of Uranium

d/m/M*	
Range	Average
0- 2,000	1,100
1- 29,000	600
0- 20,000	10,000
6- 950	220
3-175,000	36,000
1- 40,000	21,000
1- 980	400
1- 31,000	11,000
1-115,000	21,000
1- 6,400	1,600
1- 960	500
1- 180	43



Fig. 11.—Loading reduction furnace shell with refractory liner.

oxide is mixed with the appropriate refractory lining by introducing a mixture, then tamping the lining and cylinder lining (Fig. 11). The space between the prepared lining is then finally the re-rotating a lid in place the highly which the tem-perature of its melt-ting of its high collects at the top of the reaction of the reaction; it is opened. It is not possible from the lining without breakout is the reaction in metal

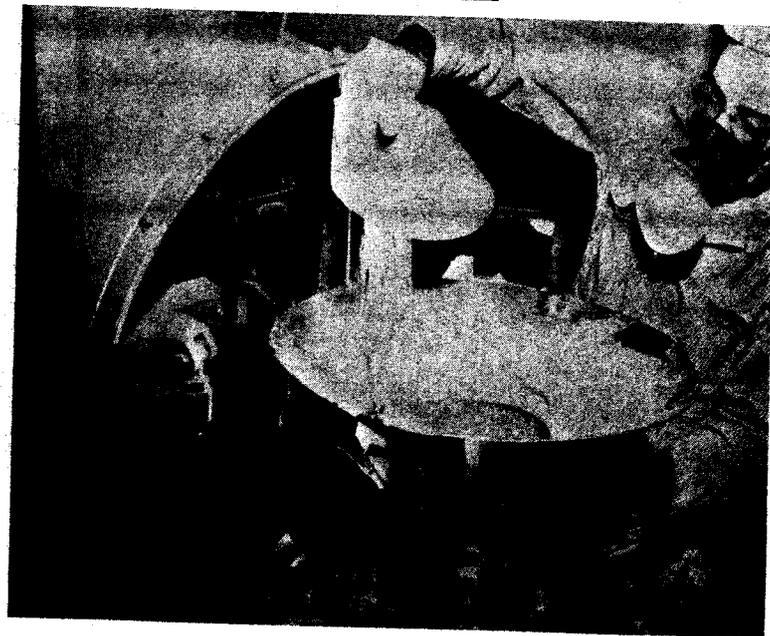


Fig. 12.—Loading lined reduction furnace shell with UF_4 -Mg mixture.

ject, the bomb of dynamite which the particle size that it formed could then be

filled with the uranium fluoride, magnesium mixture. About 1950, it became evident that the magnesium fluoride slag which was produced by the reaction could probably be processed to form a perfectly acceptable liner material. If this could be done, yield would be improved and the product contamination reduced. This, however, introduced an additional hazard, in that the slag material contained significant quantities of radioactive impurities. The equipment which was used for "jolting" the bomb liners was reasonably well ventilated for removing the relatively innocuous dolomite but not satisfactorily for the new type of material. Therefore, exposures increased when the slag liner was used. With the construction of the new plants, adequate ventilation around the top of the bomb was provided and exposures again were reduced to permissible levels.

From the early days of the thermite reaction, tamping of the uranium fluoride magnesium mixture into the lined reduction container had been considered to be a fine art. The degree of densification of this mixture in the refractory determined the yield of the melt. A significant design effort went into devising a completely mechanical system to duplicate the "feel" of the operator. The uranium tetrafluoride is loaded into a double cone blender with the appropriate amount of magnesium. After blending, the charge is placed in a retractable chute which goes to the bottom of the lined bomb. The chute moves slowly up and down as it is raised, providing the necessary degree of compaction. This machine is all enclosed in a ventilated booth which maintains air concentrations within permissible levels under most circumstances.

