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OBSERVATIONAL STUDIES AS HUMAN EXPERIMENTATION: THE URANIUM MINING EXPERIENCE IN THE NAVAJO NATION (1947-66)

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ABSTRACT

This article evaluates how an observational epidemiologic study of federal agencies in uranium miners became an experiment of opportunity for radiation effects. Navajo miners and communities suffered environmental exposures caused by the practices of uranium mining and milling in the Navajo reservation during the 1947 to 1966 period. A historical review of the state-of-the-art knowledge of the health effects of uranium mining and milling during the years prior to 1947 was conducted. Contemporary prevention and remediation practices also were assessed. An appraisal of the summary of findings of a comprehensive evaluation of radiation human experimentation conducted by the U.S. federal government in 1995-96 (ACHRE) demonstrates that uranium miners, including Navajo miners, were the single group that was put more seriously at risk of harm from radiation exposures, with inadequate disclosure and often with fatal consequences. Uranium miners were unwilling and unaware victims of human experimentation to evaluate the health effects of radiation. The failure of the State and U.S. Governments to issue regulations or demand installation of known mine-dust exposure control measures caused widespread environmental damage in the Navajo Nation.

BACKGROUND

Navajos and Uranium Mining

In 1998 the Uranium Radiation victims Committee (URvC), an organization from the Navajo Nation, reported that in the period between 1947 and 1966, there were 2,450 registered Navajo uranium miners who worked at any time on reservation land. Of those, 412 have died of various causes, including lung cancer [1]. URvC assembled this data to provide information to former miners or their surviving families to be considered for compensation under the Federal Radiation Exposure Compensation Act of 1990. This act provides monetary compensation to miners who were exposed to radiation greater than 100 WLM (Working Level Months, a unit of internal radiation exposure) and who contracted lung cancer or respiratory disease. Some Navajo miners have been able to collect compensation under the act but, in general, they complain of the impossibility of documenting exposures that took place more than thirty years ago [2]. How did it come about that thousands of Navajos were exposed to radiation during uranium mining? What did the U.S. government know about the consequences of exposure to the uranium mining environment? What did the mining companies and the government do to prevent the consequences of these exposures? And finally, did the U.S. and state governments' studies of miners' exposure and mortality constitute human experimentation? This article will try to provide some answers to these questions.

The Effects of Uranium Mining

The evaluation of the state-of-the-art knowledge on occupational and environmental effects of uranium mining in this period (1947-66) permit us to conclude that the practices of uranium extraction and beneficiation allowed for widespread radiation and chemical exposures for workers and their communities, especially in the territory of the Navajo Nation. The U.S. government (Human Radiation Interagency Working Group) decided to look at the history of human experimentation in U.S.-sponsored radiation research. The Advisory Committee on Human Radiation Experiments (ACHRE) summarized the findings of radiation human experimentation in a lengthy report published in October 1995 [3]. It is remarkable that uranium mining was considered a "case study" of human experimentation where observational studies were conducted on groups of people exposed to radiation as a consequence of government-sponsored programs. This study will illustrate how, notwithstanding the secrecy of uranium production, the tragedy of Navajo uranium miners developed in the open, with the participation of at least three federal agencies (the Atomic Energy Commission (AEC); Public Health Service (PHS); and Bureau of Mines (BOM)), some of them with a clear formal degree of authority and responsibility to prevent disease and contamination. The federal agencies, specially the AEC, had the means to ensure that actions be taken to address a known risk. The U.S. government through the AEC instead chose to block any preventive action, coldly accepting the responsibility for inflicting harm in an unfolding disaster that appears to have been preventable from its onset.

URANIUM MINING AND MILLING PRACTICES IN THE NAVAJO RESERVATION (1947-1966)

Early Uranium Mining in the United States. Uranium mining in the United States developed in five chronological stages based on the uses of the metal [4].

