NAVAJO BIRTH OUTCOMES IN THE SHIPROCK URANIUM MINING AREA

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Abstract—**The role of environmental radiation in the etiology of birth defects, stillbirths, and other adverse outcomes of pregnancy was evaluated for 13,329 Navajos born at the Public Health Service/Indian Health Service Hospital in the Shiprock, NM, uranium mining area (1964–1981). More than 320 kinds of defective congenital conditions were abstracted from hospital records. Using a nested case-control design, families of 266 pairs of index and control births were interviewed. The only statistically significant association between uranium operations and unfavorable birth outcome was identified with the mother living near tailings or mine dumps. Among the fathers who worked in the mines, those of the index cases had histories of more years of work exposure but not necessarily greater gonadal dosage of radiation. Also, birth defects increased significantly when either parent worked in the Shiprock electronics assembly plant. Overall, the associations between adverse pregnancy outcome and exposure to radiation were weak and must be interpreted with caution with respect to implying a biogenetic basis.**
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Key words: environmental impact; uranium mines; radiation damage; tailings, uranium

INTRODUCTION

In the U.S., uranium mining developed during the late 1940s in the Colorado Plateau region incorporating parts of the Navajo Indian Reservation around Shiprock, NM. For more than three decades, until mining was discontinued around 1975, many Navajos in the Shiprock area were exposed to radiation from alpha and gamma emissions associated with uranium mines and housing located near mines or tailings, or houses constructed of radioactive materials. Particularly in the early years, uranium ore was often mined from poorly ventilated mines (Dare 1961; Tso and Shields 1980). One of four large mill tailings piles on the Navajo Reservation was located at the outskirts of Shiprock (Chenoweth 1984). Exposures to alpha radiation from the decay of radon and radon daughter nuclides inhaled with dust in many early uranium mines (1940–1960) could reach levels in excess of 100 times greater than the present permissible limit of four working level months (WLM), annually.[||] In addition, lung cancer in uranium miners, including Navajos, has been associated with alpha radiation (Samet et al. 1984).

By the end of the 1970s, accumulating anecdotal reports of increased rates of spontaneous abortion and congenital malformations in the Navajo population living in the Shiprock area fueled speculation about a possible association between congenital defects and environmental or occupationally based radiation.

Genetic effects of radiation

Little research has been directed toward possible genetic effects of radiation in mining populations. A study from Czechoslovakia found a decrease in secondary sex ratio of children born to miners after they started uranium mining (Müller et al. 1967). Also, elevated rates of chromosomal aberrations have been found in lymphocytes cultured from blood of uranium miners (Brandom et al. 1978).

^{210}Po that enters the body by inhalation, swallowing, or by being generated from the decay of ^{210}Pb in the skeleton, can be solubilized and concentrated in soft tissues, particularly the liver and kidneys and to a lesser extent the gonads (Blanchard and Moore 1971). Since the effective half-life of ^{210}Pb is about 6.5 y in bone, exposure of soft tissue from ^{210}Po translocated from the skeleton can occur long after the original exposure. In addition, gamma rays from uranium ore above the permissible level of 5 μSv h^{-1} (0.5 mR h^{-1}) demonstrated in some mines and also in residential sections of mining areas, could directly affect the gonads.

Study of adverse birth outcomes from radiation

The present study, conducted at the Shiprock Public Health Service (PHS) Hospital, was designed to identify association of adverse birth outcomes with

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|| Alpha exposure from radon daughter concentration is expressed as working levels (WL): 1 WL = 11.1 Bq L^{-1} (300 pCi L^{-1}) in mine air and the amount of time worked in each mine. A WLM represents exposure to a radon daughter concentration of one WL for 170 h.

exposure of either parent or the grandparents to radiation from having worked in a mine or having lived near a mine, mine dump, or tailings. The Shiprock PHS Hospital serves most Navajos residing in the Shiprock Service Unit of the Navajo Reservation. Most births of Navajos living in the Shiprock area during the study period occurred there. The hospital's medical records provide a nearly comprehensive source of data about prenatal, obstetrical, neonatal, and medical care for Navajos of the Shiprock area. Access to these records offered a possibly unique opportunity to study patterns of adverse birth outcomes and their frequency in a geographic setting of active uranium mining and milling.

