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Preliminary Partial Dose Estimates from the Processing of Nuclear Materials at Three Plants during the 1940s and 1950s¹

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1. Introduction

We analyzed some data in regard to working conditions and radiation exposures of workers at three nuclear materials processing facilities, pursuant to a contract between USA Today and the Institute for Energy and Environmental Research. The plants were:

1. The Simonds Saw & Steel Co. of Lockport, New York.
2. The Harshaw Chemical Co., Cleveland, Ohio
3. Electro-Metallurgical Co., Tonawanda, New York

All three plants processed uranium during portions of the 1940s and 1950s. Simonds also processed thorium metal. This study is a preliminary and partial evaluation of worker exposure in some job categories or locations. Its purpose was to perform screening type of calculations to ascertain whether the doses to workers in at least some locations or job categories were high enough to cause serious health concerns. This study is necessarily limited in scope and partial since a thorough effort would require far more documentation and data, time, and resources than were available in this project.

Since we did not have the data to perform individual worker dose assessments, or even to determine whether such assessments could be reliably performed, a relatively low dose in a particular job category may not correspond to a low dose for a specific worker. We performed only partial dose evaluations by job category. We have not assessed external doses. Job category

¹ This report was produced by the Institute for Energy and Environmental Research (www.ieer.org) under contract to *USA Today*, which supplied IEER with the plant documents as well as summaries of operating periods for the plants. This report was first posted to the *USA Today* web site, as part of its series, "Poisoned Workers & Poisoned Places," beginning on September 1, 2000, at <http://www.usatoday.com/news/poison/cover.htm>.

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dose estimates would lead to the most reliable conclusions for those workers who spent most or all their working time doing the jobs specified in the calculations, or working at the locations where the conditions described were prevalent. A low dose estimate for a particular job category may not correspond to an actual low dose, since our estimates are partial.

We have estimated doses due to inhalation of uranium by first calculating the amount of uranium breathed in by a worker in a typical work-day at a specific location or in a specific job category. In most cases, the time-weighted air concentrations were available in the documents provided to IEER by USA Today. The air concentration calculations were done by plant personnel at the time by estimating the total time spent in various locations by personnel in various job categories. For instance, a portion of the day would be at the specific location where uranium was being machined or processed, a portion in the general area of the processing, a portion in the lunch-room, etc. By weighting the air concentrations in various locations with the time typically spent in each location, the total amount of uranium that a worker was exposed to for the day can be calculated.

The dose from this intake of uranium can then be assessed, if we know the chemical form of the uranium, which tells us its solubility and hence approximately how long that uranium would remain in the body. Standard tables of “dose conversion factors” – the radiation dose per unit of a particular radioactive material inhaled or ingested – have been published by various scientific and regulatory bodies and provide differing factors depending on the solubility of the material. The dose conversion factors used in the United States are published in a 1988 report by the U.S. Environmental Protection Agency called the Federal Guidance Report No. 11.⁵ We have used these in our calculations.

All dose calculations shown here are “committed doses.” When a radioactive material is inhaled, it is eliminated gradually from the body, and the dose is received over a considerable period of time (depending on the solubility, particular size, and method of incorporation into the body). The term “committed doses” reflects the fact that exposures resulting from a single intake are considered over the entire time that inhaled uranium remains in the body.

Dose estimates derived from a given air concentration depend greatly on the assumed solubility of the material that is inhaled. To illustrate this point, we calculated the dose to lung tissue using the dose conversion factors in the Federal Guidance Report No. 11 from inhalation of natural uranium over an entire year (2000 working hours). We have assumed constant exposure at the in-plant maximum permissible concentration of 70 disintegrations per minute per cubic meter (dpm/m³) in the plant air that was in effect at the time these facilities were operating.⁶ The federal limit for concentration in air prevalent since 1949 was 38 dpm/m³.⁷ This limit was

⁵ K.F. Eckerman et al., *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, Federal Guidance Report Number 11. Washington, DC: U.S. Environmental Protection Agency, 1988.

⁶ U.S. Atomic Energy Commission, New York Operations Office. *Health Hazards in NYOO Facilities Producing and Processing Uranium (A Status Report – April 1, 1949)*. Prepared by NYOO Medical Division. Issued April 18, 1949. Appendix III of this document details the calculation of this air concentration limit.