After the reduction, the uranium breakout from the steel bomb is accomplished inside an enclosure equipped with a grill-work floor. Downdraft ventilation serves to remove fine particulate matter from the operator's breathing zone while broken slag and liner is permitted to fall through the grill where it is collected for reprocessing. The remaining uranium "derby" is a short

cylinder of approximately equal diameter and height and weighs about 60 to 100 pounds.

Impurities and slag are removed by chipping the surface of the reduced metal derby with a pneumatic chisel. The derbies are then stacked in a crucible and vacuum remelted to form ingots of appropriate size and shape for fabrication purposes. Recasting is conducted under vacuum to prevent oxidation of the metal and also to remove volatile impurities. After recasting, the graphite crucible from which the ingot is poured is burned out with a gas flame, producing large quantities of fine fume. The "burnout" operation and rebuilding operation are all carried out in an enclosure with remote handling.

By a technique developed in 1953, much larger reductions of tetrafluoride and magnesium produced massive metal ingots of approximately 3,300 pounds. Bomb preparation is similar to that described for derby production except on a much larger scale. Reduction is similarly batchwise in a lined steel bomb. Breakout of the bomb results in a massive ingot in which the impurities are concentrated in the periphery. Purification, therefore, does not require vacuum recasting. Instead, the ingot is scalped on a lathe to remove the surface impurities, and the resulting billet is suitable for metal fabrication.

For industrial hygiene control purposes metal reduction may be considered in three phases: (1) bomb preparation, (2) thermite reduction, and (3) bomb breakout.

When bomb preparation was conducted during 1948 and 1949, the operators' daily average exposures varied from 15,000 d/min/cu. m. to 40,000 d/min/cu. m., with peak breathing zone exposures in excess of 400,000 d/min/cu. m. All of the bomb preparation was conducted with hand tools and little, if any, ventilation (Fig. 11). Half-face respirators provided the primary control for operator protection. Reduction furnace operators and bomb breakout operators were not exposed to such high levels.

Vol. 5, Nov., 1960

Bomb Prep
BZ Load
BZ Jolting
GA Prep
Weighted

Reduction
BZ Chan
GA Redr
Weighted

Bomb Brea
BZ Clean
BZ Chlpj
GA Brea

In the con expanded p niques have operations l tilated hood facilities w have resulte in excess o for metal r given in T

Recasting by thermite tion which fuel. This to the outer method of : ing the met ingots of s casting fro volatile con volatile ma the uranium is separatec ingot is sav contaminati able for rol

Included ized during β -emitting These colle the furnacc occasional doses. The

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TABLE 8.—Dust Concentrations During Metal Reduction—d/min/cu. m.

Operations	Before Modification		Remote Handling	
	Range	Average	Range	Average
Bomb Preparation				
BZ Load bomb	700-320,000	90,000	1-220	45
BZ Jolting	12,000-110,000	50,000	10-200	36
GA Preparation area	80- 5,900	2,650	1-311	21
Weighted average exposure	300- 2,300	875	7-130	30
Reduction Operations				
BZ Change bombs	300- 2,700	1,200	0-144	27
GA Reduction furnace area	80- 2,200	520	0-32	7
Weighted average exposure	130- 970	300	7-20	11
Bomb Breakout				
BZ Clean and unload shell	370- 5,000	1,600	0-146	43
BZ Chipping derby	400- 6,000	2,000	0-300	70
GA Breakout area	26- 2,100	530	0-75	25

In the construction of newer facilities for expanded production, remote handling techniques have been incorporated and the dusty operations have been conducted inside ventilated hoods. Since 1951, when these newer facilities went on stream, no operations have resulted in average weighted exposures in excess of 110 d/min/cu. m. Exposures for metal reduction and derby handling are given in Table 8.

Recasting.—Metallic uranium produced by thermite reduction contains contamination which makes it unsuitable for reactor fuel. This contamination is mostly confined to the outer surface of the cast metal. As a method of altering the shape and of purifying the metal, derbies are vacuum cast into ingots of suitable size and shape. Vacuum casting from graphite crucibles removes volatile contamination and permits the less volatile materials to float to the surface of the uranium. After air cooling, each ingot is separated from its mold. The top of the ingot is sawed off to remove lighter metal contamination, whereupon the billet is suitable for rolling or extruding.