These stages are described in Table 1. Uranium was mined and milled in the early years (until 1967) mostly in the Colorado Plateau in the U.S. Southwest [4]. The uranium-producing region included the northern and western mountains in the Navajo Nation. Mining and milling was concentrated geographically in the Four Corners Region of the Southwest. This region is defined by the common borders of the four southwestern states of New Mexico, Colorado, Utah, and Arizona. The Navajo Reservation is located in this region, with the bulk of its surface in Arizona and smaller portions in New Mexico and Utah. Uranium mining in the reservation took place from 1947 to 1966 [5].

Early uranium mining (the 1925-1945 period) was almost exclusively a manual underground operation of extracting carnotite ore (a mixture of uranium (U) and vanadium (V) oxides) [4]. From 1940 to 1945, the U.S. Army Manhattan Project stimulated uranium recovery from vanadium mining in the Navajo Nation and across the Southwest. This was a period of very low uranium production, since the interest was in mining vanadium and uranium only as a by-product. In 1942, the Metal Reserve Company (U.S. government-owned) was created for the purpose of acquiring vanadium and at the same time processing uranium from vanadium ores [4]. However, most of the uranium for the first atomic bombs came from stockpiles obtained in Africa from the Belgian Congo [4]. The uranium boom era started in earnest with the simultaneous creation of

Table 1. Phases of Uranium Mining and Milling in the United States Southwest

Period	Uses	Major Mining and Milling Operators
1871-1905	Ceramics, coloring	Two private
1905-1925	Radium (Ra) Extraction	Eight private
1925-1945	By-product of Vanadium (V) mining	Two private, one U.S. government owned metal reserve co.
1945-1967	Military and Energy Applications	U.S. Atomic Energy Commission (AEC) created, procures all U produced. Twenty-two private companies
1967-1970	Military and Energy Applications	AEC ends procurement commercial mining

Source: Modified from Reference 4.

the AEC in 1945 and the initiation of the Cold War. A summary of uranium production from the Navajo Nation appears in Figure 1 [5].

AEC Activities. The AEC, in cooperation with the U.S. Geological Survey and the U.S. Bureau of Mines, conducted mining surveys, assays, and exploratory drilling for uranium/vanadium mining prospectors and operators at no cost [4]. These subsidized activities started in 1943-1944 [4]. It is estimated that by 1948, there were 500 active uranium mines in the U.S. Southwest and as many as 2,000 active prospectors in the field [4]. As much as $2.5 million was expended in these services to uranium mining operators and prospectors in the 1943-1967 period [4].

These uranium mining and milling activities were being conducted in the Navajo Reservation by private operators subsidized by the AEC. There also was the additional advantage of a dependable buyer, since AEC would guarantee the purchase of all of the ore that the mines produced. Hundreds of mines of different sizes flourished in the Navajo territory. Uranium mills also were constructed by private companies, with AEC subsidies. Whenever a critical number of mines were in operation in different reservation sectors, the AEC would assist in building a milling facility [4]. Uranium mining production in the reservation increased

