Ethnic Differences in the Prevalence of Nonmalignant Respiratory Disease among Uranium Miners

ABSTRACT

Objectives. This study (1) investigates the relationship of nonmalignant respiratory disease to underground uranium mining and to cigarette smoking in Native American, Hispanic, and non-Hispanic White miners in the Southwest and (2) evaluates the criteria for compensation of ethnic minorities.

Methods. Risk for mining-related lung disease was analyzed by stratified analysis, multiple linear regression, and logistic regression with data on 1359 miners.

Results. Uranium mining is more strongly associated with obstructive lung disease and radiographic pneumoconiosis in Native Americans than in Hispanics and non-Hispanic Whites. Obstructive lung disease in Hispanic and non-Hispanic White miners is mostly related to cigarette smoking. Current compensation criteria excluded 24% of Native Americans who, by ethnic-specific standards, had restrictive lung disease and 4.8% who had obstructive lung disease. Native Americans have the highest prevalence of radiographic pneumoconiosis, but are less likely to meet spirometry criteria for compensation.

Conclusions. Native American miners have more nonmalignant respiratory disease from underground uranium mining, and less disease from smoking, than the other groups, but are less likely to receive compensation for mining-related disease. (*Am J Public Health.* 1997;87:833–838)

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Introduction

In addition to its well-known association with lung cancer, uranium mining is associated with an increased risk of nonmalignant respiratory diseases.[1] The atmosphere of uranium mines may contain high concentrations of silica dust, radon, and diesel fumes; in addition, non-Hispanic White miners are known to have high rates of tobacco use.[1] Studies of uranium miners in the Colorado Plateau have found excess mortality from pneumoconiosis and other respiratory diseases in non-Hispanic White and Native American miners.[2,3] These studies have suggested differences in the rates of nonmalignant respiratory disease among non-Hispanic White and Native American uranium miners, although the relative contribution of cigarette smoking and mining exposure in each group has not been addressed.

Uranium mines in New Mexico and the Colorado Plateau were responsible for the majority of the US uranium production during the Cold War.[4] Many of the earliest mines in this area, known as "dog holes," were infamous for their lack of ventilation and poor working conditions. Non-Hispanic Whites, Hispanics, and Native Americans from the region were recruited to work in the mines, which were often located on Native American reservations.[5(pp183–202)] It has been alleged that uranium mining is an example of "environmental (in)justice," wherein certain racial and economically disadvantaged groups incur an undue burden of illness from hazardous exposures.[5(pp183–202),6–8]

In 1990, the Congress of the United States passed the Radiation Exposure Compensation Act (RECA) to atone for illness sustained by these miners in an industry considered vital to the national defense.[9] RECA specifies that to receive compensation for a nonmalignant respiratory disease, a miner must have the following: (1) a forced expiratory volume in 1 second (FEV_1) or forced vital capacity (FVC) less than 75% of what is predicted by the Knudsen 1983 formula,[10] (2) a chest radiograph demonstrating at least a 1/0 profusion score by the International Labor Organization rating system, and (3) proof of 200 working-level months of underground mining exposure if a nonsmoker, or 500 working-level months if a smoker. Although it is accepted practice to use ethnic-specific prediction equations whenever they are available,[11] RECA uses the Knudsen formula, based on non-Hispanic White nonminers, as the standard for all miners.

Since 1989, the New Mexico Miners' Outreach Program has offered free screening for mining-related diseases to active and retired miners in the southwestern United States. This paper describes the results from this program and addresses the following questions: (1) Have Native American miners incurred a higher prevalence of nonmalignant respiratory disease associated with underground uranium mining than non-Hispanic White or Hispanic miners? (2) How does the use of

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This paper was accepted August 6, 1996.

Editor's Note: See related comment by Northridge and Shepard (p 730) in this issue.

impairment criteria based solely on spirometric prediction equations for non-Hispanic Whites affect Native American and Hispanic miners?

Methods

The New Mexico Miners' Outreach Program is conducted by Miners' Colfax Medical Center in Raton, NM, in collaboration with pulmonary physicians from the University of New Mexico Health Sciences Center. The program is designed to detect mining-related diseases in persons who have worked in mines of any type. Any self-identified current or former miner is eligible for free health screening. Participants are examined at the Miners' Colfax Medical Center or in a mobile clinic that periodically visits mining communities in New Mexico and south central Colorado.