Included in the volatile products vaporized during the vacuum remelting are the β -emitting daughter products of uranium. These collect, with metallic magnesium, on the furnace lid and surfaces, resulting in occasional fires and strong β -radiation doses. The newest furnaces are made so

that the lids are cleaned remotely, with consequent reduction in β -radiation and airborne dust levels.

Operations auxiliary to recasting include crucible preparation and cleaning for reuse. With the exception of the period prior to 1951, no operators have been exposed to excessive amounts of dust as a result of normal crucible handling. In destroying discarded crucibles, however, the operators are occasionally exposed to concentrations as high as 28,000 d/min/cu. m.

Upon opening the vacuum furnace to remove the casting, occasionally the magnesium burns with a flash, producing a cloud of magnesium oxide and some UX_1 and UX_2 . Ventilation is necessary to remove this fume from the operator's breathing zone.

Fluorination.—Separation of U^{238} from lighter isotopes is carried out by controlled diffusion of gaseous uranium hexafluoride through multiple porous plates. Some data are presented here on the preparation of hexafluoride from uranium tetrafluoride by reacting it with anhydrous fluorine. In the case of fluorination of UF_4 to produce UF_6 , however, agitation or any other means of renewing reacting surface is not necessary. By removing the hexafluoride product as it is formed, the chemical reaction can be driven to completion. UF_6 is easily con-



Fig. 13.—Unventilated manual loading of UF_4 prior to fluorination to UF_6 .

densed to a liquid which may be redistilled to purify the product.

In early industrial practice, green salt (UF_4) was spread in shallow trays (Fig. 13), sealed in reaction tubes, and placed in a reactor furnace. Fluorine was introduced at elevated temperatures. This reaction produces gaseous UF_6 which is then condensed to a liquid inside water-cooled cylinders. Since the reaction is rather selective for uranium, impurities in the tetrafluoride tend to remain in the trays. Decay products of uranium also remain behind and can present a considerable beta radiation problem.

The UX_1 and UX_2 daughters which remain in the trays have been removed by brushing and vacuuming the ash into a collector drum. β - and γ -Radiation in the vicinity of the collector approaches 1 roentgen per hour, but by quickly sealing the

drum and storing the contents for six months before further handling, it is possible to maintain workers' exposures at permissible levels. It must be mentioned, however, that radiation exposures as measured by personnel monitoring film badges have been recorded at 4 to 12 roentgens per month over extended periods for those operators who manually scraped the reactor trays. Later a vacuum and brushing system (Fig. 14) was installed in a ventilated enclosure and radiation exposure at this operation was reduced to between 100 and 200 milliroentgens per week. In modern equipment the UF_6 is formed in a vertical continuous reactor, and the ash which collects in an ash pit at the bottom may be removed automatically.

HASL air dust data for hexafluoride production is limited to one plant and extends

