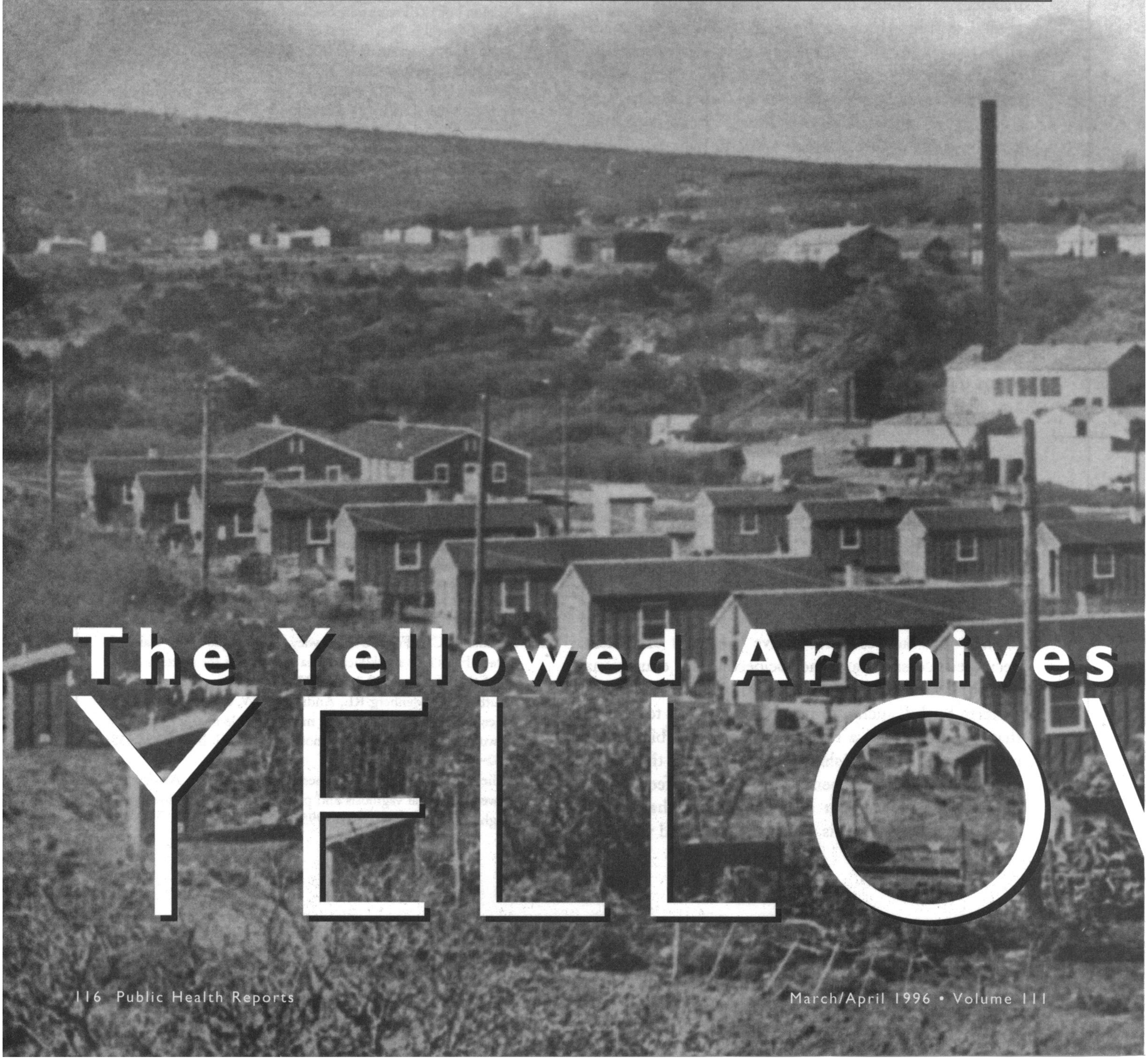
SYNOPSIS

EXTENSIVE HISTORICAL DOCUMENTATION of exposures and releases at government-owned energy facilities is a unique and valuable resource for analyzing and communicating health risks. Facilities at all stages of the atomic fuel cycle were the subject of numerous industrial hygiene, occupational health, and environmental assessments during the Cold War period. Uranium mines and mills on the Colorado Plateau were investigated as early as the 1940s. One such facility was the mill in Monticello, Utah, which began operation as a vanadium extraction plant in 1943 and was later adapted to recover uranium from carnotite ores. The mill ceased operation in 1960. The site was added to the federal Superfund list in 1986. ATSDR held public availability sessions in 1993 as part of its public health assessment process, at which several former mill workers voiced health concerns.