⁷ National Bureau of Standards, *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water*. National Bureau of Standards Handbook 52, Washington DC: U.S. Department of Commerce, issued March 20, 1953. This handbook provides concentration limits for certain radionuclides in the body, air, and water (Table 3). The values for uranium provided in Table 3 were agreed upon at the meeting of the University of Rochester Atomic Energy Project and members of the Atomic Energy Commission, Rochester, NY, Sept. 27, 1949 as cited on page 17.

established based on the chemical toxicity of uranium and seems to have been ignored both by the government and its contractors, so far as we can determine. A limit of 0.009 μCi of uranium lung burden (apparently with a 90 day biological half-life) seems to have been established in 1951.⁸

The resulting doses calculated using an air concentration of 70 dpm/m³, the prevailing radiological standard in the plants, and as calculated by present methods, are as follows:

- High solubility (class D): 0.084 rem/yr
- Moderate solubility (class W): 4.2 rem/yr
- Low solubility (class Y): 79 rem/yr

The difference between the lowest and the highest estimate is a factor of 940. It is apparent that if the solubility of material is not known, the results of calculations are subject to major uncertainties. For comparison, the federal limit of doses to any individual organ of the body, established in the early 1950s was 0.3 rem/week (or about 15 rem/year).⁹

Rather than relying on assumptions about the mixture of the materials, we used the results of our previous analysis of historical records for the workers at the Feed Material Production Center (FMPC) uranium facility in Fernald, Ohio. This allows the direct determination of the solubility of the inhaled material by comparing concentrations measured in lung tissue and in urine excretion.¹⁰ This approach is justified because various processes at the three plants analyzed in this report were all done at the Fernald plant at one time or another. The Fernald worker data suggested that on the average, the inhaled uranium had metabolic characteristics of a mixture of material with about 90% moderate solubility (class W) and 10% of low solubility (class Y). For the above example, one year of continuous inhalation of natural uranium at the historical maximum permissible concentration of 70 disintegrations per minute per cubic meter results in a committed dose to the lung tissue of 12 rem. We believe that using the solubility mixture that was found for the Fernald facility provides the best estimate at the current time for the three plants reviewed here. Our assumption is subject to review and revision if more information about the specific mixtures of materials in the air at these three plants becomes available. An additional factor of uncertainty is the particle size of the material. The dose conversion factors are based on a mean aerodynamic size of 1 micron (μm). For 5 micron (μm) particles, doses could be up to 30% lower. The default assumption of a 1 micron particle size is standard practice when no data are available.

We have used a rather conservative estimate for the breathing rate of 20 liters per minute, averaged over a working day, corresponding to light work. Many operations involving uranium would fall into the category of heavy work, so that the average breathing rate over the working

⁸ *NBS Handbook 52*, Table 3A. While the handbook was issued in 1953, the values in the table are from October 1951

⁹ *NBS Handbook 52*, p. 13. The handbook states that the “maximum permissible concentration of radioisotopes in air and water and the external radiation should not exceed values that will permit an exposure of 0.3 rem/week to any part of the body except the epidermal skin layer.”

¹⁰ Bernd Franke and Kevin Gurney, *Estimates of Lung Burdens for Workers at the Feed Materials Production Center, Fernald, Ohio*. Institute for Energy and Environmental Research, July 1994. Additional reports describing the methodology and theory are cited in this document. The Fernald worker report was produced for the plaintiffs in a class action lawsuit filed by the Fernald workers against the contractor of the plant, National Lead of Ohio. The U.S. Department of Energy (called the Atomic Energy Commission during the decades immediately after World War II) owns the plant, which was closed in 1989. The US government settled the lawsuit in 1994, one week after the trial began, providing most of the workers with medical monitoring as well as \$15 million in compensation.

day for typical workers involved in manual work may well have exceeded that assumed here. Moreover, heavier breathing rates would likely apply to periods of work in more contaminated areas, so that average air concentration, weighted by breathing rate would be higher than the one we have assumed. Since the estimated dose is directly proportional to the breathing rate, our assumption of a 20 liters/minute breathing rate (as recommended by the ICRP for default calculations) may result in a considerable underestimate of doses for some workers.¹¹

While the lung tissue is the organ that receives the largest dose from uranium of moderate to low solubility, doses can also be expressed in terms of "effective dose equivalent." The effective dose equivalent (EDE) is a calculated value for which doses to various tissues are multiplied by a factor that indicates the relative risk of a fatal cancer as a result of the tissue exposure. In the above example calculation, a 12 rem lung dose results in an EDE of 1.44 rem. According to the International Commission on Radiological Protection,¹² an effective dose of 1 rem is associated with a 0.04% excess risk of cancer mortality, assuming a linear dose-response relationship. While this risk factor is subject to uncertainties and its accuracy is being debated in the scientific community, we used this widely applied value as a benchmark to illustrate the risks associated with the exposures.

If the uranium activity in air were to contain more soluble compounds, the estimated radiation doses and cancer risk would be smaller. However, forms of soluble uranium, such as uranium hexafluoride and uranyl fluoride, are associated with more severe nephrotoxic effects. Nephrotoxicity – damage to the kidney – is a well-known effect of uranium as a heavy metal. That is, it results from uranium as a heavy metal (like lead or mercury), rather than as a radioactive material. Severe damage to the kidneys could, in turn, cause a variety of other serious health problems and death.