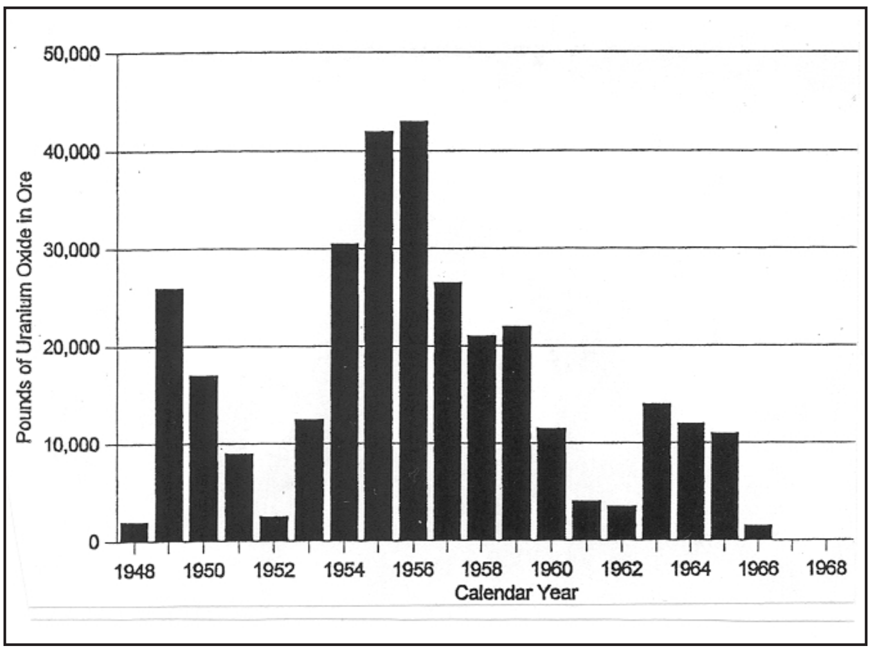

Figure 1. Uranium production in the Navajo Nation, Northern and Western Carrizo Mountains. **Source:** Modified from Reference 5.

from less than 2,000 pounds a year of uranium oxide in ore in 1947 to more than 25,000 in 1949 and higher than 40,000 pounds a year in 1955 and again in 1956, the peak production years [4]. Production in the Navajo Nation steadily declined from 1956 to 1967, when it practically stopped with the end of the AEC monopoly on ore buying [5].

AEC and PHS Partnership. A look at the historical record of uranium mining shows that AEC and PHS, the two federal agencies with the knowledge and regulatory power to protect miners, failed to inform miners of the known hazards; permitted uncontrolled radiation exposure; and performed scientific studies without obtaining participants' informed consent. As described below, the historical record of lung cancer and uranium mining from Europe (the German and Czech experiences) was concealed. A scientist from the National Cancer Institute (NCI), W. C. Hauper, who in 1942 reported the cause-effect relationship between uranium mining and lung cancer, was repressed by the NCI and his professional activities curtailed under pressure from the AEC [3]. The AEC considered any references to occupational cancer and uranium mining to be "not in the public interest" [3]. The AEC's urgency to produce an uninterrupted flow of uranium for weapons created an atmosphere of fear that made advocacy for protective exposure standards an unpatriotic act.

The AEC deceptively insisted that there were no data on miners' lung cancer at the time (1947-1960); therefore, there was no justification for an occupational standard [3].

The PHS, to its credit, decided to study the impact of uranium mining as early as 1948. However, the PHS entered into a verbal agreement with the mine operators not to inform the miners of any study findings in order to secure entrance into the mines to perform air sampling and medical surveillance [3]. Although one PHS representative claimed those agreements were routine procedure at the time [3], it is clear that the miners were neither informed of the hazards nor consented to take the high risk associated with radiation exposure. Even in its publications to uranium miners (which were only in English), the PHS never discussed the potential risks. Instead, it tells the miners that ". . . scientists are working to find the level of radon (and daughter) that you can be exposed to safely . . ." [3].

The Radiation Hazards of Mining and Milling

Uranium Mining and Milling. Reports of early uranium mining in the United States describe mining until 1940 as a manual operation. When demand for the metal increased after 1941, small mining equipment was introduced (five- to ten-ton mining machinery) for underground and open pit operations [6]. This type of equipment was used in the Navajo Nation, as photographs of the period show [2].

Underground mining takes place whenever ore bodies are detected at depths of more than 200-300 feet. Concentrations of uranium oxide in the ore ranged from 0.50 percent to 0.01 percent. However, in unusual situations, the uranium percentage of some rich ores can range from 3-10 percent [7]. The constituents of typical U.S ores appear to be discussed by PHS in a 1974 publication [8].

The underground method of mining starts with the construction of a main vertical shaft equipped with a hoist. When the ore body is identified and mining starts, the hoist is the means for moving workers and materials underground. One or more of these hoists will be built to transport the ore to the surface. Horizontal tunnels reach out from the main shaft to the ore bodies. The ore is drilled, blasted, and moved by mechanical means to the tunnels, where it is transported into ore car trains [6]. Open pit mining or surface mining takes place when the ore deposits are within 200-300 feet of the surface.