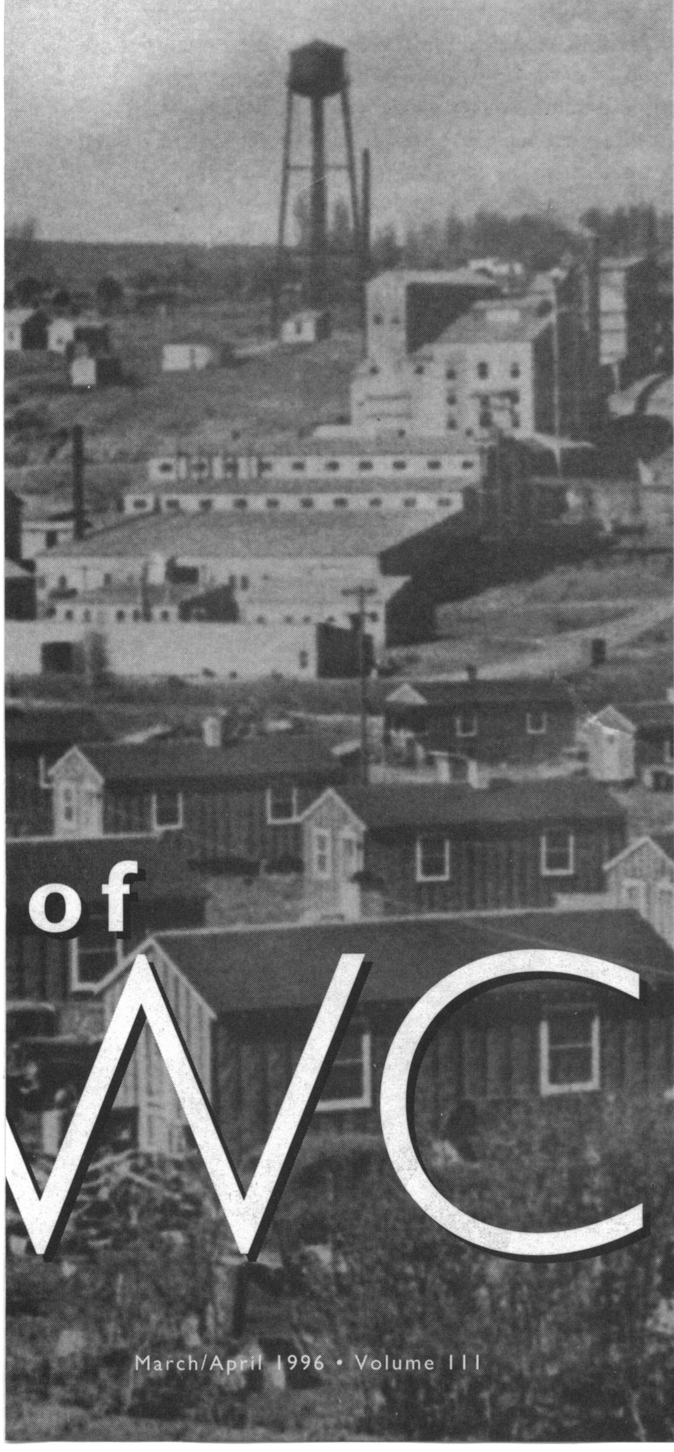
An extensive literature search yielded several industrial hygiene evaluations of the Monticello mill and health studies that included Monticello workers, only two of which had been published in the peer-reviewed literature. In combination with the broader scientific literature, these historical reports provide a partial basis for responding to mill workers' contemporary health concerns. The strengths and limitations of the available exposure data for analytical epidemiologic studies and dose reconstruction are discussed. As an interim measure, the available historical documentation may be especially helpful in communicating about health risks with workers and communities in ways that acknowledge the historical context of their experience.



The Yellowed Archives

YELLO

Ken Silver, SM



Mill worker housing at the Monticello, Utah, uranium mill.

The Mormon pioneers who settled in San Juan County, Utah, a century ago called their town Monticello, with a soft "c." Patriotic yet individualistic, independent yet family-oriented, pragmatic yet spiritual, they held fast to the values of their forbears. Mormon culture imparted a tenor of comfort and civility to this region of rugged mountains and mesas. Jeffersonian ideals about the role of government flourish here amidst the sprawling ranches, farms, and grazing areas that employ many of the local people. Yet in the aftermath of federally sponsored uranium mining and milling activities across the Colorado Plateau during the Cold War years, some of Jefferson's loftiest ideals about the role of government in the lives of citizens are being put to a severe test in the town of Monticello. "The care of human life and happiness and not their destruction," wrote the third President, "is the first and only legitimate object of good government."

During World War II, the federal government began to promote the processing of uranium ore from the mines of the Colorado Plateau, an "object" neither Jeffersonian nor divine in intentions but a welcome source of jobs and pride to many local people. A mill owned by the U.S. Atomic Energy Commission (AEC) operated in Monticello until 1960. Today, "human life and happiness" are at long last being addressed, as federal authorities complete work on an assessment of the mill's impact on public health and the environment.

In December 1993, as part of its public health assessment (PHA) of the Monticello Uranium Mill Superfund site, the federal Agency for Toxic Substances and Disease Registry (ATSDR) held public availability sessions in Monticello and Blanding, Utah. Public availability sessions are intended to