The present study is based on a review of medical records of 13,329 consecutive Navajo births at the Shiprock PHS Hospital during an 18-y period (1964–81). Incidences of birth defects were compared with those available from other studies of Indian Health Service (IHS) Hospital birth records (Niswander et al. 1975), and conditions having increased incidence are reported in this paper.[¶]

Causal inferences from the ecologic association of increased incidence rates of specific clinical diagnoses with specific environmental conditions, such as uranium mining and milling, are necessarily inconclusive. Additional environmental changes were occurring in and around Shiprock during the 18-y study period that could confound any inferences relative to working in mines or living near uranium mining and milling operations. Notably, an electronics assembly plant in Shiprock had been operating for 10 y until it closed in 1975. The electronics plant employed nearly 1,200 Navajos, mostly women. Workers in the plant were exposed to a variety of chemicals and solvents, including trichloroethylene, which can enter fetal circulation in pregnant women. Some of the workers may have also been exposed to gamma emissions from ^{85}Kr used to detect flaws in seals on electronic equipment and ^{60}Co used to measure thickness of materials being plated.[#]

In order to specifically address the association between birth outcomes and exposures from uranium mining and milling operations, an analytic study was performed using a nested case-control design drawn from the survey of births at the Shiprock PHS Hospital. The results are reported in this paper. Two hundred sixty-six matched pairs of index births and controls were identified for whom family interviews could be conducted on possible occupational and residential radiation exposures of the parents and grandparents. The interviews also requested information on whether either parent had worked in the electronics assembly plant.

[¶] The full results of the survey will be reported separately.

[#] Personal communication (1987), Tutt, J. M., former chief chemist at the electronics plant, Shiprock, NM. Present address: Director, Crownpoint Institute of Technology, P.O. Drawer K, Crownpoint, NM 87313.

Additional data, available from records of the National Institute of Occupational Safety and Health (NIOSH), are presented for a limited number of Navajo miners in the study showing cumulative WLMs of exposure to radon daughters in the mines. For these miners, the limited gonadal effective dose equivalents** were calculated from estimates of ^{210}Pb concentration in bone and external whole-body exposures, primarily gamma, from uranium ore in the mines.

MATERIALS AND METHODS

All congenital and perinatal conditions, stillbirths, and infant deaths were identified from the survey of 13,329 consecutive Navajo births at the Shiprock IHS Hospital during 1964–81. The newborn record was abstracted to note vital status, gestational age, health status, congenital defects, treatments, and referral or consultative reports. The mother's prenatal and birth records were abstracted to include mother's birthplace, residence at time of birth, gavidity, parity, complications of pregnancy, and notation of alcohol abuse and smoking.

The index cases for the case-control analysis were infants with congenital abnormalities, stillbirths, and development disorders, as well as infant deaths from causes other than injuries. Only single pregnancies were included. The primary outcome variables follow:

- Chromosomal disorders established by karyotype;
- Single gene mutations identified clinically and confirmed through specialist consultation;
- Multifactorial (polygenic) conditions having confirmed morphologic anomalies (excluding hip);
- Hip dysplasia or dislocations severe enough to require hospitalization (usually surgery) for treatment;
- Cerebral palsy, mental retardation, and gross developmental delays clinically diagnosed and requiring subsequent management or special care in childhood;
- Stillbirths not associated with anomalies or conditions classifiable elsewhere;
- Infant deaths, excluding deaths from injury;
- Deaths associated with prematurity (e.g., respiratory distress syndrome) and other identified perinatal conditions;
- Deaths and conditions associated with parturition (e.g., nuchal umbilical cord) and obstetrical complications; and
- Anomalies and syndromes identified in the medical record with a teratogen (e.g., fetal alcohol syndrome) or with other external cause.

Spontaneous abortions were not systematically recorded at the Shiprock PHS Hospital and were not

** Effective dose equivalents will be referred to simply as dose throughout the remainder of this paper.

included in the study. Also, infants with low birth weight, alone, were not included.