Open pit mining follows a similar sequence as underground mining: drilling, blasting, and moving, but with different bigger drilling machines and with bulldozers to move the ore to diesel trucks. All operations take place on the surface with no underground activities. Grading and road building are also part of the open pit mining process.

Uranium milling processes start with the crushing of the rock, followed by acid or alkali leaching (a solvent extraction process) of the powdered ore. Uranium is purified and concentrated as a soluble salt of U_{308}. After drying, washing, and removing impurities by roasting, the final product is a yellow dust identified as yellow cake. Yellow cake is packed in fifty-five-gallon drums for shipment [7]. About four pounds of yellow cake are extracted from a ton of uranium ore [6].

The Radiation Occupational Health Effects of Mining and Milling

Mining. Inhalation of uranium ore dust from blasting, crushing, and mechanical handling has been known to expose underground miners to significantly high doses of radiation [6]. Radon is continuously emitted into open underground areas of the mine from surrounding rock and broken ore [6]. Since radon is highly soluble in water, it also could be carried in the mining environment by ground water [6]. External radiation from gamma rays and internal radiation from radioactive aerosols generated during the mining process are the sources of radiation exposure. Internal exposures are created by inhaled radionuclides that undergo radioactive transformations in the body, emitting alpha and beta particles and gamma rays [6]. Bronchogenic cancer is caused by inhalation exposure to radon and radon progeny, the most common of the radioactive products of the decay of uranium [3]. The main effort to evaluate radiation risk in uranium mines has been directed toward measurement of short-lived alpha particles generated by the decay of radon and its progeny [8]. Other longlived alpha emitters in the mining atmospheres of hygienic interest have also been identified. They are three uranium isotopes (U_{238}, U_{235}, and U_{233}), thorium, and polonium.

Work in underground uranium mines has been associated with bronchogenic cancer in miners since the last part of the nineteenth century [3]. This association was reported in the United States by Hueper of the NCI as early as 1942 [9]. Early PHS studies also confirmed excess cancer deaths among uranium miners [10]. "The first reports were published in the scientific literature in 1963 [11]. However, the PHS initiated a series of publications on cancer and uranium mining starting in 1949 and continued until the 1980s [11]. The PHS recognized radon concentrations . . . in the mines . . . high enough to cause injuries to the miners as early as 1949" (reference 49 in [3]). Recommendations for mining operation controls of radon were made by the PHS as early as 1950 (reference 47 in [3]). This was done even before the connection between radon progeny and bronchogenic cancer was fully established in 1951.

The risks of cancer and other chronic diseases in uranium miners associated with radiation exposure are summarized in a continuing PHS study. Results of the study in 1977 reflect the status of the uranium miner cohort followed since 1949 [11]. Cancer of all sites was found in uranium miners at levels 2.25 times higher (SMRs) than expected in the general population. Lung cancer had the highest proportion among the cancer deaths found in the miners studied (4.85 times higher than expected). A summary of the studies used to justify a new mining standard appears in Table 2 [11]. There have been few mortality studies of Navajo uranium miners. The three discussed in the medical literature are a follow-up study of 780 miners in 1976; a lung cancer case series in 1982; and a lung cancer case control study that found extremely high relative risk for lung cancer in Navajo uranium miners (relative risk greater than 14). A summary of the studies appears in Tables 3 and 4.

Recent mortality studies of East German uranium miners have concluded that it is not only bronchogenic cancer that is found in excess among miners. Preliminary studies have concluded that the observed cancer of the mouth, pharynx, and larynx has a probability of causation of 50 percent from a year of work in an underground uranium mine (WISMUT). For bone and connective tissue cancers, the same probability is found after four to eight years of underground work. Leukemia, liver, and kidney cancer had a probability of causation between 25 percent and 50 percent after more than eight years of underground work, according to this study [12].

Milling. The uranium milling operations expose workers to uranium isotopes (gamma and alpha emitters) and to radioactive isotopes of thorium, radium, and lead [13]. Internal organ exposure is the principal concern. Lung and lymph nodes concentrate radioactive uranium and thorium [13]. Excesses of lung cancer and lymphatic cancer were found by studies in 1973 [13]. Only two other studies of uranium mill workers appear in the literature, the last published in 1983 [3]. Millers and open-pit uranium miners associate numerous health problems with their occupational exposures [3].