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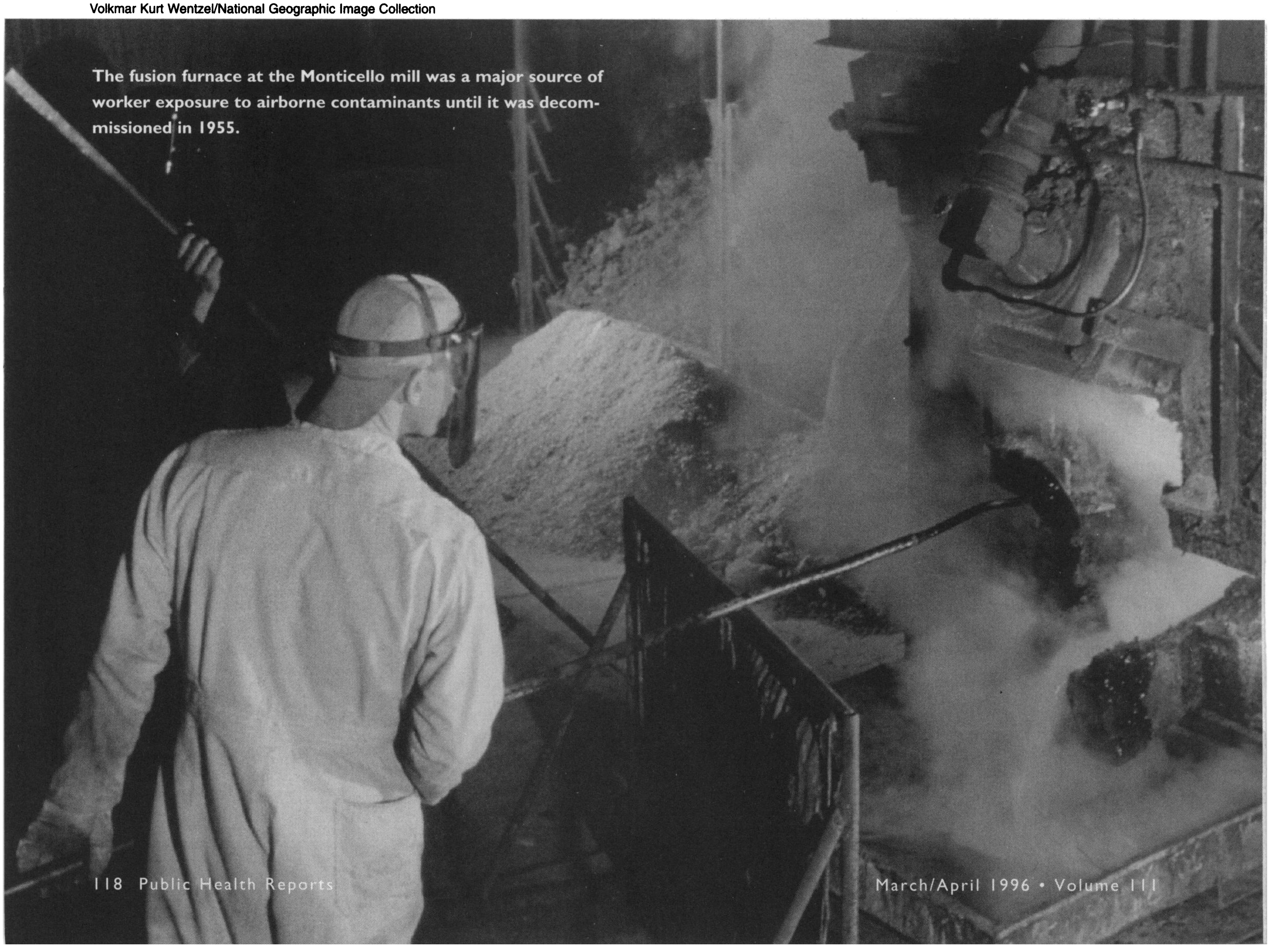
serve as forums at which citizens can go "on the record" with health and environmental concerns to be addressed by the PHA. Present at the sessions were several former uranium mill workers who voiced concerns regarding long-term health risks from exposures they received at the mill (see Box.) They raised questions about the work-relatedness of lung cancer, chronic lung disease, and early loss of teeth. Mill workers graphically recalled dusty working conditions and asked whether family members exposed via household contact might also be at risk for radiation-induced or chemically-induced illness. In accordance with established guidelines, the two public availability sessions were conducted early in the PHA process, as a way to define the issues to be addressed by ATSDR's final report.

Targeting of the town of Monticello for a PHA came about as a result of inclusion on the federal Superfund list of the Monticello Mill Tailings Site and the Monticello Vicinity Properties. An ATSDR public health assessment is intended to be "an evaluation of relevant environmental data, health outcome data, and community concerns associated with a site where hazardous substances have been released,"[1] leading to any of a number of follow-up interventions and activities. Sites on the National Priorities list are required to undergo a PHA, while other sites may be targeted for PHAs in response to a citizen petition. The addition of the Monticello sites to the Superfund list in 1986 was not surprising. As was common in Western mill towns, substantial quantities of tailings were used off-site in a variety of construction applications, and tailings dust was reported to have been frequently carried by the wind over residential and commercial districts of town. Since the early 1970s at least four radiological surveys of properties in town have been conducted by federal agencies.[2] More than 200 properties have been iden-

Partial List of Health Concerns Expressed by Former Monticello Mill Workers

Chronic lung disease in nonsmokers
Lung cancer
Household contact of family members via laundry
Yellowcake "was everywhere" in mill work areas
Bad ventilation
No respirators
Early loss of teeth
Environmental exposures, such as air and stream pollution

Volkmar Kurt Wentzel/National Geographic Image Collection



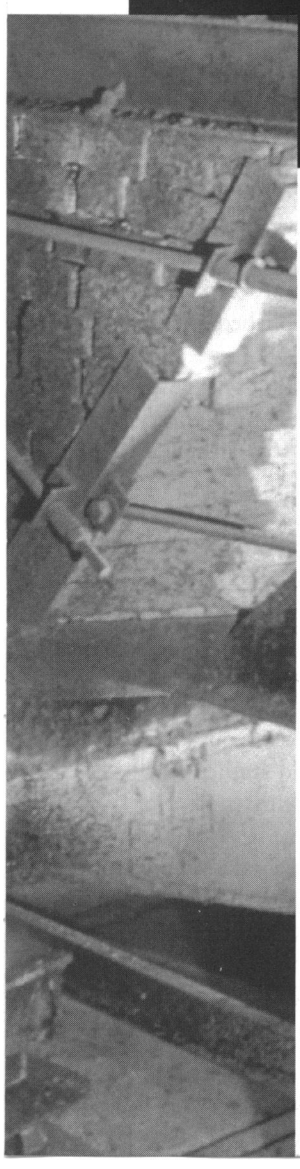
The fusion furnace at the Monticello mill was a major source of worker exposure to airborne contaminants until it was decommissioned in 1955.

tified as being "anomalous" in terms of the levels of radiation exposure likely to be received by occupants.