Miners are recruited through mining unions, physician referrals, and notices in newspapers and on radio. The health screening is composed of a standardized medical questionnaire administered by a trained interviewer, a posterior-anterior chest radiograph interpreted by a certified "B" reader who is not aware of the clinical history, and spirometry performed according to American Thoracic Society guidelines by a certified respiratory therapist.[11] From the inauguration of the clinic on December 5, 1989, through May 18, 1995, a total of 2964 miners were screened, 1809 of whom report having worked in a uranium mine. Fifty miners who were missing chest-radiograph or pulmonary function data were excluded; 253 miners who worked less than 3 years in uranium mining were excluded, because this is the minimum time needed to accumulate the working-level months of radon exposure required by the RECA. Of the 1506 remaining, 23 females; 17 persons reporting an ethnic background other than non-Hispanic White, Hispanic, or Native American; and 107 persons who were missing data on total years of uranium mining, pack-years of smoking, or physiometric data were excluded. The remaining 1359 persons were included in our analysis.

Definitions of obstructive and restrictive lung disease and pneumoconiosis are based on the RECA criteria. Obstruction is defined as an FEV_1 less than 75% of what is predicted by the Knudsen formula,[10] with an FEV_1/FVC ratio below 70%. Restriction is defined as an FVC less than 75% of what is predicted by the Knudsen formula,[10] with an FEV_1/FVC ratio above 70%. Radiographic pneumoconiosis is defined as a profusion of 1/0 or greater as read by a certified "B" reader using the International Labor Organization classification system. Pack-years were calculated by dividing the average number of cigarettes the miner used per day over his lifetime by 20, and then multiplying by the total number of years he smoked.

Multivariate models for obstructive lung disease, radiographic pneumoconiosis, and FEV_1 were developed by ethnic group to look for evidence of effect modification on the basis of ethnicity. Analysis of factors associated with restrictive disease was limited by the small number of miners meeting the restrictive disease definition. Univariate analysis was used to identify important factors to be included in the models. Uranium miners who worked exclusively underground had a higher risk of obstructive lung disease and radiographic pneumoconiosis than those with any above-ground experience, so above-ground uranium mining was included in the nonunderground uranium-mining category. Stepwise regression was used to arrive at the most parsimonious models, with covariates eliminated if they were nonsignificant ($P > .05$). Underground uranium mining was retained in all models as the exposure of interest. Pack-years of cigarette smoking and mining other than underground uranium mining were also retained in all models as important confounders.

All data were stored and processed using SAS applications programming.[12] Demographic data were analyzed by one-way analysis of variance using the SAS GLM procedure, with differences between groups tested with the use of a Scheffé test for the difference between means at a .05 significance level. Differences in the proportions of spirometric and radiographic abnormalities among ethnic groups were tested with exact procedures.[13] Multiple linear regression and logistic regression models were calculated with the GLM and LOGISTIC procedures in SAS. Differences in the coefficient estimates between ethnic groups were tested using the Student's t test for the difference between independent means, with a P value of .05 or less designated as significant.

To find the effect of using compensation criteria based on non-Hispanic Whites for Hispanic and Native American miners, spirometric prediction equations based on Hispanic adult men from New Mexico and Native American adult men from Utah were selected as the reference standards for these two groups.[14,15] The number of Hispanic and Native American uranium miners in our survey disqualified for compensation by the RECA was calculated through a comparison of (1) the number with FEV_1 or FVC less than 75% of what is predicted by the Knudsen equation with (2) the number with less than 75% as predicted by the appropriate ethnic-specific equation.

Results

Of the 1359 miners in this study, the majority were Native American (63.4%). The Native American group was significantly older than the Hispanic and non-Hispanic White groups (Table 1). The non-Hispanic White group was significantly taller and heavier than the other two groups; however, there was no significant difference in the body mass index among the three groups.