A total of 320 kinds of defective congenital conditions were identified. The control for each index case selected was the chronologically nearest normal single birth, matched by sex, mother's age within 5 y, and gravidity (within two pregnancies if more than primagravida).

A case-control pair was entered into the analysis only if families from both the index case and control could be found and interviewed. Families identified for interview were contacted and recruited for participation mostly by household visits, since telephones were seldom available in this population and mailing addresses were unreliable. Some participants were locatable only after their names were given over local radio broadcast. Interviews were in English or Navajo using a fixed interview format.

Exposure variables for the infants' parents and grandparents for the time prior to the birth included work in a uranium mine or mill, residence within 0.805 km (0.5 mi) of a uranium mine, mine dumps or mill tailings, and living in a home built of uranium mine rock. The number of years of being subjected to each exposure situation prior to the birth was noted and entered as a continuous variable. Similarly, work by either parent at the electronics plant and number of years worked were included as categorical and continuous variables, respectively.

For mine workers whose radiation exposures had been requested and obtained from NIOSH records, data consisted of years of mining and cumulative and average minimal WLM exposure. Estimated gonadal dosages from alpha radiation were computed based on a sequence of two correlations: the correlation between cumulative WLM and skeletal concentrations of ^{210}Pb (Blanchard et al. 1969) and the correlation between skeletal ^{210}Pb concentrations and the concentrations of ^{210}Po in the gonads (Blanchard and Moore 1971). An estimated whole-body radiation exposure was added to the ^{210}Po exposure based on two studies of uranium miners in similar working conditions that found exposures ranging from 3–8 mSv y^{-1} (300–800 mR y^{-1}), mean 5.5 mSv y^{-1} (mean 550 mR y^{-1}) (NCRP 1989). One-half of this external exposure, a mean of 2.75 mSv y^{-1} (275 mR y^{-1}), was estimated to reach the gonads (Schull et al. 1981).

Additional variables included in the analysis were period of birth by 6-y intervals in the 18-y study period and co-morbidities identifiable from the mothers' hospital records and verified in the interview, including tobacco smoking and alcohol abuse.

Data were analyzed using Statistical Analysis Systems. In the matched case-control analysis, the odds ratios were determined and confidence limits and tests for significance computed using the exact test based on the binomial distribution (Schlesselman 1982). The Wilcoxon rank sum test was used to compare the numbers of years of exposure for those parents of case and controls who had been subjected to each exposure situation (Dawson-Saunders and Trapp 1990).

RESULTS

We calculated relative risk for each of 33 selected congenital conditions from the newborn record and continuing medical chart of Navajos at the Shiprock PHS Hospital[††], compared to the same defect diagnosed within two to five days after birth by the PHS Hospital newborn records only, for 43,711 American Indians (Niswander et al. 1975). Shiprock births were significantly ($p < .05$) greater for 10 diagnoses: microtia, hydrocephalus, hip dysplasia, microcephalus, cataract, trisomy 18, hypertelorism, craniosynostosis, cortical blindness, and asymmetry of skull. The validity of these risk calculations is doubtful because the survey of American Indian births identified conditions documented by the newborn record during only the first five days of life. The Shiprock survey was based upon the entire available medical record.

Analysis of the case-control pairs for frequency of parental exposure yielded numbers sufficient for statistical analysis for fathers employed in a mine, mill, or at the electronics plant; mothers employed at the electronics plant; and fathers and mothers living near a mine, mine dump, or tailings pile. Exposure prevalences were insufficient and precluded analysis for mothers working at a mine or mill, for either parent living in housing known to be built of uranium-bearing rock, and for grandparents working or living in any of the settings being studied.

Frequencies of the various parental exposures prior to the birth for cases and matched controls were compared by date of birth within 6-y subintervals and by the mother's age (Table 1). Index cases were well-represented throughout the 18 y spanned by the study and were distributed across maternal ages in a manner reflective of Navajo births in Shiprock at that time, but skewed slightly toward older age groups. Multiple logistic regression tests found no significant effects on birth outcomes regarding the following variables: 6-y interval of birth year and maternal age. Greater total numbers of parents of cases compared to controls appeared in each category of exposure studied.