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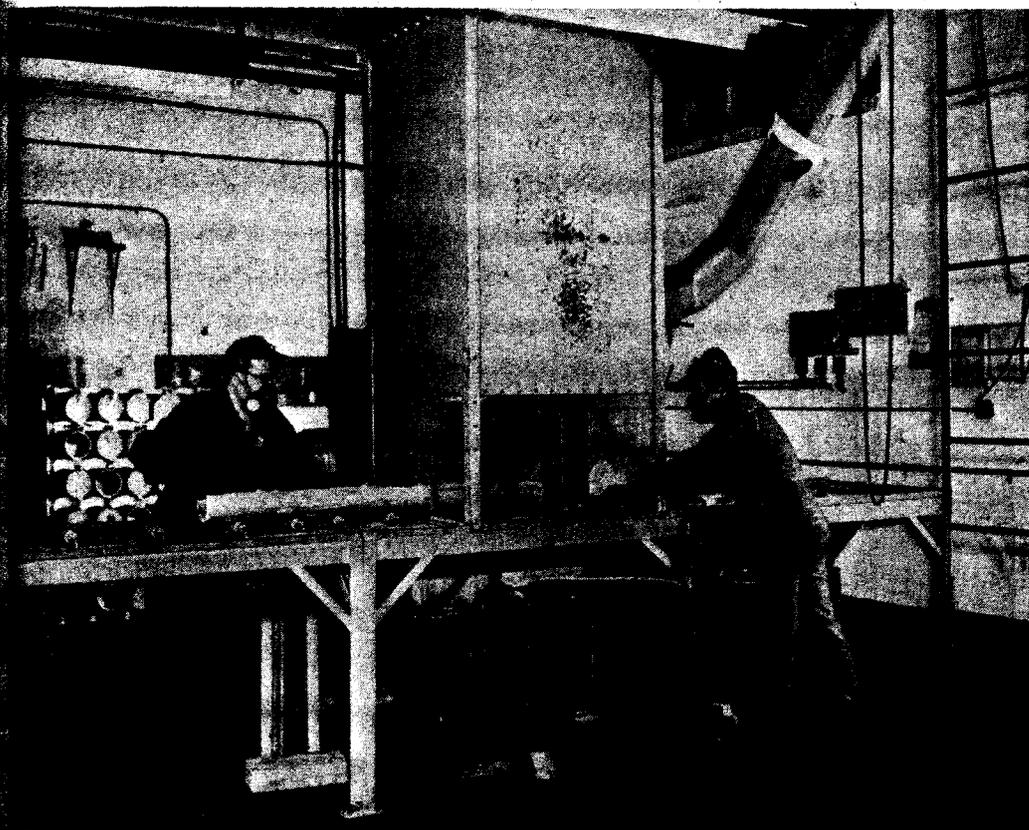


Fig. 14.—Ventilated loading of UF₄ tray prior to UF₆ conversion.

TABLE 9.—Dust Concentrations During Recasting—d/min/cu. m.

Operation	Before 1951		After 1951	
	Range	Average	Range	Average
BZ Load crucible	28- 2,700	1,050	64- 870	250
GA Crucible loading area	6- 77	25	5- 87	32
Weighted average—crucible loading	25- 77	51	15- 86	36
BZ Open furnace and clean furnace	20-77,000	32,000	130-4,600	2,100
BZ Remove crucible	6,600-10,000	8,400	800-1,700	1,300
GA Recasting furnace area	11- 3,400	580	0- 200	34
Weighted average—recasting	110- 4,100	1,100	11- 83	47
GA Crucible burnout area	17- 140	55	0- 250	32
Weighted average—crucible burnout	25- 100	50	7- 360	70
BZ Billet removal	1,200- 3,800	2,700	78- 310	180
BZ Clean billet with chisel	4,900- 6,300	5,600	—	—
BZ Degrease and weigh billet	46- 70	59	45-1,200	130
Weighted average—billet cleaning	14- 80	47	14- 49	28
BZ Assemble crucible	56- 2,800	1,300	12- 270	81
BZ Clean crucible parts	160- 360	250	92-1,000	320
GA Crucible assembly area	17- 140	80	13- 280	81
Weighted average—crucible assembly	100- 540	360	31- 81	55

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TABLE 10.—Dust Concentrations During Fluorination—d/min/cu. m.

	Range	Average
Hex Loaders		
BZ Remove ash	1,000-14,000	5,800
BZ Loading tubes into furnace	400-26,000	8,200
BZ Connect line to receiver	1,000-35,000	2,100
DWA Hex loaders	670- 7,300	2,600
Fluorination Operators		
GA Cell room and steam room	10- 90	55
GA Fluorination area	210- 7,500	1,500
DWA Fluorination operators	150- 5,600	1,100
Redistillation Operators		
BZ Make or break line connections	35- 2,000	530
BZ Remove receivers	55- 450	190
GA Distillation area	66- 1,300	450
DWA Still operators	65- 910	350
Central Loaders		
BZ Dump UF ₆ to central hopper	1,900- 6,300	4,400
BZ Vacuum ash from tray	1,200- 1,400	1,350
BZ Load UF ₆ at central loading	190- 370	240
GA Central loading room	100- 430	220
DWA Central loaders	220- 1,000	550

only to 1951. During these three years every operator concerned with hexafluoride production was exposed to average concentrations greater than the permissible level of 110 d/min/cu. m. The operators' exposures are summarized in Table 10.