The proportions of miners who were smokers, exsmokers, or nonsmokers varied dramatically among the three ethnic groups. Of Native American miners in the study, 72.9% reported never smoking cigarettes, compared with 22.2% of non-Hispanic Whites and 34.6% of Hispanics. Of the miners who were current or previous cigarette smokers, the mean pack-years of cigarette use also varied significantly among the three ethnic groups. Native Americans who had ever used cigarettes smoked an average of only 6.4 cigarettes per day, while non-Hispanic White and Hispanic smokers averaged 20.5 and 14.3 cigarettes per day, respectively.

Mining experience also varied significantly among the three ethnic groups (Table 1). Native Americans in our survey were more likely to have worked only in underground uranium mining, as opposed to working above ground at an underground mine or at a surface or "open-pit" mine. The Native Americans in our survey were also more likely to have engaged only in uranium mining, while non-Hispanic Whites and Hispanics often worked in several different types of mines. Metal mining was the most common other type of mining engaged in by the non-Hispanic Whites and Hispanics in our survey; in New Mexico, this includes underground molybdenum and open-pit copper mining. Coal mining was the most common other type of mining engaged in by the Native Americans in our survey; in New Mexico, coal mining is usually open-pit mining.

The prevalence of spirometric and radiographic abnormalities by ethnic group was tabulated with the RECA definitions (Table 1). The non-Hispanic Whites had a significantly higher proportion with obstructive lung disease ($P < .001$), while the Native Americans had a higher proportion with restrictive lung disease ($P < .05$). The non-Hispanic White and the Native American groups did not differ in the prevalence of radiographic pneumoconiosis despite the significantly lower average lifetime mining exposure of Native Americans.

Risk factors for obstructive lung disease in our study were, overall, underground uranium mining, other types of mining, cigarette smoking, and advanced age (Table 2). Height, weight, and working exclusively above ground did not significantly affect risk for obstructive lung disease. The adjusted odds ratio for underground uranium mining exposure is greater in the Native American group than in the others, and significantly higher than for the Hispanic group. Although mining experience in other mines was also associated with an increased risk of obstructive lung disease in the overall model, the adjusted odds ratios for the individual groups were highly variable and not significantly different. Cigarette smoking was also significant only in the overall model. The adjusted odds ratios for age were lower in the Native American group than the other groups. This age effect could be due to residual confounding from smoking, because of inaccuracies in estimation of pack-years and because of the positive correlation in non-Hispanic White and Hispanic miners between pack-years and age.

Underground uranium mining was associated with a statistically significant reduction in FEV_1 only in the Native American group (Table 3). The FEV_1 decreased by an estimated 8.0 mL for each year the average Native American worked in an underground uranium mine, yielding a mean decrease of 79.2 mL for the group, or a decrease of 160 mL after 20 years in uranium mining. The estimates for uranium mining in the non-Hispanic White and Hispanic groups were less than for Native Americans, but not statistically different. The mean decrease in FEV_1 associated with uranium mining was 62.4 mL and 33.1 mL in non-Hispanic Whites and Hispanics, respectively. The decrease in FEV_1 associated with working in other types of mines was also significant only in the Native American miners; however, the estimates in this category were very unstable. The decrease in FEV_1 associated with each pack-year of cigarette smoking was similar for the three groups. However, because of the differences in smoking behavior among the three groups, the net effect of smoking on each group is very different. For those persons in each group who reported ever smoking cigarettes, the smoking-related decrease in FEV_1 averaged 161, 67, and 27 mL for non-Hispanic White, Hispanic, and Native American miners, respectively. Note that these figures apply only to miners who have ever smoked, and 72.9% of the Native American miners never smoked. In summary, underground uranium mining was related to a significant decrease in FEV_1, and the degree of reduction in FEV_1 associated with 1 year of uranium mining is similar to that seen with 1 pack-year of cigarette smoking. Because of the differences in smoking behavior among the three groups, most of the decrease in FEV_1 in the Hispanic and non-Hispanic White groups is attributable to cigarettes, while most of the decrease in FEV_1 in the Native American group is attributable to uranium mining.

Multiple logistic regression was used to analyze factors associated with pneumoconiosis on chest x-ray (Table 4). Underground uranium mining was a statistically significant factor only in the Native American and Hispanic models, although the adjusted odds ratios among the three groups were not significantly different. Experience in other types of mines and smoking were not associated with radiographic pneumoconiosis in any group. The adjusted odds ratio estimates for age were greater in the Hispanic and non-Hispanic White groups.