Of available indicators of mother's health status at the time of birth, the use of alcohol and tobacco were significantly associated with outcomes. Identified alcohol users (N = 14) and smokers (N = 3) were distributed exclusively in mothers of cases, but not in association with any of the variables of radiation exposure.

Frequencies of parental exposures by categories or type of outcome in the cases were examined along with the matched controls (Table 2). Low incidence in some categories, such as chromosomal disorders and single gene mutations, precluded meaningful statistical analy-

[††] Shields, L. M.; Wiese, W. H.; Charley, B.; Wagner, J. Congenital malformations among a Navajo Indian population. Manuscript in preparation.

Table 1. Numbers of case and matched control births by site of exposure of father or mother, by birth date within 6-y intervals, and by age of mother.

	Total number		Occupation						Residence							
			Father in:				Mother in:		Father lived near:				Mother lived near:			
			Mine/mill		Electronics		Electronics		Tailings/ dumps		Mine		Tailings/ dumps		Mine	
	Case	Control	Case	Control	Case	Control	Case	Control	Case	Control	Case	Control	Case	Control	Case	Control
Birth year																
1964–1969	87	87	27	27	2	2	6	7	8	9	16	17	8	6	14	15
1970–1975	100	100	24	12	11	7	33	22	11	7	13	7	16	7	15	7
1976–1981	79	79	11	10	13	4	20	10	6	5	12	4	11	7	11	8
	266	266	62	49	26	13	59	39	25	21	41	28	35	20	40	30
Maternal age (y)																
≤20	46	42	2	1	4	1	3	3	3	0	4	0	9	0	6	0
20–24	69	76	10	6	11	6	19	9	5	4	5	5	9	6	6	10
25–29	70	56	14	15	6	3	17	15	6	9	10	10	8	9	7	7
30–34	27	49	12	14	3	2	9	10	4	4	8	8	5	4	10	7
35–39	39	31	17	12	2	1	9	2	5	4	9	5	2	1	6	5
≥40	15	12	7	1	1	0	2	0	2	0	5	0	2	0	5	1
	266	266	62	49	27	13	59	39	25	21	41	28	35	20	40	30

sis. For purposes of organizing the analysis, the cases were further classified into three groups. Group 1 consisted of chromosomal disorders, single gene mutations, and selected discrete morphologic disorders (i.e., clefts, cardiac and gastrointestinal anomalies, and malformed extremities). Group 2 included other outcomes that might be associated with radiation exposure of the parent but which would be more difficult to discern from background incidence rates. Hip dysplasias and dislocations, particularly common among the Navajo, were placed in this group because any effect from a single environment variable presumably would be submerged in the background incidence. Group 2 also included cases of conditions that are more clinically heterogeneous, including cerebral palsy and developmental delay. Stillbirths that could not be explained otherwise were placed in this group, along with infant deaths from infection, neoplasm, and other uncategorized causes (excluding injury), on the assumption that these could reflect some inborn susceptibility. Group 3 consisted of deaths and conditions that were distinctly unlikely to be related to radiation. This group included deaths associated with premature birth, the majority of which resulted from immaturity of the respiratory system and other identifiable perinatal and obstetrical conditions. Infants with defects attributable to effects of known teratogens, including fetal alcohol syndrome or other external causes, were also included in this group. If a positive association with parental exposure emerged in cases in Group 3, response bias would have to be considered.

Correlation coefficients among exposure variables showed expected associations reflecting that fathers and mothers shared exposures and that a person who was working or living near a mine was also likely to live near a mine dump or mill tailings (Table 3).

Effects of exposure to uranium operations

The odds ratios by exposure to the various uranium operations for all outcomes were not significantly elevated, except for mothers living near tailings or mine dumps [odds ratio (OR) 1.83, $p = .05$, Table 4]. In subanalysis, a statically significant association emerged between the mothers living near tailings or mine dumps and outcomes in Group 2 (OR 2.71, $p = .03$). Within Group 2, the differences were most evident in infant deaths and abnormalities of the hip.