Figure 15 illustrates the cylinders in which hexafluoride was condensed. They were connected to the reaction furnace by flexible metal tubing fastened with flare nuts. The copper tubing plugged frequently and had to be disconnected and poked out. Occasionally the fittings leaked. UF₆ was evolved in both circumstances. In Figure 15 a leaking connection may be seen at the second furnace from the left. Upon decomposition in moist air the UF₆ produces UO₂F₂ which is particulate and HF gas which is, of course, highly corrosive. UF₆ was almost continually being evolved, forming clouds of smoke which frequently were so severe as to obscure vision in the plant. The fuming was most noticeable during

periods of ties which inhalation c early days to accident: posed to fo: persons cor HF poisoni

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Fig. 15.—UF₆-UF₆ ventilated conversion furnace showing water-cooled condenser.



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Scrap Re volves a p uranium va used as ref or as urani step, scrap multiple he nium prese

ese three years with hexafluoride average concentration permissible level operators' exposure table 10.

ie cylinders in condensed. They tion furnace by med with flare gged frequently and poked out. ked. UF_6 was ces. In Figure r be seen at the . Upon decom- UF_6 produces e and HF gas corrosive. UF_6 evolved, form- frequently were m in the plant. ticeable during

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periods of high humidity. The only fatalities which have been reported as due to inhalation of uranium occurred in the very early days of production. These were due to accidental spills of UF_6 which decomposed to form dense clouds of UO_2F_2 . The persons concerned exhibited symptoms of HF poisoning.

Ineffective ventilation in the hexafluoride plant permitted the escape of this dust into the work area, resulting in general air concentrations which during the seven surveys conducted of this operation varied from 90 to 7,500 d/min/cu. m. An idea of the extent of this leakage may be had from figures gathered during air pollution surveys. The plant was exhausted by 75,000 ft³ of general exhaust. Stack samples of these exhausts yielded an estimated monthly loss of about 2,500 pounds. This was later reduced to about 500 pounds by the improvement of local ventilation and the installation of collection equipment.

UF_6 was differentially distilled from the collecting cylinders into transport cylinders by warming the pots with steam and cooling the receivers with cooling water. Here again leaking connections resulted in high dust concentrations. The general air in the vicinity of redistillation pots averaged 50 d/min/cu. m. over the four-year period from 1948 to 1951. Simple ventilated hoods were instrumental in confining contamination to the immediate vicinity.

Modern design has this operation performed as a continuous process. There is normally insignificant air contamination formed by this process, but line plugs and leaks in the system can result in temporary flooding of the area with extremely high concentrations.

Scrap Recovery.—Recovery of scrap involves a procedure for concentrating the uranium values to a form which can be used as refinery feed, usually as a uranate or as uranium oxide. In the first recovery step, scrap is dried and calcined in trays or multiple hearth furnaces. Any metallic uranium present is burned to the oxide with

the evolution of fume. The calcining operation contributed the majority of the high exposures in scrap recovery, with individual breathing zone concentrations as high as 140,000 d/min/cu. m.

It must be recognized that in scrap recovery the extreme variability of composition and physical form of the uranium-bearing materials lead to variable air dust concentrations. Scrap as it enters the recovery plant might be high-purity metal (99%), low-grade ore, slag and dross from remelting operations, or thermite-reduction bomb lining. Each of these materials presents somewhat different handling problems, but, in general, a furnace converts metals and easily oxidized compounds to U_3O_8 . The following steps are then used. First, scrap is calcined in a furnace to convert metals and easily oxidized compounds to U_3O_8 . The oxidized material is pulverized, digested with acids, filtered, then treated with hydroxide to precipitate uranium. This is separated from the liquor and then purified and concentrated to form a diuranate salt which can be processed in the refinery.