Table 2. Five Primaray Mortality Studies Used by NIOSH to Establish Radon Progeny Mining Standard

Epidemiologic Studies	References	Mean Dose (Cumulative WLM)	Person-Years (PY)	Lung Cancer Deaths		
				OBS	EXP	SMR[a]
U.S. Uranium Miners	[14]	821 (median = 430)	62,556	185.0	38.4	482
Czechoslovakian[b] Uranium Miners	[22] [23]	289	56,955	211.8	42.7	496
Ontario Uranium Miners	[3]	40-90[c]	202,795[c]	82[c]	56.9[c]	144
Swedish Iron Miners	[5]	81.4[d]	24,083[d]	50	12.8[d]	390[d]
Newfoundland Fluorspar Miners	[10]	—[e]	37,730[e]	104	24.38[e]	427[e]

[a] $p < 0.05$, *P*-values were unspecified by Mueller et al. [3], Radford and St. Clair Renard [5], and Morrison et al. [10]. They were estimated from the observed lung cancer deaths and the Poisson frequency distribution.

[b] Based on the subcohort of uranium miners who started mining 1948-52, "group A" miners.

[c] Uranium miners with no prior gold mining experience. It is unclear from the article [3] whether the authors lagged the dose to calculate cumulative exposures.

[d] PY for the first ten years after start of mining were excluded; expected deaths were also adjusted for smoking status. Dose was lagged by five years.

[e] Includes PY for surface, as well as underground, miners. Radon progeny exposure levels were recently reestimated [10]. PY for the first ten years after start of mining were excluded in the calculation of expected deaths and PY.

Table 3. Summary of Navajo Uranium Miners Early Epidemiological Studies

Type Study (Year)	Number	Results (Lung Cancer)	Reference
Follow-Up (1948-74) Miners	780	O/E = 11/2.6	Archer, ANYAS, 1976
Lung Cancer Case Series (1965-79)	17	16 uranium miners	Gottlieb, Chest, 1982

Table 4. Lung Cancer Case Control Study of Navajo Uranium Miners

Type of Study (Years)	Cases and Controls	Ever Mined Uranium	Remarks
Lung Cancer Case Control (1969-81)	32 (Primary Lung Cancer)	23 (Uranium Miners)	RR = Infinity Smoking: (8) no smoking (15) 1-3 cig/day Avg)
	64 (Control Other Cancer)	0 (No Uranium Miners)	

Source: Samet et al., Uranium Mining and Lung Cancer in Navajo Men, *New England Journal of Medicine, 310,* p. 23, 1984.

The Radiation Environmental Health Effects

Mining and milling operations have been known to release radiation to the general environment [7]. The principal sources of radioactive dust are tailings generated during uranium mining and milling operations. This includes dust particles contaminated with solid radon daughters (progeny) (internal radiation potential) and other long-lived radon decay sources. Particles of dust from tailings settle relatively quickly and only affect people near uranium facilities [7]. However, this radiation contamination also could be distributed over great distances depending on regional wind patterns. A 1979 report of the U.S. Health, Education and Welfare Interagency Task Force on Ionizing Radiation [8, 12] listed the potential radiation exposures from uncontained tailing piles:

1. Radon progeny exposures to the lung from inhalation (internal exposure).
2. Whole body gamma radiation from sources in pile (external exposure).
3. Deposition of radio nuclides in the body because of ingestion of contaminated food and water (internal exposure).
4. Exposure to radon daughters (progeny) and radium if tailings are used as land fill or construction materials (internal exposure).

Mining and milling operations are known to contaminate with radioactive isotopes both surface waters and ground waters on or near the production centers. The main operation that affects water quality during uranium mining is de-watering [14]. De-watering is the continuous pumping out of ground water in underground mines that allows mining operations to occur in a relatively dry environment. De-watering normally continues for years after mine production has stopped for economic reasons, in order to avoid flooding the mining underground structures. This drainage exposes mineralized rocks to non-saturated groundwater flow, so radioactive and toxic materials contained within the ore can be oxidated and dissolved, and contaminate the surface and groundwaters [8].