Further analysis was conducted by duration of exposure prior to birth. For those mothers of cases and controls who had lived near tailings or mine dumps, the mean reported durations of such exposures were similar for both groups (5.8 y for cases and 5.6 y for controls), and there was no difference when analyzed by the Wilcoxon rank sum test for unmatched groups ($p = .81$). The lack of effect of reported duration of exposure tends to discount the importance of the statistically significant odds ratio for mothers who had lived near mines, tailings, and dumps.

Analyses were conducted on other exposure groups for effect of years of exposure even if the increase in overall odds ratio was not statistically significant. Only for the fathers who had worked in the mines did the duration of exposure approach statistical significance. The mean reported durations of employment were increased in the fathers of cases (5.2 y) compared with fathers of controls (3.8 y). The differences of duration

Table 2. Numbers of case and matched control births in which the father or mother was exposed, listed by site of exposure for father and mother for each type of outcome in the cases.

		Occupational exposure						Residential exposure							
		Father in:				Mother in:		Father lived near:				Mother lived near:			
		Mine/mill		Electronics		Electronics		Tailings/dumps		Mine		Tailings/dumps		Mine	
Type of outcome[a]	Number of cases	Case	Control	Case	Control	Case	Control	Case	Control	Case	Control	Case	Control	Case	Control
Group 1															
Chromosomal disorders	9	1	1	1	0	2	0	2	1	2	0	2	0	2	0
Single gene mutations	8	0	2	1	0	1	1	0	0	2	2	1	0	1	3
Multifactorial conditions with morphologic anomalies (excluding hip)	97	20	15	6	5	19	18	8	6	14	6	10	8	13	12
Group 2															
Hip dysplasia and dislocation	20	8	3	1	0	3	2	4	0	4	1	7	0	6	2
Cerebral palsy, mental retardation and developmental delays	16	4	3	2	2	2	1	3	3	3	3	2	2	2	0
Stillbirths without identified anomaly	38	10	7	3	1	8	4	0	4	2	8	2	4	1	4
Death from illness in infancy:															
Infection	34	9	9	5	2	11	6	5	4	6	5	5	1	6	3
Neoplasm and other	5	0	0	1	0	2	1	0	0	1	0	3	0	3	0
Group 3															
Deaths associated with premature birth and perinatal conditions	20	7	7	4	3	9	5	2	2	4	2	3	4	3	4
Obstetrical complications	13	2	2	3	0	2	1	1	1	1	1	0	1	2	2
Teratogenic effects and other outcomes of known cause	6	1	0	0	0	0	0	0	0	2	0	0	0	1	0
Total	266	62	49	27	13	59	39	25	21	41	28	35	20	40	30

[a] Outcomes are diagnostic classifications of the cases.

had a p value of .07 in the Wilcoxon rank sum test. This effect was most evident in fathers of cases in Group 1.

Effects of exposure from work in electronics plant

History of work by either the father or mother at the electronics assembly plant proved to be a significant exposure variable (Table 5). The overall odds ratio for the father having a prior history of work at the plant was 2.56 ($p = .02$). The overall odds ratio for the mother was 2.05 ($p = .01$). The distributions were particularly evident in outcome Groups 2 and 3, and less evident and not significant in Group 1. For those fathers and mothers who had worked at the plant, further analysis by duration of exposure (using the Wilcoxon rank sum test) showed no trend to suggest that parents of cases had longer durations of exposure than the parents of

Table 3. Correlations coefficients among parental exposure variables.

	Father worked with:		Mother worked with:	Father lived near:		Mother lived near:
	Mine/mill	Electronics	Electronics	Mine	Tailings/dumps	Mine
Father worked with electronics	0.01	—				
Mother worked with electronics	0.02	0.11	—			
Father lived near a mine	0.52	0.08	−0.04	—		
Father lived near tailings/dumps	0.39	0.14	0.03	0.56	—	
Mother lived near a mine	0.36	−0.01	0.06	0.46	0.24	—
Mother lived near tailings/dumps	0.16	0.09	0.13	0.27	0.49	0.53

Table 4. Odds ratios by site of parents' exposure to uranium operations for each diagnostic grouping of pregnancy outcome.