We next examined the effect of using compensation criteria based on spirometr-

TABLE 1—Demographic, Spirometric, and Mining Data by Ethnicity: New Mexico and South Central Colorado Uranium Miners, 1989 through 1995

	Non-Hispanic White (n = 162)	Hispanic (n = 335)	Native American (n = 862)
Demographic data			
% of total (n = 1359)	11.9	24.7	63.4
Mean age, y[a] (SD)	57.3 (11.8)	54.0 (10.6)	60.1 (10.6)
Mean height, cm[b] (SD)	174.4 (7.3)	168.8 (6.4)	169.3 (5.7)
Mean weight, kg[b] (SD)	85.9 (17.1)	79.6 (12.8)	79.2 (14.1)
Smoking			
Never, no. (%)	36 (22.2)	116 (34.6)	628 (72.9)
Exsmoker, no. (%)	85 (52.5)	125 (37.3)	193 (22.4)
Pack-years[a] (SD)	31.0 (30.0)	16.9 (18.1)	6.8 (13.2)
Smoker, no. (%)	41 (25.3)	94 (28.1)	41 (4.8)
Pack-years[a] (SD)	36.1 (33.3)	19.1 (14.6)	4.5 (6.3)
Mining experience			
Underground uranium only, no.[a] (%)	101 (62.4)	199 (59.4)	727 (84.3)
Above-ground uranium only, no.[c] (%)	15 (9.3)	25 (7.5)	32 (3.7)
Underground and above-ground uranium, no.[c] (%)	46 (28.4)	111 (33.1)	103 (12.0)
Mean years underground uranium mining[c] (SD)	13.0 (8.0)	13.8 (8.4)	9.9 (6.7)
Mean years other mining[a] (SD)	7.5 (9.5)	3.6 (6.7)	1.5 (4.9)
Miners meeting RECA criteria			
Obstructive disease, no.[b] (%)	27 (16.7)	22 (6.0)	37 (4.3)
Restrictive disease, no.[c] (%)	1 (0.6)	2 (0.6)	16 (1.9)
Radiographic pneumoconiosis, no.[d] (%)	21 (13.0)	24 (7.2)	122 (14.2)

Note. RECA = Radiation Exposure Compensation Act.
[a]Difference between all groups significant ($P < .05$).
[b]Difference between non-Hispanic Whites and other groups significant ($P < .05$).
[c]Difference between Native American and other groups significant ($P < .05$).
[d]Difference between Hispanic and other groups significant ($P < .05$).

TABLE 2—Multiple Logistic Regression Results Providing the Important Risk Factors for Obstructive Lung Disease by Ethnic Group: New Mexico and South Central Colorado Uranium Miners, 1989 through 1995

	Non-Hispanic White OR (CI) (n = 162)	Hispanic OR (CI) (n = 335)	Native American OR (CI) (n = 862)	All, OR (CI) (n = 1359)
Underground uranium mining for 10-year intervals	1.114 (0.643, 1.930)	0.839 (0.491, 1.431)	1.561 (1.027, 2.372)	1.347 (1.030, 1.763)
Other mining for 10-year intervals	1.186 (0.759, 1.852)	0.777 (0.432, 1.399)	1.166 (0.700, 1.941)	1.139 (1.096, 1.751)
Smoking for 10 pack-years	1.097 (0.973, 1.236)	1.085 (0.843, 1.397)	1.236 (0.898, 1.699)	1.188 (1.081, 1.305)
Age, y	1.041 (0.994, 1.091)	1.090 (1.038, 1.144)	1.009 (0.976, 1.042)	1.028 (1.006, 1.051)

Note. OR = odds ratio; CI = confidence interval. Values expressed as adjusted odds ratios and Wald 95% confidence intervals. Model: logit(*P*[have obstructive lung disease]) = $\alpha + \beta_1$ (underground uranium mining) + β_2 (other mining) + β_3 (smoking) + β_4 (age) + ϵ.