Scrap has been calcined to oxide in open trays and in multiple hearth calcining furnaces. Both methods led to similar occupational exposures of about 1,000 d/min/cu. m. Scrap concentration and purification operations, such as filtration, digestion, and precipitation, were maintained at dust concentrations between 10 and 50 d/min/cu. m. A summary of the dust levels encountered in the scrap recovery plants is contained in Table 11.

Summary

The total number of refinery operating personnel has risen from about 400 in 1948 to 500 in 1954 and to about 3,000 in 1960. During the years from 1948 to 1956 the average refinery operating force of 400 men was broken down as follows: ore sampling, 25 men; refining, 225 men; reduction and recasting, 150 men.

TABLE 11.—Scrap Recovery—d/min/cu. m.

	Trays	Caliner
Furnace operators' average exposures up to 1952	3,000
Furnace operators' average exposures since 1952	300	1,000
GA furnace area	900	200
BZ dump scrap into furnace	23,000	135,000
BZ rake charge	2,500	2,000
BZ remove material from furnace	7,500	4,000
Digest operator average exposure	28	
Filtration operator average exposure	10	

Figure 16 represents a compilation of all our survey information on refinery workers' occupational exposure to α -emitting dust. Operators' exposures are plotted on the ordinate and time in years on the abscissa.

It is apparent that in 1948 almost all the workers were exposed to greater than the present permissible airdust level. In a very few years, this had changed so that about half the workers were excessively exposed. By 1955 only two operations led to occupational exposures in excess of the present permissible levels.

By 1948 and 1949 men were exposed to as much as 400 times the present acceptable levels; by 1955 the maximum occupational exposure was reduced to 4 times the admittedly conservative permissible level of 110 d/min/cu. m.

376 Hudson St. (14).

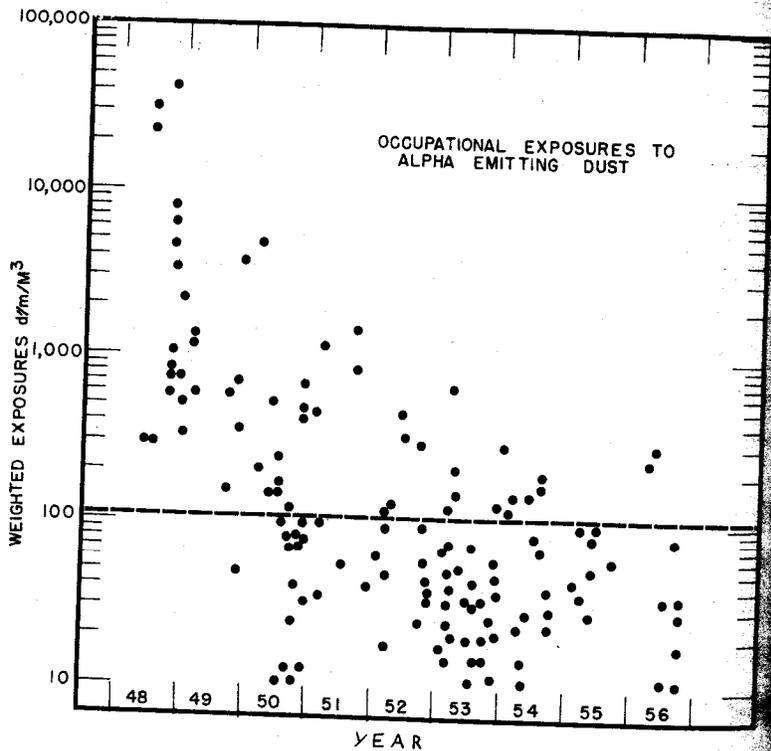


Fig. 16.—Average exposure to α -emitting dusts for all occupations year by year.

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