	Worked in mine or mill	Lived near tailings/dump		Lived near mine	
Outcome group	Father	Father	Mother	Father	Mother
Group 1 ($n = 114$)					
Odds ratio[a]	1.25 (0.55, 2.92)	1.43 (0.49, 4.42)	1.62 (0.62, 4.52)	2.43 (0.96, 6.93)	1.09 (0.44, 2.73)
p value	.70	.63	.38	.06	1.00
Group 2 ($n = 113$)					
Odds ratio[a]	1.56 (0.80, 3.13)	1.11 (0.41, 3.09)	2.71 (1.09, 7.64)	0.92 (0.38, 2.19)	2.29 (0.89, 6.57)
p value	.21	1.00	.03	1.00	.09
Group 3 ($n = 39$)					
Odds ratio[a]	1.20 (0.31, 4.97)	1.00 (0.07, 13.80)	.33 (0.01, 4.15)	3.00 (0.54, 30.39)	1.00 (0.23, 4.34)
p value	1.00	1.00	.62	.29	1.00
All outcomes ($n = 266$)					
Odds ratio[a]	1.39 (0.87, 2.25)	1.22 (0.63, 2.42)	1.83 (1.00, 3.46)	1.59 (0.91, 2.85)	1.43 (0.72, 2.56)
p value	.18	.64	.05	.11	.23

[a] Odds ratios with 95% confidence intervals in parentheses.

controls in either the overall group of plant workers or the subgroups.

Births to mine workers with documented exposures

Information about duration of underground mining and cumulative exposure in WLM prior to the birth of cases or controls was available from NIOSH for 14 fathers and eight grandfathers of cases and for 11 fathers and three grandfathers of controls. From this information, the total gonadal dose of radiation prior to the birth could be estimated.[‡‡] These total estimated exposures, ranging from 12–68 mSv (1.2–6.8 rems), are shown along with pregnancy outcomes for fathers and grandfathers (Table 6). Average estimated gonadal levels were only moderately greater in the fathers of cases, 37 mSv (3,680 mrem or 3.7 rem) than in controls, 30.7 mSv (3,074 mrem, 3.1 rem). The differences are not statistically significant. The possible importance of the higher average level in the cases outcome Group 1 is mitigated by the observation that two of the four cases were Down's syndrome, born to mothers 42 y old, an age that is a risk factor that could account for the condition.

The average measured exposures prior to the birth of the parent were more than two-fold greater in grandfathers of cases than in grandfathers of the controls. The numbers available for this computation are few and the levels of exposure relatively low. The differences are not statistically significant.

[‡‡] Total gonadal doses for each father and grandfather were calculated by Richard L. Blanchard, 102 Saccapatoy Drive, Montgomery, AL 36117.

Table 5. Odds ratios for parents working in electronics plant for each diagnostic grouping of pregnancy outcome.

Outcome group	Worked in electronics: Father	Mother
Group 1 ($n = 114$)		
Odds ratio[a]	1.60 (0.46, 6.22)	1.27 (0.54, 3.10)
p value	.58	.69
Group 2 ($n = 113$)		
Odds ratio[a]	3.33 (0.86, 18.85)	2.71 (1.09, 7.64)
p value	.09	.03
Group 3 ($n = 39$)		
Odds ratio[a]	5.00 (0.56, 236.49)	6.00 (0.73, 269.27)
p value	.22	.12
All outcomes ($n = 266$)		
Odds ratio[a]	2.56 (1.14, 6.28)	2.05 (1.16, 3.76)
p value	.02	.01

[a] Odds ratio with 95% confidence intervals in parentheses.

DISCUSSION

Genetic damage from exposure

Radiation has produced genetic effects in every plant and animal species that has been appropriately studied.[§§] Public concern about the effects in humans is understandable. Studies yielding adequate data in humans have been few. In Japan, 56,262 single births (from 1948–1954) to a cohort of survivors of an estimated 0.1 Gy (10 rads) of combined gamma and neutron gonadal exposures at Hiroshima and Nagasaki were examined at birth for four indicators of genetic effects of radiation (Schull et al. 1981). In no instance was there a statistically significant effect of parental exposures but for all indicators, the observed effect was in the direction suggested by the hypothesis that genetic damage resulted from the exposure.