We checked our calculations for consistency against the scant urine data that were available for the Harshaw plant, and this check confirms our principal conclusion that many workers were severely overexposed to uranium dust. An extensive and definitive check is not possible, since the necessary urine data are not available.

One more note on methodology is in order. The methods used to calculate doses in the 1940s and 1950s were not the same as those prevalent today. We have used dose estimation factors that are in use today for regulatory purposes in the United States. Methods prevalent at the time would have resulted in dose estimates about a factor of two lower for the same uranium air concentration data.

2. The Simonds Saw & Steel Co.

Between 25 and 35 million pounds of uranium metal was rolled at Simonds between March or April 1948 and 1956 (with the vast majority of the work done between 1948 and 1952).¹³ About

¹¹ International Commission on Radiological Protection. *Limits for Intakes of Radionuclides by Workers*. Annals of the ICRP, ICRP Publication 30, Part 1, Vol 2, No. 3/4. Oxford: Pergamon Press, 1979, p. 9. The ICRP recommends 20 liters/minute, the value for "light activity," as the default value in the absence of more precise information.

¹² International Commission on Radiological Protection. *1990 Recommendations of the International Commission on Radiological Protection*. Annals of the ICRP, ICRP Publication 60, Vol. 21, No. 1-3. Oxford: Pergamon Press, 1991, p. 70.

¹³ This information comes from an undated government memorandum, apparently generated by Oak Ridge circa 1958. It is contained in the New York State Archives and is part of materials obtained through the Freedom of Information Act by the State of New York in preparation for a 1981 report by the New York

99 percent of this work was done on a 16 inch mill, while the rest was done on a 10 inch mill.¹⁴ Simonds also rolled 30,000 to 40,000 pounds of thorium metal. Thorium was processed on the 10 inch mill.

The work with uranium and thorium was done approximately half-time during the period of peak production (1948-1952), while the same machines were used to roll steel for commercial applications the rest of the time.¹⁵ There is ample evidence that the plant premises became seriously contaminated during processing of radioactive materials. For instance, even air in the lunch areas was measured to have contamination far above allowable limits of contamination.¹⁶ As a result, workers were certainly exposed to radiation, for instance through re-suspended particles, even when steel processing was going on. We have not attempted to assess the doses to workers during steel processing. We have also not attempted to estimate the consequences of food becoming contaminated as a result of poor industrial hygiene. Including all of these factors could substantially increase the dose estimates.

We have also not attempted to assess the radiological consequences to workers and the general public of processing, transporting or using steel that was fabricated on machines that were contaminated in a plant that was contaminated. Finally, we have not estimated the exposures suffered by the families of the workers who may have tracked significant amounts of radioactive contamination home on their clothes, bodies, and vehicles. Doses in some of these categories may have been significant. In particular, doses to workers during the periods when they were processing steel were likely to have been significant in at least some cases, since the working environment was severely contaminated. The re-suspension of uranium and thorium dust during work operations as well as during clean-up of the plant premises were not evaluated. In other words, our calculations were strictly limited to calculating the dose to workers from uranium (and thorium) inhaled during the days when processing of these materials was done.

We did not have data on all the radiological surveys. We have used the available data to make estimates of doses from uranium metal processing up until 6 August 1954. We do not have survey data covering the rest of the period through the end of operations in December 1956. Thus, the doses presented here are partial exposure estimates that underestimate doses to personnel who worked through the entire period of processing. We have made exposure estimates by job classification. If one person did the job for the entire period, the dose estimate represents a typical expected exposure (see below for discussion of uncertainties). If the personnel doing the

State General Assembly. The documents were obtained by the State from the Environmental Protection Agency, which obtained the document in 1977-1978. The title of the page is *Uranium History*.

¹⁴ *Authority Review for the Former Simonds Saw and Steel Co., Lockport, New York*. Formerly Utilized Sites Remedial Action Program (FUSRAP), Aug. 9, 1984.

¹⁵ According to the *Uranium History*, Simonds processed approximately 5.46 million pounds of uranium per year in the time period 1948-1952. Another document, *Industrial Hygiene Survey of Uranium rolling at Simonds Saw & Steel Co.* by Charles E. Schumann, Health and Safety Division, National Lead Company of Ohio, February 5, 1953, describes the rolling procedures. Processing approximately 300,000 pounds of uranium required 130 working hours and was done using two shifts of ten hours each. Therefore, processing the annual throughput of 5.46 million pounds would require a total of 2400 hours per year. Assuming two shifts per day were always used and a fifty week work-year, this would require approximately 24 working hours per week. We have rounded this estimate to one significant figure and used 20 hours per week in our calculations.