Surface water and groundwater in the Navajo Nation have been contaminated by mine de-watering processes from 1950 to 1980 [14]. Mine water from de-watering contained radioactivity (measured as gross-alpha from uranium and radium) between 100 and 1,000 times greater than natural runoff [14]. Unfiltered water samples from the Little Colorado River Basin showed substantial amounts of radioactivity in the Puerco and Little Colorado rivers inside the Navajo Nation. Results appear in Table 5 [14]. These measurements show that water contamination still exists in mined zones, even more than thirty years after the mining and milling operations stopped (see Cameron's data on Table 5, for example).

Table 5. Radioactive Contaminants and Dissolved Metals Levels in Unfiltered Water Sampled from the Little Colorado Water Basin in 1994—EPA Drinking Water Standard

<table>
<tr><th></th><th>Uranium activity in Suspended Sediment uCi/gm</th><th>Radon 226/228 pCi/L</th><th>Radon 220 pCi/L</th><th>Gross Alpha pCi/L</th><th>Uranium ugm/L</th></tr>
<tr><td>EPA Drinking Water Standard</td><td>—</td><td>5</td><td>300</td><td>15</td><td>20</td></tr>
<tr><td colspan="6">Locations Sampled by the U.S. Geological Survey in 1994</td></tr>
<tr><td>Zuni</td><td>2.0</td><td rowspan="8">Exceeded EPA Water Standard in 41 out of 41 Samples (100%)</td><td rowspan="8">No Water Samples for Radon were Reported</td><td rowspan="8">Exceeded EPA Water Standard in 82 out of 91 Samples (90%)</td><td rowspan="8">Exceeded EPA Water Standard in 51 out of 54 Samples (95%)</td></tr>
<tr><td>Black Creek</td><td>2.2</td></tr>
<tr><td>Manuelito[a]</td><td>1.9</td></tr>
<tr><td>Chambers[a]</td><td>2.6</td></tr>
<tr><td>Woodruff</td><td>2.5</td></tr>
<tr><td>Joseph City</td><td>2.6</td></tr>
<tr><td>Cameron[b]</td><td>3.1</td></tr>
<tr><td>Grand Falls</td><td>2.5</td></tr>
<tr><td>Church Rock Pileline Arroyo[a]</td><td>2.2</td><td>1000</td><td>—</td><td>From 1500 to 15000</td><td>—</td></tr>
</table>

[a]Recent mining activity.

[b]Mining activities thirty years ago.

Note: Unfiltered samples exceeded the Arizona standard (equal or better than EPA's) in every measured instance for: Beryllium, Lead, Chromium, Copper, Manganese, Nickel.

Source: Modified from Reference 15.

The Non-Radiation Hazards of Mining and Milling

Occupational Health Effects

In addition to radiation exposure, uranium miners are exposed to silica-containing dust and other toxic components in the ore such as vanadium, cobalt, arsenic, nickel, chromium, selenium, and in some cases, molybdenum [7, 8]. The toxicology of these metals is well known and health effects from both occupational and environmental exposures have been reported [15].

Environmental Health Effects

The non-radioactive components of uranium ores have been found in surface and groundwaters near mine and mill tailing sites [7, 14]. A 1994 study of the U.S. Geological Survey reported that unfiltered samples from the Puerco and Little Colorado rivers exceeded the Arizona standard in every measured instance for beryllium, chromium, copper, lead, manganese, and nickel [16]. Two recent studies [17, 18] have demonstrated health impacts for residents of communities affected by uranium extraction. In 1995 researchers from the University of Texas found that the inhabitants of Kerns County, Texas, who resided near uranium mining operations had a higher mean frequency of cells with chromosome aberrations and higher deletion frequency but lower dicentric frequency than the reference group, although the difference was not statistically significant. After cells were challenged by exposure to gamma rays, the target population had a significantly higher frequency of cells with chromosome aberrations and deletion frequency than the reference group. The latter observation shows abnormal DNA repair response in the target population [17]. Another study conducted in 1992 in the Navajo Nation looked at the impact of uranium mining and milling activities on the health of a Navajo community. Reproductive health indexes were evaluated in Shiprock, New Mexico, where mining and milling took place from 1940 to 1967. This study demonstrated that babies from mothers who lived near the tailings dump suffered a significant increase in birth defects by a factor of 1.83. Since no association between duration of exposure prior to birth and birth outcomes could be found, the result was viewed by the authors with caution, although it was statistically significant [18].