The Monticello Mill

Older mills that were originally built for the extraction of vanadium "had no great emphasis on dust control," according to the extensive survey of 12 uranium mills conducted by the AEC's Health and Safety Laboratory.[3] Built in 1942 by the Vanadium Corporation of America for the extraction of vanadium from carnotite-bearing ores, the Monticello mill site was chosen for its central location relative to the carnotite mines of the Colorado plateau and its abundant water supply (the site straddles Montezuma Creek).[4] Prized for its use in armor plate steel, vanadium was one of the many strategic materials whose production and stockpiling was aided by the War Production Board and Defense Plant Corporation. Soon after construction, the mill was treating more than 100 tons of carnotite ore and yielding 3,000 pounds of finished vanadium concentrates daily.

> By weaving together technical data and local history in communicating about risks, health agencies can provide working people some official validation for their health concerns, their sacrifices, and the shared memories of their lives at work.



In 1943 the mill began producing uranium-vanadium sludges for the Manhattan Project. The war years were followed by a period of inactivity (1946–48), during which time ownership of the mill passed from the War Assets Administration to the AEC. Discovery of several new deposits of uranium on the Colorado Plateau in 1946 set the stage for a renewed boom. In 1948 the AEC announced an ore-buying program, offering to purchase yellowcake (uranium oxide) at $7.14 per pound, a nearly tenfold increase over the 77 cents per pound paid during World War II.[5] The following year, the Galligher Company entered into a contract with the AEC to renovate and operate the Monticello mill for the production of uranium.

Government ownership made the Monticello mill unique among the ten or so postwar uranium mills of the Colorado Plateau, the rest of which remained in private hands. While operators of other mills received the per-pound price for uranium, the Galligher Company was "paid for the costs of their operation of the mill and related facilities, plus negotiated fixed fees to compensate them for their managerial efforts."[6] The National Lead Company took over operation of the Monticello mill in 1956. Production of yellowcake, which had averaged 200,000 pounds per year under the previous owner, increased to an average of 600,000 pounds. Daily capacity reached 600 tons of ore per day in 1957. However, the National Lead Company appears to have entered the uranium business at its peak. By 1960 the price of yellowcake dropped to $8.75 and the mill was closed down. An ore-buying station, under separate management, continued to operate in Monticello until 1962, when the AEC announced major revisions in its program.

Overall employment in the uranium milling industry reached 3,000 workers[7] around the time that production peaked.[8] In 1957, 214 workers were employed at the Monticello mill.[9] The most significant process change occurred in 1955 with the advent of the acid-leach resin-in-pulp extraction process, an ion exchange technique. The new method obviated the need for salt roasting of the ore, previously a major source of metallic and corrosive fumes,[10,11] and reduced the dependence on hand labor in the packing of yellowcake, also a serious occupational hazard. Yet, as described below, a number of other steps in the processing of ore posed serious occupational and environmental hazards for as long as the mill was operating.

Uranium Mill Worker Studies

While the exposures and health experience of uranium miners have been studied extensively, health risks to uranium mill workers have received relatively little attention. The available analytical epidemiologic studies of uranium mill workers have found small excesses of deaths due to lymphatic and hematopoietic cancers (other than leukemia), renal disease, and nonmalignant respiratory disease not likely to be due to smoking.[12] The finding of lymphatic cancer in mill workers[13] seems biologically plausible in light of the tendencies for the radionuclides present in uranium ore to concentrate in bone[14,15] and in the reticuloendothelial system.[16] Retired crushing house workers have been found to have higher levels of urinary thorium and fecal uranium and

An advertisement in a newspaper supplement, c. 1957, heralds the economic boom in uranium mining on the Colorado Plateau.

As a result of recent federal initiatives to bring a new "openness" to health concerns related to Department of Energy facilities,[21] previously classified or little-circulated reports of evaluations of uranium mills dating back to the 1940s are now becoming available. The Monticello mill and some area mines were included in several of these evaluations. Overall, these historical studies provide an important documentary record of working conditions and health problems in the very industry, during the very time period, that is of concern to Monticello residents. Useful insights can be gleaned from these reports regarding the magnitude of past exposures, temporality of exposure and outcomes, and the historical context of mill workers' experiences. Utilizing such data has the potential to make the PHA a more responsive, scientifically defensible instrument of public health practice.

Pursuant to the terms of a Cooperative Agreement with ATSDR, the author endeavored to respond to the health concerns expressed by mill workers at the December 1993 public availability sessions, in part by assembling and synthesizing the available documentation of past working conditions. An extensive literature search, using the resources delineated in the Table, yielded several industrial hygiene evaluations of the Monticello mill or health studies that included Monticello workers, only two of which had been published in the peer-reviewed literature.

In the ensuing sections this paper will review former mill workers' contemporary health concerns in light of the historical record.

thorium than community controls,[17] but whole-body counting has been unavailing.[7,18] From the standpoint of chemical toxicity, exposure to uranium may explain the excesses of renal disease[13] and renal toxicity[19] that have been reported among mill worker populations. Whether the absence of elevated rates of lung cancer will persist in the wake of the more than 30 years that have elapsed since the peak of uranium milling in the United States is one of the intriguing questions that will hopefully be answered by an update of the NIOSH cohort study, now getting underway with funding from the U.S. Army. The answer could have legal ramifications in the realm of victim compensation,[20] an issue not far from the minds of former Monticello workers, who, unlike uranium miners, are not yet covered by the Radiation Exposure Compensation Act.