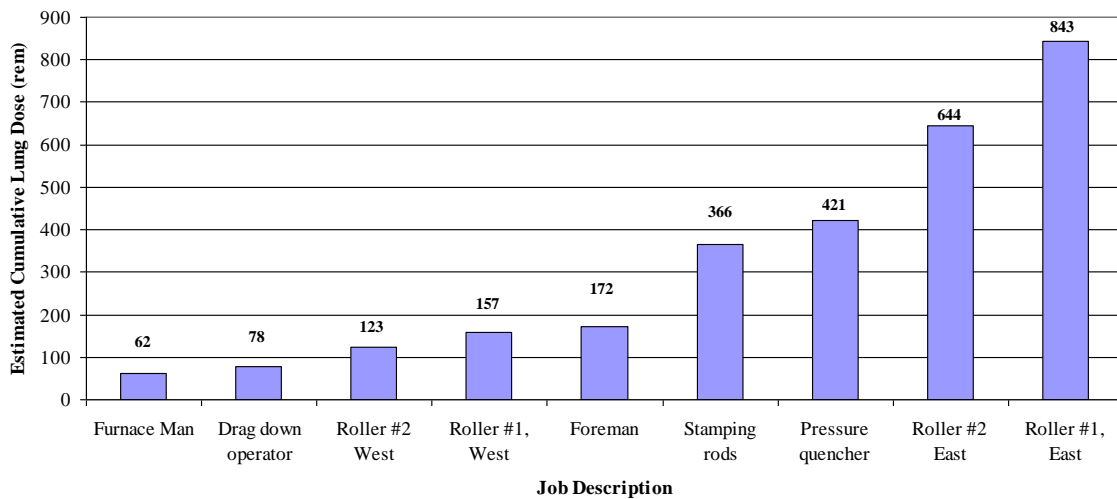
¹⁶ For example, one survey found that the alpha radiation concentration in the lunch area air was 1,410 dpm/m³ (20 times the plant's maximum permissible concentration). *Simonds Saw and Steel Co., Occupational Exposure to Radioactive Dust, Visit of October 27, 1948*.

job changed, this dose estimate would not apply to any particular individual, but rather to the sequence of individuals who did the particular job over the specified period.

When uranium metal is rolled it becomes hot and can even catch fire. The emissions from the operation are typically a mixture of oxides of uranium, whose solubility range from very insoluble to moderately soluble. It may take many months or years for highly insoluble materials to be eliminated once lodged in the lung, while moderately soluble materials may be eliminated within a few weeks. Figure 1 shows the lung dose estimates for the particular jobs associated with uranium rolling operations at Simonds during the peak production period of 1948-1952.

Figure 1

Estimated Cumulative Partial Lung Doses Due to Uranium Exposure at Simonds Saw and Steel From April 1, 1948 to December 31, 1952



Workers in the same job may have had doses several times higher or lower than this, depending on specific working times and conditions, as well as individual differences in the metabolic behavior of uranium in the body.

The records for the period from 1953 to the end of the contract in 1956 indicate that the amount of uranium processed per year was lower by about an order of magnitude than the early years. Air concentrations of uranium dropped considerably in the 1953-1956 period, hence the cumulative dose in this period would likely have been much lower to many or most workers than in the previous period. Finally, we have no data for 1955 and 1956. For these reasons, we have not included any estimate of dose for the 1953 to 1956 period. The shorter work times and lower concentrations would likely result in lower average doses in the 1953-1956 period though this does not preclude the possibility that individual workers may have had substantial doses in this period.

Many workers were also exposed to thorium dust. Even though the amount of thorium processed was almost a factor of one thousand less than uranium, exposures to workers who processed thorium appear to have been substantial. This is because exposure to thorium results in larger doses than uranium per unit of radioactive contamination of air. Further, thorium doses are far less sensitive to assumptions about solubility than uranium doses (i.e. differences in solubility result in much smaller differences in the final dose with thorium). Finally, radioactive decay products build up relatively rapidly in thorium, if it is stored for a few years before processing.

We have not been able to estimate doses due to these decay products, since we do not have data on how long the thorium was stored after conversion to metal and prior to rolling operations.

Thorium processing operations may have taken as little as one week and possibly much longer.¹⁷ Based on available data, it is not possible for us to estimate the total number of full time equivalent days for which the thorium milling operation was conducted. We have therefore calculated thorium doses corresponding to one week of full time work. Bone surface doses over a one-week exposure period would range from about 400 rem to almost 2,500 rem, depending on working conditions and thorium solubility. We do not have a basis on which to select a mix of solubilities based on the available data. If the work was carried out for several weeks, then the dose estimates would be correspondingly higher.