STATE-OF-THE-ART KNOWLEDGE OF PUBLIC HEALTH IMPACTS AND REMEDIATION (1947-1966)

State-of-the-Art Knowledge of the Hazards Created by These Practices

Occupational Health

Aerosols exposure during uranium mining was known to induce respiratory cancer in the silver and uranium miners in the Erzgebirge mountains on the border between the Czech Republic and Germany. In 1879, two researchers identified the disease as intrathoracic malignancy. They reported that about 75 percent of the miners died of lung cancer [3]. By 1932, both Germany and Czechoslovakia had declared miners' cancer a compensable occupational disease [3]. As mentioned above [9], in 1942, Hueper in the United States published a review of the literature in English concerning occupation and lung cancer. This review suggested that radon gas was implicated as the cause of lung cancer in miners [9].

A further refinement of this finding took place in 1951, when two Rochester, New York, AEC scientists were able to show that solid highly radiative particles generated during the radioactive decay of radon (radon progeny) have the ability to attach to respirable-size dust particles. If these particles are inhaled, the lung (bronchi) will be irradiated at high doses, enough to explain the high human cancer rates [3]. These findings also explained why early animal experiments using pure radon gas (without dust exposure) had failed to produce cancer in experimental animals [3].

In 1946 the PHS urged the AEC to improve conditions in mining because "our early environmental studies in American mines indicated that we have concentrations of radioactive gases considerably in excess of those that have been reported in the literature" (D. Holaday from PHS, quoted in [3]. The PHS started an environmental study of the mines from 1950 to 1956 and a parallel mortality study that is ongoing [3]. The same exhortations for controls from D. Holaday were made by M. Eisenbud, an industrial hygienist from the New York office of AEC in 1948 [3]. However, these early warnings did not generate occupational standards for radon until the trends for lung cancer deaths showed an accelerated increase of cases from 1954 to 1965 (from two cases to eighteen cases) (W. J. Bair in [19]). The first proposed limits for radon daughters were offered in 1967, coinciding with the ending that year of the uranium procurement monopoly of the AEC.

Community Environmental Health

As early as 1962 the U.S. PHS had expressed concerns about radiological contamination of the environment around uranium mines and mill operations. Two reports—Waste Guide for the Uranium Milling Industry, Technical Report W62-12 (1962) [20] and Radiological Content of the Colorado River Basin Bottom Sedimentation, Report PR-b (PHS 1963) [21]—showed the early concerns of the government about environmental contamination from uranium operations.

The collapsing of abandoned mine and mill structures designed to contain tailings of uranium production operations triggered studies of radiation contamination in drinking water [14] and radiation measurements in livestock and humans in the Navajo community. The radiation content of livestock organs showed levels as high as 100 times those of livestock that were not contaminated with uranium. However, whole body radiation measurements in Navajo community members showed what the researchers considered to be acceptable levels (personal communication with Dr. Keith Kreiss, CDC, NIOSH on NIOSH-DOE Study). German scientists who evaluated the results have challenged the methodology used to conduct the whole body radiation of the affected persons (personal communication, H. Wasserman GSF-Berich, 1995).