Chronic Lung Disease. Wolf's seminal observations, contained in a memo to the director of the AEC's Colorado Raw Materials Area,[22] drew attention to three respiratory hazards facing uranium mill workers. First, Wolf described workers' accounts of "vanadium hack," a short-term irritation of the upper respiratory tract, and raised questions about the possibility of chronic lung damage, questions which could only be answered by further field studies. Second, the memo revealed serious problems with control of silica dust. A lack of ventilation on crushers, screens, and elevators was noted at all three mills visited, including Monticello. Settled dust—as thick as one to three inches on rafters, floors, catwalks, and stairs—was found to contain 41% to 49% free silica. Third, exposure to radioactive dust was termed "excessive" in areas of the mills handling dry uranium products. Pre-employment and periodic medical exams, including chest x-rays, were among the 14 recommendations proffered.

Subsequent field surveys by U.S. Public Health Service personnel elaborated on the themes of vanadium hack, silica dust, and respirable radioactivity. Holaday's 1951 "Progress Report"[10] describes a green coating on the mucous membranes of the mouth and throat of workers affected by upper respiratory tract irritation and cough in association with vanadium fume, particularly among workers around the fusion furnaces. Subsequently, several cases of respiratory illness discovered in medical exams were "attributed to long-term exposures to relative low concentrations of vanadium compounds."[23] Preliminary findings with respect to silicosis were more portentous. Among whites, 26.5% of millers and 13.8% of miners were found to have evidence of pulmonary fibrosis, compared to 7.5% of "controls"; precisely who served as controls was not specified. For American Indians, the corresponding figures were 20% and 13.2%, with no fibrosis seen in controls. Ten "definite cases" of silicosis were noted among "workers," all of whom were said to have had a history of hard rock mining, thus leaving doubt as to whether mill work alone would be sufficient to cause silicosis. The authors were unequivocal, however, in their calls for improved ventilation in specific operations and for annual medical exams.

The paper by Miller and coworkers[11] represents the first peer-reviewed scientific paper by the U.S. Public Health Service team of investigators. In it they reiterated the finding of chronic irritation among vanadium-exposed workers in the vicinity of the fusion furnace—one of the last stages in processing the final product—which was also noted to be a source of uranium fume. Considerable emphasis was placed on industrial hygiene controls.

In 1959, Kusnetz submitted a "Review of Environmental Health Studies in Uranium Mills" to the Congressional Joint Committee on Atomic Energy.[24] This report summarized the industrial hygiene data collected since 1950 by the U.S. Public Health Service and presented comparisons to the Threshold Limit Values (TLVs) in effect at the time. An

Table. Industrial hygiene and occupational health evaluations of the Monticello Mill

Author(s) Institution	Years of Field Work (or follow-up)	# of Mills Represented	# Mines Represented	How Discovered	How Obtained
Wolf (1948) Atomic Energy Commission	1948	4	1	Footnote in Eichstaedt (1994)	ACHRE
Holaday et al. (1951) USPHS	1950–1	6	60	Footnote in Eichstaedt (1994)	ACHRE
Holaday et al. (1952) USPHS	1950–2	8	50	Footnote in Eichstaedt (1994)	ACHRE
Miller et al. (1956)* USPHS	1950–3	8	147**	Search of Older Toxline	Library
Industrial Hygiene Branch (1958) Atomic Energy Commission	1957	1 (Monticello only)	—	Generic description in Beverly and MacArthur (1958)	New York Operations Office, Environmental Measurements Lab
Beverly and McArthur (1958) National Lead Co.	1958	1 (Monticello only)	—	Footnote in Archer et al. (1973)	DOE-Germantown Library
Harris et al. (1959) Atomic Energy Comm.	1957	12	—	Search of Older Toxline	Library
Kusnetz (1957) USPHS	1950–9	12 operating (9 under construction)	—	Footnote in Archer et al. (1962)	Congressional committee hearing document

*The mill work portion of this study is essentially the same as Holaday et al. (1952). But here it is published in the peer-reviewed literature, with a more extensive write-up on the mines.

**Includes two Monticello mines which were found to have a median concentration of radon daughters of 950 picocuries per liter (range: 15 to 1,900). This placed them in about the 40th percentile among mines surveyed in 1952.

estimated 46% of dust samples in the crushing areas and 38% of the millwide samples were above the estimated threshold limit for silica. A fifth of these exceedances were more than *20 times* the TLV. Similarly, 36% of airborne vanadium samples were above the TLV. While these data do not allow inferences to be drawn about specific mill sites, they do provide an overall picture of serious respiratory hazards to uranium mill workers during the 1950s.

Two air samples for silica dust were collected from the Monticello mill in 1957, one in the ore sample room and one in the crusher room.[9] They showed a free silica content of 32% to 35%. Air concentrations were four to four and one-half times the maximum allowable concentration of 20 million particles per cubic foot. According to Kusnetz's industrywide data, these samples place the crusher room of the Monticello mill in the top quartile of the industry for dustiness.

Translating...industrial hygiene data into meaningful statements about risk of chronic disease will be a challenging but unavoidable task.