TABLE 3—Multiple Linear Regression for FEV_1 by Ethnic Group: New Mexico and South Central Colorado Uranium Miners, 1989 through 1995[a]

	Non-Hispanic White (n = 162)	Hispanic (n = 335)	Native American (n = 862)	All (n = 1359)
Intercept, L[b]	−0.6194 (*P* = .69)	−1.4085 (*P* = .15)	−1.1927 (*P* = .05)	−0.8658 (*P* = .07)
Age, y[b]	−0.0373 (*P* < .01)	−0.0309 (*P* < .01)	−0.0331 (*P* < .01)	−0.0343 (*P* < .01)
Height, cm[b]	0.0351 (*P* < .01)	0.0382 (*P* < .01)	0.0374 (*P* < .01)	0.0358 (*P* < .01)
Underground uranium mining for 10 years[b]	−0.0520 (*P* = .52)	−0.0240 (*P* = .58)	−0.0800 (*P* < .01)	−0.0429 (*P* = .05)
Other mining for 10 years[b]	0.0057 (*P* = .93)	−0.0429 (*P* = .35)	−0.0789 (*P* = .02)	−0.0349 (*P* = .10)
Smoking for 10 pack-years[b]	−0.0493 (*P* = .01)	−0.0377 (*P* = .07)	−0.0425 (*P* = .12)	−0.0397 (*P* < .01)

Note. FEV_1 = forced expiratory volume in 1 second. Values expressed as parameter estimates in liters and *P* values for H_0: $\beta_i = 0$.
[a]Model: $FEV_1 = \beta_0 + \beta_1$ (age) + β_2 (Height) + β_3 (underground uranium mining years) + β_4 (other mining) + β_5 (smoking) + ϵ. H_0: $\beta_i = 0$.
[b]Difference in parameter estimates among ethnic groups not significant.

TABLE 4—Multiple Logistic Regression Results Providing the Important Risk Factors for Radiographic Pneumoconiosis by Ethnic Group: New Mexico and South Central Colorado Uranium Miners, 1989 through 1995[a]

	Non-Hispanic White OR (CI) (n = 162)	Hispanic OR (CI) (n = 335)	Native American OR (CI) (n = 862)	All, OR (CI) (n = 1359)
Underground uranium mining for 10 years	1.856 (0.940, 3.665)	1.942 (1.104, 3.417)	2.591 (1.984, 3.384)	2.124 (1.724, 2.616)
Other mining for 10 years	1.160 (0.680, 1.977)	1.114 (0.636, 1.952)	1.146 (0.819, 1.604)	1.139 (0.921, 1.407)
Smoking for 10 pack-years	0.963 (0.814, 1.140)	1.172 (0.892, 1.540)	0.796 (0.523, 1.213)	0.917 (0.811, 1.038)
Age, y[b]	1.173 (1.085, 1.268)	1.141 (1.076, 1.211)	1.061 (1.038, 1.084)	1.087 (1.067, 1.108)

Note. OR = odds ratio; CI = confidence interval. Values expressed as adjusted odds ratios and Wald 95% confidence intervals.
[a]Model: logit(*P*[have abnormal chest x-ray]) = $\alpha + \beta_1$ (underground uranium mining) + β_2 (other mining) + β_3 (smoking) + β_4 (age) + ϵ.
[b]Difference between estimates for Native Americans and others are significant (*P* < .05).

ric criteria derived from non-Hispanic Whites for Native Americans and Hispanics. The number of members of each ethnic group in our survey who met the compensation criteria by the RECA formula were compared with the number of miners who were less than 75% predicted in FEV_1 and FVC with the use of prediction equations derived from populations similar to those of our Native American and Hispanic miners. Little difference was found in the Hispanic group with the use of a Hispanic-specific equation for either FVC or FEV_1 criteria.[14] Two Hispanic miners with obstructive lung disease were excluded by the RECA formula (22 miners versus 20), and there was no difference in the number of Hispanic miners with restrictive lung disease. No miner with obstructive or restrictive lung disease by the RECA formula was excluded by the Hispanic-specific equation. For the Native American group, the discrepancy between the RECA formula and the ethnic-specific equation was greater.[15] Our survey shows that 24% of Native Americans with restrictive lung disease by the Native American–specific equation were excluded by the RECA formula (21 miners vs 16). One Native American with obstructive disease was also excluded by the RECA formula (38 miners vs 37). No

Native American with obstructive or restrictive lung disease by the RECA formula is excluded by the ethnic-specific equations.