State-of-the-Art Knowledge of Remedial Strategies to Mitigate the Hazards of Uranium Mining and Milling Practices

Occupational Health

The PHS studies in the early 1950s included specific recommendations to improve mining conditions through ventilation [8]. These recommendations were published first in 1954 [22] in mainstream technical journals readily accessible to the uranium industry and early enough to provide the basis to improve mining conditions. The U.S. Human Radiation Interagency Working Group, which includes, among others, the departments of Energy, Defense, Justice, Health and Human Services, Central Intelligence Agency, and the National Aeronautics and Space Administration, published its evaluations of human radiation experiments through ACHRE [3]. In relation to uranium miners, ACHRE concluded that the AEC "circulated to companies engaged in the production of uranium ores . . ." the PHS reports describing the known risks in mining and milling, the growing epidemic of lung cancer among uranium miners, and the recommended practices to mitigate radiation exposure. This procedure started as early as 1952 [3]. However, no actions were taken by mine operators to prevent the exposures or the health effects reported. Neither the AEC nor any federal or state agency required the operators to improve working conditions or the environmental impact of uranium production.

The U.S. Bureau of Mines (BOM) and the PHS assisted mining companies in all aspects of mining and mine safety [8]. A two-volume monograph was produced by the BOM under the title, *Controlling Employee Exposures to Alpha Radiation in Underground Uranium Mines* [referenced in 8]. The PHS published a similar monograph in the early 1950s, *Control of Radon Daughters in Uranium Mines and Calculation of Biological Effects* [referenced in 8]. These public access government publications were the summaries of the communications that already had been shared by the PHS and BOM with the AEC. As explained above, all of this information was distributed by the AEC to the companies engaged in the production of uranium ores without any evidence of improvement in the conditions reported [3].

Community Environmental Remediation

Navajo families of early uranium miners reported that clothing and shoes heavily contaminated with uranium ore dust were brought home every day and clothing was washed without any special precautions [3]. Given the total disregard for radiation and other health dangers exhibited by the mining operators inside the mine, as described in the ACHRE report [3], it is no wonder that the same irresponsible behavior was practiced in addressing potential environmental exposures to the community.

As the technical literature shows, the U.S. government had made recommendations for remediation of environments impacted by uranium extraction as early as 1962 [20]. Early evaluation of radiological contamination of the Colorado river basin, reported in 1963 [21], should have alerted mining operators to initiate remedial action as soon as possible.

CONCLUSIONS

1. Uranium miners were unwilling and unaware victims of undesigned human experimentation in what was defined as "experiments of opportunity" by the U.S. Human Radiation Interagency Working Group (ACHRE, 1995).
2. The failure of the government to warn uranium miners of the known lung cancer risks (data from 1942 and 1951) is difficult to comprehend, especially when the miners were continually studied and in frequent contact with the researchers.
3. The refusal of the U.S. agencies to set and enforce exposure limits to radon progeny in mines is also unconscionable. The first federal standard for occupational exposures in mining to radon progeny promulgated in 1967 was issued too late to protect Navajo miners. The responsible agencies based their refusal to set standards on a deceptive insistence of a lack of data. Only after the first cancer cases started being reported in the late 1960s was action taken.
4. The federal government (through the AEC) engaged in a campaign to deny any harmful effects of radiation for fear of a negative public perception of nuclear power. This misconception that anything negative about radiation might cause "harm to national security" and "not [be] in the public interest" created an environment of Cold War hysteria used to justify inaction and to vilify any attempt at radiation control in mines as unpatriotic.
5. The failure of mining firms to act on the available mine ventilation information provided by the AEC and PHS in 1954 and 1956 is an example of gross negligence.
6. The Navajo Nation's territory became a virtual national sacrifice area as one of the main mining sources of the uranium that built the post-war U.S. nuclear arsenal.
7. Most of the occupational health studies conducted in the last fifty years on this subject could be classified as a form of undesigned human experimentation.
8. Contempt for the workers' right to know on the one hand and corporate and government fear, on the other hand, that workers and community might act

defensively so as to endanger their interests unfortunately are recurring themes in the history of occupational health.

EDITOR'S NOTE

A shortened version of this article was presented as one of the keynote papers of the First International Conference on the History of Occupational and Environmental Prevention in Rome in October 1998.

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