Cancer. Wolf[22] accurately identified crushing houses as perhaps the one area of uranium milling operations where there was potential exposure to radon gas. He also recommended that later studies look at exposure to radioactive mists due to agitation of tanks with steam, a conjecture which appears never to have been substantiated. The possibility that residual radium at various stages of ore processing was contributing to workers' radiation dosages was also mentioned, but not resolved. Yet another potential source of radiation exposure was contact of workers' hands with beta-gamma radiation during handling of finished product, which Wolf felt could be addressed by the use of leather gloves. Although Holaday[10] did not immediately measure mill worker exposure to radioactivity, he felt that internal radiation had to be considered because "dust control in the mills was not too effective." By 1957, Kusnetz's[24] summary of industrial hygiene samples for the industry as a whole showed 20% of airborne uranium and 40% of airborne radium samples to be above the respective threshold limit values. Likewise, a survey of 12 uranium mills conducted by the AEC's Health and Safety Laboratory in New York estimated that between one-fourth and one-third of workers were exposed to airborne radioactive dust above the AEC's maximum permissible concentration (MPC) of 5×10^{-11} μCi/ml for alpha radiation.[3]

The Monticello mill was no exception. The AEC's unpublished industrial hygiene report for the Monticello mill found 40% (86) of the total plant population (*N*=214) to be exposed to radioactive dust above the MPC in April-May 1957.[9] Nineteen workers were exposed to concentrations of radioactive dust more than five times the standard. Time-weighted average exposures are listed in the report for 55 job descriptions at the mill. A follow-up industrial hygiene survey of the Monticello mill performed by National Lead Company in 1958 found considerable reductions in worker exposures throughout the mill.[25] Yet levels of airborne radioactive dust exceeding the MPC by 2- to 78-fold were obtained in the following areas of the plant: ore sample plant, sample preparation area, crushing area, and yellowcake drying area. Exposure to external radiation was highest in areas where yellowcake was handled.

The effort to develop a biological index of mill worker exposure focused on uranium in urine. Holaday and coworkers[23] found low levels of vanadium and uranium in urine samples. At the Monticello mill in 1958 workers in some dusty areas were found to have elevated urinary levels of uranium,[25] but the results were highly variable among individuals with similar external exposures. Similarly, considerable scatter is evident in the data collected by Harris and coworkers on 33 workers at seven mills.[3] Despite this interindividual variability, longitudinal data collected on individuals and periodic spot checks of workers employed in similar tasks appear to have served as a surveillance system at the Monticello mill.[25] The finding of more than 0.05 mg U/L triggered industrial hygiene investigations into possible sources of exposure. It was not until 1964 that the complex (triphasic), time-dependent pharmacokinetics of uranium were sufficiently well characterized to allow meaningful interpretation of urine samples.[26] The data collected at Monticello are probably of little use in estimating long-term individual risk since removal from exposure for one to two weeks is necessary in order to use urinary concentrations of uranium to reliably estimate chronic exposures. Lippman and coworkers[26] favored air monitoring over biological monitoring as a means of characterizing individual exposures. Contemporary studies offer little persuasive evidence that either air or urine monitoring serves as a reliable proxy of individual dose to the lung.[27] It does appear, however, that urinary uranium levels might serve as a useful index of population doses.[19,28]

Loss of Teeth. Holaday and coworkers[23] noted that among the 913 white miners and millers studied, "edentulous persons were slightly younger than those previously studied in other parts of the country," but no actual data are presented. No further mention of this problem was found in the literature. However, two research groups have noted potential hazards associated with the handling of acids, alkalis, and other chemicals employed in milling operations.[3,11] Some of these materials have been found to affect dentition in other industrial settings.[29]

Household Contact via Laundry. While none of the early investigators of uranium mill hazards specifically mentioned family household contact, they were virtually unanimous in recommending frequent changes of work clothes and the availability of on-site laundry facilities, locker rooms, and showers in order to minimize the hazards to workers of external radiation and vanadium dust.

Lack of Ventilation, Housekeeping, and Respirators. Beginning with the earliest investigations of Wolf[22] and Holaday,[10] several themes are apparent in the recommendations of federal health officials:

- Dry operations, including the handling of finished product, were associated with the highest exposures.
- Local exhaust ventilation, if made available, could bring under control many of the hazards in the dustiest operations.
- Better housekeeping was needed to reduce dust throughout the plants.
- Vacuuming should replace dry sweeping and compressed air for clean-up.
- Respirators may be useful as an interim measure, until engineering controls are instituted, or in transient high-exposure situations.

AEC regulations allowed mill operators to seek approval for the use of respirator efficiency factors and particle size factors in establishing site-specific TLVs more lenient than those generally applicable in industry as a whole.[30] Whether the AEC granted such variances to its own mill in Monticello is not known.

By the end of the 1950s, a large database had accumulated on worker exposure to airborne contaminants in the uranium milling industry.[24] The crushing area of the mill was most frequently associated with excessive airborne concentrations of silica, radium, and vanadium. In the final product area of the mill, uranium exposures were especially problematic, but vanadium could also pose a hazard. That many of the hazards could be controlled was "evident from conditions in individual areas of several of the plants where rigid engineering controls have been instituted." Miller and coworkers[11] were even more sanguine about the prospects for controls: "there are no health hazards in the mills which cannot be controlled by accepted industrial hygiene methods."

Checklist of Resources for Documenting Historical Releases and Exposures from DOE Sites

These resources are organized by the expense of accessing the data. In this era of shrinking budgets and expanding information technologies, on-line resources and local libraries should be exhausted before costlier options are pursued. A wealth of information is becoming available on the Internet, for example.

Locally Available Resources

DOE Office of Human Radiation Experiment's Home Page at <http://www.ohre.doe.gov/>.

DOE Office of Scientific and Technical Information's Dialog Database.

Collections of AEC-era microtext reports at selected energy and educational institutions.

Older Toxline (1965–present).

Applied Science and Technology Index.

Nuclear Science Abstracts.