As another index of the relative fairness of the act, we also tabulated, by ethnic group, the number of miners with radiographic evidence of pneumoconiosis who had spirometric values that qualified them for compensation by the RECA criteria. As Table 1 shows, 122 Native Americans, 21 non-Hispanic Whites, and 24 Hispanics had abnormal x-rays consistent with pneumoconiosis. Of the Native Americans, 10.6% (13) met the criteria for obstructive disease, compared with 33.3% (7) of the non-Hispanic Whites, and 8.3% (2) of the Hispanics. Of the Native Americans, 1.6% (2) met the criteria for restrictive lung disease, compared with 8.3% (2) Hispanics, and no non-Hispanic Whites. In summary, although Native American miners had the highest prevalence of radiographic pneumoconiosis, they were less likely than the other groups to meet the RECA compensation criteria.

Discussion

Our survey found underground uranium mining to be associated with an increased risk of obstructive lung disease, decreased FEV_1, and increased risk of radiographically evident pneumoconiosis, with the degree of impairment per year spent in uranium mining greater in Native American than in Hispanic or non-Hispanic White miners. Cigarette smoking accounted for most of the obstructive lung disease in the non-Hispanic White and Hispanic uranium miners, but not in the Native Americans. In our survey population, the current RECA compensation criteria based on non-Hispanic Whites excluded 24% of Native Americans who, according to ethnic-specific standards, had restrictive lung disease and 4.8% of Native Americans who had obstructive lung disease. The current RECA spirometric criteria also exclude from compensation more Native American miners who have radiographic evidence of pneumoconiosis than Hispanic or non-Hispanic White miners.

Our study is subject to several limitations. The measures of exposure to mining and cigarettes depend entirely on self-report, although the mean uranium mining years and the prevalence and intensity of cigarette use by ethnicity are similar to findings of previous studies of Colorado Plateau and Grants mineral belt miners.[2,3,16] Also, the smaller numbers of Hispanics and non-Hispanic Whites in our survey reduce the power to detect an effect from uranium mining in the multiple linear regression and logistic regression models in these groups. Nevertheless, when the non-Hispanic White and Hispanic groups are combined, the estimates of effect for underground uranium mining are still much lower than for Native Americans, and not statistically significant.

Cross-sectional surveys are particularly susceptible to selection bias, which may have caused some of the differences among the ethnic groups. Obviously, we are able to examine only miners who have not already died with mining-related disease. Native American miners in our survey are mostly from the northwestern part of New Mexico, where the majority of the mines operating in the 1940s and 1950s are located. In the rush to produce uranium for nuclear weapons in the early part of the Cold War, safety in the early mines was neglected, and miners were exposed to high concentrations of radon and silica dust.[4,5(pp183–202)6] Native Americans also tended to be subjected to greater underground exposures because they were less likely to work in supervisory positions.[4,6] The majority of non-Hispanic White and Hispanic miners in our survey live in the Grants Mineral Belt area, where most of the newer mines operating in the 1960s and 1970s are located, and were likely to have been exposed to much lower concentrations of silica dust and radon during their mining experience than the Native American miners. On the other hand, far fewer of the Native Americans exposed themselves to the confounding effects of cigarette smoking and nonuranium mining. Had we been able to recruit non-Hispanic Whites or Hispanic miners who worked in the same conditions and used cigarettes at the same rate as Native Americans, there is no reason to suspect the prevalence of lung disease would be any different among the three groups. Nevertheless, of the miners who were still living and participated in our survey, nonmalignant respiratory disease is much more closely related to uranium mining in Native Americans than in non-Hispanic Whites or Hispanics, and current compensation programs must reflect the burden of disease on miners alive today.