Overall, it appears that exposures to specific workers who worked on thorium may have been severe. We have not been able to assess cumulative thorium exposures in a manner similar to uranium since we lack even minimally adequate air concentration data over the requisite period of time. Our estimate of thorium exposures corresponding to one week's work indicates that for some workers, thorium exposures may have been comparable to and perhaps greater than uranium exposures. Finally, if some workers worked on both uranium and thorium, those exposures would be additive.

3. Harshaw Chemical Co.

Harshaw Chemical Co. conducted a number of chemical operations to produce uranium hexafluoride for uranium enrichment operations. Part-time operations began during the World War II Manhattan Project, during which highly enriched uranium was used to make the nuclear bomb that was dropped on Hiroshima. Production was scaled up after the war and "substantially expanded" in 1947.¹⁸

The chemical forms of uranium present at Harshaw range from the highly soluble (uranium hexafluoride) to the highly insoluble (uranium dioxide).¹⁹ Industrial hygiene was very poor, with air contamination exceeding maximum allowable concentrations in some cases by several hundred fold, averaged over the entire working day.²⁰

¹⁷ We are unable to make a reasonable estimate of the number of days for which thorium was processed. Hence there is a corresponding uncertainty concerning worker exposures to thorium. Our lowest estimate of working time is one week of full time work for thorium processing based on a comparison with uranium processing rates. The thorium throughput per hour would be about forty percent of the uranium throughput per hour due to the difference in mill sizes (10 inches versus 16 inches, yielding a cross-sectional area ratio of about 40 percent). A June 8, 1953 document indicates that thorium processing rates may have been somewhere between roughly 1,000 pounds and 4,000 pounds per day, assuming that all work indicated in a month's period was done in a single full working day. On this basis, the total thorium processing time can be estimated to be between 10 and 40 working days – that is, two to eight weeks. *Survey of Accounting Control over Source and Fissionable Material, Simonds Saw and Steel Company, Lockport New York*, with cover letter dated June 8, 1954.

¹⁸ *Review Summary Report, Harshaw Chemical Company, Cleveland Ohio. Formerly Utilized Sites Remedial Action Program (FUSRAP)*, 20 November 1984, Enclosure 1.

¹⁹ U.S. Atomic Energy Commission, New York Operations Office. *Health Hazards in NYOO Facilities Producing and Processing Uranium (A Status Report – April 1, 1949)*. Prepared by NYOO Medical Division. Issued April 18, 1949. p. 24

²⁰ For example, see Memo from R. E. Hayden to M. Eisenbud, "Health Survey of Harshaw Chemical Company, Area C." May 4, 1948.

Assuming that workers were exposed to the same mix of uranium compounds as seen at Fernald, as would be likely for at least some portion of the plant personnel, the radiation doses to the lungs of workers in moderately exposed categories would be in the hundreds of rem, cumulative (Table 1). The calculations assumed an 8-hr work day, and 20 work days per month, averaged over a year. In the case of the most severely exposed workers, who either worked in highly contaminated conditions, or for long periods, and, in the worst cases, both, cumulative lung doses were thousands of rem. If the assumptions we have made about the solubility of uranium are correct, the lung dose in the highest category in Table 1 is 8,400 rem. This is equivalent to an effective dose of about 1,000 rem, using official lung to whole body dose equivalence factor for the lung of 0.12.²¹ Using the EPA (and ICRP) fatal cancer risk factor of 4 deaths per 10,000 rem, we can estimate that a worker would have a 40 percent chance of dying from cancer as a result of an exposure of 1,000 rem. This is an increase of 200 percent in fatal cancer risk compared to unexposed persons.

Table 1. Distribution of employees by length of employment and level of dust exposure at Harshaw Chemical Co. 1945-1949. Mean lung doses were estimated assuming the same solubility of uranium as found at FMPC.

Exposure category	Number of months of exposure				
	0 to 6	6 to 12	12 to 24	24 to 36	36 to 48
0 to 70 dpm/m³					
# of workers	1	2	2	0	1
estimated mean lung dose, rem	1.4	4.2	8.4	14	20
70 to 350 dpm/m³					
# of workers	1	1	0	0	2
estimated mean lung dose, rem	6.3	9	38	63	88
350 to 1,750 dpm/m³					
# of workers	0	5	5	12	10
estimated mean lung dose, rem	31	94	190	310	440
1,750 to 8,750 dpm/m³					
# of workers	0	0	0	0	0
estimated mean lung dose, rem	160	470	940	1,600	2,200
> 8,750 dpm/m³					
# of workers	0	17	10	3	4
estimated mean lung dose, rem	600	1,800	3,600	6,000	8,400

Note 1: To estimate mean dose, we have used the geometric mean of the lowest and highest uranium concentration (except for the 0 to 70 category, where we have used the arithmetic mean, since the geometric mean gives an implausible zero result). This use of the geometric mean gives a lower mean dose estimate than would be obtained by the use of an arithmetic mean. Doses corresponding to the minimum and maximum concentrations in a category would be a factor of 2.23 lower or higher than the geometric mean dose (except for the first row, in which case the range is from 0 to a factor of two higher). We have used the arithmetic mean for the number of months. The result in this case is insensitive to the use of geometric or arithmetic mean.