Site-specific environmental surveillance reports (available retrospectively from NTIS).

Catalogues of neighboring energy and educational institutions' libraries—Internet and G.K. Hall publications (e.g., for Los Alamos, check Sandia, Lovelace, Kirtland, and DOE Abq. HQ-West).

Multisite Information Resources

DOE Coordination and Information Center, Las Vegas, Nevada (DOE clearinghouse of declassified documents; searchable via OpenNet at <http://www.doe.gov/html/osti/opennet/opennet1.html>.

Southwest Radiological Health Laboratory, USPHS, Albuquerque, NM.

DOE Environmental Measurements Laboratory, New York, NY (formerly AEC Health and Safety Laboratory).

Advisory Committee on Human Radiation Experiments, Washington, DC (soon to be searchable at <http://www.seas.gwu.edu/nsarchive/radiation/>.

Site-Specific Libraries and Archives

Community environmental reading room (usually DOE-operated).

Main library at facility; health library at facility.

Archival series listed in *Human Radiation Experiments: The Department of Energy Roadmap to the Story and the Records* (DOE, 1995).

Neighboring energy and educational institutions' libraries.

Beverly and MacArthur[25] recommended major equipment improvements for the Monticello mill, including new dust collectors for the plant crusher building and yellowcake drying and drumming area. These authors, industrial hygienists working for National Lead Company, echoed federal reports in recommending adherence to the so-called hierarchy of controls that is central to their craft:

> "[R]espirators are not considered as protective measures in lieu of permanent and adequate preventative and control measures required for successful suppression of radioactive dust."

Even more comprehensive and rigorous were the recommendations put forward by Harris of the AEC's Health and Safety Laboratory,[3] whose walk-through evaluations of all 12 operating mills turned up new opportunities for dust suppression such as wetting down ore bins and sheds; hooding and ventilating ore transfer points; eliminating open-tray drying and screening operations; and isolating bucking rooms, drying, and packaging areas from the plant proper.

> As was common in Western mill towns, substantial quantities of tailings were used off-site in a variety of construction applications, and tailings dust was reported to have been frequently carried by the wind over residential and commercial districts of town.

Outside the Mill. The disciplinary boundaries between environmental health and industrial hygiene that we presently take for granted had not yet been established or simply did not constrain the health officials who investigated uranium mills in this era. Evidently, some of the environmental problems around uranium mills were hard to miss. Wolf[22] reported that the problems at the four mills he visited were "primarily occupational, although some attention should be directed towards the matter of control over waste materials and the spread of radioactive dusts to areas adjacent to the mills." At the mill in Naturita, Colorado, an estimated 20 tons of yellowcake had been lost via air emissions, imparting a yellow hue to the countryside for "a half mile or so" and resulting in alpha counts of 300 to 500 dpm per 100 cm^2. The AEC's guideline for workplace contamination was 70 dpm. Workers and their families likely had greater nonoccupational exposures to the whole array of mill contaminants than did other residents, by virtue of the proximity of mill worker housing to the mill.

In their report on conditions at 12 operating mills, Harris and coworkers[3] recommended installing bag houses for dust collection, connecting all exhaust systems to air-cleaning equipment, excluding the general public from tailings heaps by use of fencing, and limiting the discharge of solid wastes to local ground waters. They also recommended a more extensive study of surface water contamination by radium, which previous studies[31] had indicated was present in liquid effluents from uranium mills at concentrations far in excess of permissible levels. River muds taken from below the Monticello mill in 1955 were found to have alpha, beta, and gamma counts two to three orders of magnitude above background.

In 1959, operating costs for the disposal of Monticello mill tailings were estimated as $0.64 per ton of ore processed.[32] For its part, National Lead Company undertook a series of investigations on the mass balance and fate of radium in mill throughputs.[33–35] These investigations appear to have been directed at removing radium (and hence much of the radioactivity) from mill waste streams. But the mill closed in 1960 before any discernible engineering changes were instituted. Meanwhile, in response to pressure from the public and the news media regarding drinking water contamination downstream from a mill in Farmington, New Mexico,[36] the AEC and the U.S. Public Health Service began to commit significant resources to characterizing mill tailings and effluent streams.[37,38] Inasmuch as most of these investigations took place at other sites, they are beyond the scope of this report.

Conclusions

A unique and valuable resource for evaluating health risks exists at government-owned energy facilities in the form of extensive historical documentation of exposures and releases. Facilities at all stages of the atomic fuel cycle were the subject of numerous industrial hygiene, occupational health, and environmental assessments during the Cold War period. Whereas contributors to the open scientific literature during the Cold War era seem to have taken pains to conceal the identities of the specific facilities they studied,[3,39,40] the official memos, industrial hygiene reports, and government health studies reviewed for this paper are explicit in their inclusion of the Monticello mill and hence are of greatest relevance to the health concerns raised by former Monticello uranium mill workers at public meetings in 1993. These data may be useful for a variety of purposes, including exposure assessment, risk communication, and social healing.

Exposure Assessment. One serious limitation of the available data on Monticello is the lack of individual monitoring for nonradioactive materials. Other carcinogenic elements, such as arsenic, were present in concentrations that may have varied with the source of the ore and quite possibly varied in time at the mill, depending upon which mine's ore was being milled. Another nonradioactive contaminant is silica dust, whose potential contribution to lung cancer risk in workers exposed to inhaled radionuclides is controversial.[41] Silica may be more important for uranium mill workers than has heretofore been demonstrated for uranium miners.[42] In contrast to miners whose exposures were confined to certain dusty operations (dry drilling, mucking, and blasting), certain mill workers would have been continually exposed to silica dust. Kusnetz's[24] summary presentation of silica concentrations for the uranium milling industry as a whole offers hope that the diasaggregated data, by mill site and by work area, may be archived somewhere.