Previous studies of uranium miners in the Colorado Plateau and New Mexico suggested an association between obstructive ventilatory defects and uranium mining, but were unable to analyze the contribution of smoking or differences between ethnic groups. An early study of the Colorado Plateau miners found reductions in FEV_1 and FEV_1/FVC ratio associated with years of uranium mining and smoking; however, the methods of spirometric testing would be unacceptable by today's standards; the effect of silica dust exposure was dismissed; and Native Americans were specifically excluded.[17] Trapp et al. intensively studied 34 former uranium miners and concluded that silicosis was an important component of their lung disease, but were unable to measure the relative contributions of silica dust and radon.[18] A survey of mostly Hispanic and non-Hispanic White miners of the Grants Uranium Belt in New Mexico found a small decrease in the percentage of predicted FEV_1 and maximum mid-expiratory flow attributable to uranium mining by multiple linear regression.[16] FEV_1 was predicted to decrease by 0.46% of predicted rates for each year of uranium mining, while current smoking decreased the FEV_1 by 7.75%. However, when multiple linear regression analysis was performed on the spirometric parameters without expressing them as a percentage of predicted value, the significance of uranium mining was lost, suggesting that there may have been errors in the prediction equations. Non-Hispanic White and Hispanic miners could not be analyzed separately, owing to the small number of miners surveyed.

Silica dust and radon gas are the two main exposures thought to result in nonmalignant respiratory disease in uranium mining; however, it is difficult to assess the relative contributions of each. Uranium in the Colorado Plateau and the Grants mineral belt in New Mexico is found in quartz sandstone, and uranium miners in these areas have been found to have a high prevalence of radiographic silicosis.[2,16,18,19] The Colorado Plateau studies have found an association between working-level months of radon exposure and increased mortality from nonmalignant respiratory disease, but have neglected the effect of silica dust.[2,3] Animal studies have found that rats and dogs exposed to high concentrations of radon develop interstitial fibrosis and emphysema,[20] and studies in which Syrian hamsters and beagle dogs were exposed to radon and uranium ore dust found increased rates and severity of interstitial lung disease compared with animals exposed to radon alone.[21,22] Because of the variation in radon concentrations in the uranium mines and the relatively poor

records of radon and silica exposures for each miner, it is unlikely that we will be able to estimate the relative contributions of radon and silica dust to nonmalignant respiratory disease in our miners.

We have demonstrated that the current compensation program is unfair to Native American uranium miners; however, designing a fair system will be problematic. No fully adequate reference standards are available for persons of advanced age in any ethnic group. Evidence also suggests that a "healthy-worker effect" is present in most mining populations, which produces a bias against the miners if standards based on the general population are used for comparison.[23] The contribution of cigarette smoking to uranium-mining-induced malignant and nonmalignant lung disease is substantial, but is not understood well enough to make individual assessments about the relative importance. Until the relationship between uranium mining and respiratory disease is better understood, it would probably be more equitable to establish criteria for respiratory disease on arterial blood gas measurements or exercise tests.

Another problem with the RECA standards is the requirement of a chest radiograph with profusion of 1/0 or greater. We have identified 119 Native Americans in our survey who have spirometric abnormalities below the RECA standard, but whose chest x-rays do not meet the criteria. Autopsy studies have shown that a large proportion of miners with a moderate to severe degree of silicosis cannot be diagnosed by routine chest x-rays.[24] Several studies have also shown that the physiologic abnormalities associated with silica dust exposure are not substantially different in persons with and without mild radiographic abnormalities.[18,25] High-resolution computerized tomography may be able to detect evidence of mining-related disease not found on routine chest x-rays, but relatively few controlled studies have been reported.[26] More research in this area is needed.

In conclusion, our study suggests that (1) Native American uranium miners in our survey have sustained a disproportionate burden of respiratory disease from uranium mining, and (2) current compensation programs are biased against Native Americans. Further research is needed on the interactive effects of radon, silica dust, and smoking, as well as a review of criteria for compensation for mining-related lung disease among uranium miners. □

Acknowledgments

Support was provided by a grant from the Miners' Colfax Medical Center. Partial support for this work was also provided by National Research Service Award 5T32H207733.

The authors wish to thank Ron Roe, RRT, Rose Whitten, the members of the Pulmonary Division at the University of New Mexico Health Sciences Center, and the staff of the Miners' Colfax Medical Center for their assistance in the New Mexico Miners' Outreach Program.

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