Note 2: The dose for the final category was calculated using the geometric mean of 8,750 dpm/m³ and the maximum exposure recorded, which was 25,900 dpm/m³ (370 times the maximum allowable concentration).

Note 3: No doses were calculated beyond the 48-month exposure category. However, it is necessary to note that one worker received exposures less than the MAC for over 48 months and eleven workers received exposures at levels between 5 and 25 times the MAC for over 48 months.

²¹ ICRP Publication Number 60, Oxford, 1991, p. 8.

If the uranium were to be of more soluble compounds, the estimated radiation doses and cancer risk would be smaller and the likelihood of severe nephrotoxic effects would be far larger. Plant documents indicate that such kidney damage was in fact reported.²² Lower radiation doses and higher nephrotoxic effects would be more likely for workers who were exposed primarily to soluble uranium, notably uranium hexafluoride and its hydration product, uranyl fluoride.

The results were checked against a simple calculation of the expected amount of uranium in the urine of a hypothetical worker exposed to the level of uranium in air that would be consistent with a lung dose of about 15 rem/yr. The excretion in urine expected from exposure to this level and particular mix of uranium would be about 10 micrograms per liter.²³ Urine data for six individuals from Harshaw are as follows²⁴:

- 1 person: 17 micrograms per liter
- 2 persons: between 100 and 200 micrograms per liter
- 1 person: between 200 and 300 micrograms per liter
- 2 persons: more than 300 micrograms per liter.

These data are consistent with our dose calculations made from uranium concentrations prevalent in the plant and tend to support the hypothesis that many workers were exposed to more than prevailing dose limits.

Harshaw documents also indicate that external gamma and beta doses, were also high in some cases. Uranium emits x-rays, and the uranium decay products include both beta and gamma emitters, leading to external radiation exposures. Cumulative doses due to external beta-gamma radiation measured with film badges were reported to be up 160 rep.²⁵ Further, thorium-234 and protactinium-234, are present in larger than usual concentrations in the types of operations that took place at Harshaw. These two radionuclides give rise to beta radiation exposures. We have not attempted within the scope of this limited study to systematically quantify external exposures. However, even a cursory review of Harshaw documents shows that for at least some workers, these may have been high and that they would compound the problems resulting from internal uranium exposure.

Finally, the manufacture of uranium hexafluoride involves the use of severely toxic chemicals, including fluorine. Moreover, when uranium hexafluoride makes contact with the humidity in air (which would be high in the Cleveland area during at least some parts of the year), it readily combines with water vapor to yield uranyl fluoride and hydrofluoric acid. Hence, exposure to uranium hexafluoride would also generally entail exposure to hydrofluoric acid, which is highly toxic.

²² For example, see U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Division. *Monthly report of Field Activities, September 1950*. p. 6

²³ For an explanation of the methodology of converting lung burden to urine concentration see Franke and Gurney 1994.

²⁴ Letter from W.E. Kelley, Manager, New York Operations Office, Atomic Energy Commission, to C.S. Parke, Vice-President, The Harshaw Chemical Company, January 28, 1948.

²⁵ U.S. Atomic Energy Commission, New York Operations Office. *Health Hazards in NYOO Facilities Producing and Processing Uranium (A Status Report – April 1, 1949)*. Prepared by NYOO Medical Division. Issued April 18, 1949. Figure 8. Rep - "Roentgen equivalent physical" is a historical dose unit used in the 1940s. One rep represents the energy absorption of 93 ergs per gram of tissue. The measurements are difficult to interpret, however, since the specific sensitivity of the film badges to beta and gamma radiation is not known. Hence, the depth of tissue penetration cannot be determined without additional information. At least some parts of worker skin tissues are likely to have been exposed to the level measured with film badges.

4. Electro-Metallurgical Co. (Electromet)

Uranium metal was fabricated at Electromet from uranium tetrafluoride (also called “green salt”).²⁶ The process involves the mixing of green salt with magnesium metal flakes, and the insertion of the mixture into a furnace, where the green salt is reduced to metal. Historically, the process was typically troublesome, involving frequent blow-outs, especially under conditions of production pressure that characterized the first two decades of the nuclear era. The uranium would typically be a mixture of moderately soluble and insoluble compounds, with the former predominating, since green salt belongs in this category. Electromet also conducted other operations including thorium processing, which we are not addressing in this report.