A further limitation of the available data is the scanty basis for estimating internal dose; *in vivo* chest counts do not appear to be widely available, and gross specimens are few in number. Modelling of internal doses of radionuclides to the lungs of mill workers would require numerous assumptions regarding respirator usage; breathing rates; the prevalence of lung disease and its effect on clearance parameters; and estimation of exposures for certain jobs where actual data are lacking.[43] Despite these limitations, it would appear that the four criteria proposed by Smith[44] for the use of such modelling in epidemiologic studies are satisfied, or very nearly so: causal agents are present, exposure intensities vary markedly in time and space, and pharmacokinetic models are indeed available.[45] A fourth criterion, that risk vary with the time profile of tissue concentration, is the fundamental tenet of standard setting for internally deposited radioncuclides, whose effective half-lives are a function of biological clearance and physical decay. An exercise in modelling uranium mill workers' internal doses would be beyond the scope of the PHA, but perhaps a fruitful contribution to the cohort study. A cooperative arrangement with the suriving uranium mill workers might result in the sharing of much valuable information.

> A number of...steps in the processing of ore posed serious occupational and environmental hazards.

Risk Communication. Sometime in the next few months, this historical information will be shared with community residents in a follow-up public meeting. Translating the industrial hygiene data into meaningful statements about risk of chronic disease will be a challenging but unavoidable task. Such statements, properly and honestly couched in terms of the limitations of scientific methods, may serve an interim function until the NIOSH cohort study of uranium mill workers has been completed. On an individual level, former mill workers will be given an opportunity to view the industrial hygiene monitoring conducted at Monticello, down to the level of work area and job description, and may thus gain some insight into their past exposures. Trade journal and popular magazine articles from the era in which the mill was operating contain photographs depicting specific operations at Monticello, including several for which historical industrial hygiene data are available. An understandale, lay-oriented presentation is currently under development,[46] which uses a template of the mill's physical layout to illustrate the accretion of exposure data over time.

Social Healing. A long legacy of distrust between citizens and government has grown up around facilities that produced weapons and materials during the Cold War era.[47] Dawson found "contempt for the government and the companies" among Navajo uranium mill workers and their families[48] and a widespread belief among Anglo and Navajo uranium mill workers employed prior to 1970 that they were not informed about the hazards of radiation.[49] Historical documentation of working conditions at the Monticello mill has only become generally available as a result of recent changes intended to replace decades of official secrecy with a policy of "openness." A strong reaction on the part of former mill workers and their survivors viewing the available historical exposure data for the first time would hardly be surprising. The ethical solecism of conducting epidemiologic studies of uranium miners without worker notification or aggressive intervention is widely regarded as a taint on the record of the American public health establishment. [5,50–52] Likewise, the President's Advisory Committee on Human Radiation Experiments reached stern judgments regarding the lack of worker notification or other timely interventions by the AEC and Public Health Service in the health studies of uranium miners. A footnote refers to the problems of uranium mill workers, correctly noting their exclusion from the Radiation Exposure Compensation Act.[53] It will be interesting to contrast the former mill workers' (or their survivors') perceptions of this ethical issue with the conclusions of this prestigious panel.

An important lesson for contemporary public health servants who interact with citizens who live around sites in the nuclear weapons complex may be found in the words of Willard Wirtz, Secretary of Labor in the Johnson Administration. Testifying before Congress in 1967, Wirtz recounted how hazards to underground uranium miners managed to escape effective federal intervention for more than two decades:

"The record reflects continuing attention by a variety of State and Federal agencies—including the Department of Labor—to both the standards and the inspection problems in connection with uranium mining. It is a record, nevertheless, of literally hundreds of efforts, studies, meetings, conferences, and telephone calls—each of them leading only to another—most of them containing a sufficient reason for not doing anything then—but adding up over a period of years to totally unjustifiable 'lack of consummative action.'"[54]

The ATSDR public health assessment of the AEC's own uranium mill in Monticello, Utah, offers an opportunity to tack a hopeful footnote onto this dark chapter in public health history. On a collective level, by sharing long-archived documentation of worker and community exposures with uranium mill communities, the PHA has an opportunity to vitalize the process of risk communication by acknowledging to the former mill workers of the Colorado Plateau, in effect: "We hear you. You're not crazy. There's a great deal of truth to what you say happened." On a broader plane, the fact that this inquiry was undertaken in response to health concerns expressed at public meetings should be instructive in showing how government health agencies can turn potentially divisive encounters with citizens into edifying, constructive experiences. By weaving together technical data and local history in communicating about risks, health agencies can provide working people some official validation for their health concerns, their sacrifices, and the shared memories of their lives at work. Health agencies that adopt such an approach may gain a new respect in the eyes of communities impacted by toxic and radioactive contamination, particularly among citizens who spent their working lives in the nation's defense industries.

A complete reckoning of the environmental and occupational health impact of weapons production during the Cold War era is only now becoming possible, due in large part to the public release of previously classified, or little circulated, evidence of past exposures. Department of Energy sites invite novel uses of historical records, including the evaluation of and response to community concerns. These are not substitutes for, but adjuncts to, the use of historical records in a phased evaluation of the need, desirability, and feasibility follow-up interventions and activities. The checklist of information resources shown in the Sidebar suggests several starting points for locating such records. If the magnitude of historical exposures in uranium mills is at all indicative of other parts of the weapons complex, practitioners must be prepared to disabuse themselves of nostalgia for the "good ole days."

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