We did not have adequate data covering the entire time period of Electromet operation, which began during the Manhattan Project and ended in 1953.²⁷ We know that full time uranium metal production was occurring in the late 1940s, for which we have some data on the range of air concentrations found in working areas, as well as air concentrations weighted over the working day.²⁸ We have performed dose calculations using these figures for one individual over 240 working days (corresponding to a working year of 48 weeks, 5 days per week). Actual exposure for personnel who worked for a large portion of the period for which the plant operated can be expected to be considerably higher. However, we cannot assume that they would be a simple multiple of the calculated doses, since air concentration data are not available in the detail needed to make even an approximate calculation for the entire period.

Industrial hygiene at Electromet was very poor. Many workers were evidently severely overexposed, since highly contaminated environmental conditions persisted in the workplace for prolonged periods. We estimate that for production workers, committed lung doses due to exposure over a single twelve-month period would range from over 50 rem to well over 6,000 rem. The most severely exposed workers would have a very high probability of contracting cancer. One would also expect to find some heavy metal toxicity to the kidneys due to exposure to green salt.

²⁶ U.S. Atomic Energy Commission, New York Operations Office. *Health Hazards in NYOO Facilities Producing and Processing Uranium (A Status Report – April 1, 1949)*. Prepared by NYOO Medical Division. Issued April 18, 1949. p. 68.

²⁷ Electro Metallurgical Company (Electromet), Niagara Falls, New York. Formerly Utilized Sites Remedial Action Program (FUSRAP), 11/1985. P. 5-120 – 5-121. The site did not have continuous AEC operations between 1946 and 1953, but rather conducted AEC operations on specific projects for a few months or more at a time (in one case for two years). It should also be noted that after the AEC contract was terminated in June 1953, Electromet continued to process uranium and thorium for commercial use.

²⁸ U.S. Atomic Energy Commission, New York Operations Office. *Health Hazards in NYOO Facilities Producing and Processing Uranium (A Status Report – April 1, 1949)*. Prepared by NYOO Medical Division. Issued April 18, 1949. pp. 30-31 and *Dust Hazards at Electrometallurgical Company*. Transmitted to Mr. E.C. Forbes, Superintendent of Area Plant, Electrometallurgical Company by F.M. Belmore, Director, Production Division. New York Operations Office, U.S. A.E.C., June 18, 1948.

5. Uncertainties

There are two types of uncertainties in our estimates (other than the issue of the partial nature of the calculations themselves, which means that actual doses would be systematically higher than the ones reported here). First, there are the variations in conditions experienced among the workers, the differences in physiology leading to different metabolic rates, and so on. For instance, some workers at Harshaw would likely have encountered mainly insoluble types of uranium, while others would have encountered mainly soluble types of uranium.

The second type of uncertainty relates to the uncertainties in the measurements of air concentrations, in fluctuations in such concentrations from one day to the next, in the estimates of dose conversion factors for any particular chemical form of uranium, and in estimates of the effects of radiation exposure.

In addition to these uncertainties, our estimates are partial since we have not included external doses, and since we have not been able to estimate doses over the entire working period in several cases.

Actual exposures of workers within any group could easily be several times lower or higher than those estimated here. The limited nature of the study and the preliminary and partial nature of the calculation does not justify extensive effort on a formal uncertainty analysis. We recommend that a more formal effort, with a more complete set of data be undertaken. However, there is enough evidence to come to a reasonably certain conclusion that due to poor working conditions, exposures to many workers were very high and far above then-prevailing regulations.

6. Conclusions

Working conditions at these three plants were very poor and among the most terrible reported for any plant in the United States. Based on our screening calculations, doses to many workers are likely to have exceeded the dose limit of about 15 rem per year that was established in 1949. The data and our calculations also suggest that the highest exposed workers had a high probability of cancer mortality as the result of the exposure. It must be remembered that we have arrived at this conclusion even though our dose calculations are partial and do not cover the entire periods of plant operation and all types of doses. Other types of health problems, including kidney damage, would also be likely among those workers exposed to the more soluble forms of uranium.

We do not have comparable data from nuclear weapons plants that processed uranium in the Soviet Union during the late 1940s and early 1950s. Some external dose data for workers at a reactor and a reprocessing plant in the southern Ural Mountains have been reported. Heretofore, we have assumed, based on available evidence, that worker exposures were far higher in the Soviet Union than in the United States.²⁹ However, the partial estimates that we have made here are so high that this assumption may need to be revisited for many of the workers at these forgotten nuclear weapons plants. We should also note that the extent of the health damage may have extended to the families of workers and to the general public in ways that we have not assessed in this preliminary report.

Finally, there is ample evidence that plant authorities as well as the government of the United States, which contracted with these privately-owned companies to process material for its nuclear

²⁹ Arjun Makhijani, Howard Hu and Katherine Yih, eds., *Nuclear Wastelands*. Cambridge, MA: MIT Press, 1995, Chapter 7, p. 367.

weapons program, were well aware at the time that workers at these plants were being severely overexposed over prolonged periods of time. There is also evidence that the US government deliberately misled workers about health and safety issues by concealing the facts of very poor working conditions from them and by failing to undertake the needed level of radiation dose surveillance, including frequent and widespread urine sampling, that was warranted. A number of documents discuss inadequate controls of contamination and recommendations for improvement that were only sometimes taken into account. For example, in discussing the problems at Harshaw, one document states that:

These findings [90% of plant workers being exposed to higher than the “preferred level” of contamination with 76% exposed to 10 to 374 times that level] are consistent with the results of other NYOO investigations, and show that the equipment and procedures presently used for the control of alpha-emitting dust and fumes are completely inadequate. The last survey points up the urgent need for control measures, which have been previously recommended in considerable detail to the contractor. The situation was discussed in a conference held during the month with the Plant Manager. A summary of the survey findings, together with all recommendations to date, will be given to the contractor, whose attention has been called to contractual obligations for observing health and safety requirements.³⁰

In some cases, there was a hesitation to spend money to correct problems in plants that were expected to be placed on stand-by and no longer be in use for production. At least a year before the Electromet facility was to transition to stand-by, one AEC document notes that:

In order to provide for adequate dust control, a substantial sum of money (\$50,000 to \$100,000) would have to be spent. As before, whether or not extensive dust exposures are corrected will depend on policy decision as to the advisability of spending funds for the purpose of placing stand-by plants in satisfactory medical condition.

During the next few months, minor changes in process ventilation can be expected to alleviate the dust exposure to some extent.³¹

One document points clearly to the practice of keeping information about the health risks of their jobs from the workers. In a letter from W. E. Kelley, Manager of the New York Operations Office of the AEC to the vice-president of the Harshaw Chemical Company, a briefing for workers is described. In that briefing, a staff member of the AEC spoke to the employees to “explain to them that all of our [AEC] records indicated that no unusual hazard existed, but that the Harshaw Company, with the assistance of the Atomic Energy Commission, was proceeding more intensively in an effort to uncover any possibility of danger.” This was done because it was understood that “extensive sample taking . . . may upset employees and cause them to wonder about their health and safety.” However, the very next paragraph of the letter states that according to their early animal studies and general knowledge of radiation, 50 micrograms per cubic meter was the “most popular figure” of what could be tolerated and that this level had been exceeded. Measurements indicated levels exceeding 1,000 micrograms per cubic meter (34 out of 67 samples) and even 10,000 micrograms per cubic meter (17 out of 67 samples). Thus, it was clear that the levels of radioactive material in the air were above what was coming to be

³⁰ *Monthly Status and Progress Report for December 1948*. Submitted by the New York Operations Office of the Atomic Energy Commission by W.E. Kelley, Manager. January 5, 1949. p. 17

³¹ U.S. Atomic Energy Commission, New York Operations Office. *Health Hazards in NYOO Facilities Producing and Processing Uranium (A Status Report – April 1, 1949)*. Prepared by NYOO Medical Division. Issued April 18, 1949. p. 31

understood to be the limit that was tolerable. At the same time the workers were being told that “no unusual hazard existed.”³²

The findings of this study may have broad applicability to many other privately owned plants where uranium processing was done during the 1940s and 1950s. One of our findings, relating to the high radiation doses due to thorium-232 exposure at the Simonds plant, has considerable importance for some government-owned nuclear weapons plants as well as the privately owned plants not studied here. Thorium processing occurred at several other places (including the Fernald plant near Cincinnati, for instance). This is an issue that needs to be more carefully evaluated, since it is possible that exposures to workers, their families and to members of the general public due to thorium processing (and possibly also thorium handling) may have been considerable despite the relatively small amounts (compared to uranium) of thorium that were processed.

It is clear that the effects of the nuclear weapons enterprise on society are even vaster than heretofore acknowledged. The tasks of health monitoring for affected populations, health care for the sick, and environmental remediation of the legacy of nuclear weapons production will be even more complex and larger than currently anticipated.

³² Letter from W.E. Kelley, Manager, New York Operations Office, Atomic Energy Commission, to C.S. Parke, Vice-President, The Harshaw Chemical Company, January 28, 1948.