A more recent analysis has been published based upon the children born in Hiroshima and Nagasaki between 1946 and 1985 to survivors who received significant amounts of radiation, using the revised estimates of organ doses that became available in 1986 (Neel 1991). The cohort consisted of 31,150 persons. Based on the analysis of eight indicators of genetic effect, humans appeared less sensitive to radiation than previously assumed on the basis of past extrapolations from experiments with mice (Neel et al. 1990). The most likely doubling dose for the combined eight indicators under study was estimated as between 1.7–2.2 Sv (1 Sv = 100 rem) (Neel et al. 1990).

Chronic vs. acute exposure

The levels of gonadal exposure likely to have been reached by some Navajos in the present study were of the same order of magnitude as estimated for the Japanese. The radiation exposure in Japan was largely from a single blast event, whereas the exposures to the Navajos accumulated over years. Studies in animals have suggested that dose response for genetic effects is less when radiation exposure is chronic than when it is acute (Russell 1963).

Radiation exposure in uranium mines

Government inspection reports provide information about working levels of exposure and gamma radiation in the uranium mines. Reports for 1954–1967 are available for 24 mines in eight locations on the Navajo Reservation which should represent the range of exposures typical for other reservation mines.[‖‖] One WL was considered an acceptable exposure in the 1950s. In only nine mines were the levels consistently below 1 WL. In six mines, the levels exceeded 1 WL in some working areas. In nine mines, exposures exceeded 1 WL in all work areas, with levels ranging to as high as 19 WL. Gamma levels in all 24 mines measured less than the permissible 5 μSv h^{-1} (0.5 mR h^{-1}).

Radiation exposure in residential mine areas

Gamma radiation data for residential sections of mining areas are available for a few sites in the Shiprock area. Measurements taken from certain locations in 1988 and 1989 showed levels >1 μSv h^{-1} (0.1 mR h^{-1}). In one area near homes built of radioactive dump rock, exposures range from 1.7–5.2 mSv y^{-1} (165–521 mR y^{-1}),[¶¶] contrasting with current standards of public exposure of 0.25 mSv y^{-1} (25 mR y^{-1}) (U.S. EPA 1977).

Gonadal exposure

The levels of gonadal exposure following years of underground mining or living continuously in proximity to mines, mine dumps, or mill tailings could accumulate to more than .01 Sv (or several rems). Such levels were computed from the data provided by NIOSH in the present study for mine workers.

Our results showed increased odds ratios for adverse birth outcomes in children of fathers who had worked in a mine and for mothers or fathers who had lived within 0.805 km (0.5 mi) of a mine, mine dump, or mill tailings pile. The only statistically significant odds ratio was in children of mothers living near a mine dump or tailings. When these outcomes were analyzed by specific diagnostic groups, significant odds ratios emerged in congenital hip problems, a common condition among the Navajo, and in infant deaths. Neither of these had been particularly anticipated as likely outcomes of radiation exposure. No association was found, however, for longer duration of exposure among

[§§] Neel, J. V. The studies on the potential effects of the atomic bombs. AAAS Symposium, environmental effects on reproductive outcome. New York: 25 May 1984.

[‖‖] Bureau of Land Management. Mine inspection reports, 1954–1967 (selected, unbound), provided by Paul Buss in 1988, Phoenix District Office, Bureau of Land Management, 2015 West Deer Valley Road, Phoenix, AZ 85027.

[¶¶] Charley, P. H. Preliminary radiological survey reports (unbound pages; 1984). Beclabito Abandoned Mine Lands Reclamation Field Office, Navajo Tribe, P.O. Box 3605, Shiprock, NM 87420.

Table 6. Radiation exposures and pregnancy outcomes in selected fathers and grandfathers of cases and controls.

			Total gonadal dose		
	Years mining[a]	Cum. WLM[b]	(mSv)[c]	(mrem)[d]	Result
Fathers:					
Case Group 1 ($n = 4$)	14	1,394	67.6	6,762	Cleft lip and palate
	5	1,795	27.8	2,780	Down's syndrome[f]
	10	2,493	69.3	6,930	Down's syndrome[f]
	6	2	17.5	1,746	Aganglionosis of bowel, albinism, clinodactyly
Mean ± sem[e]	8.8 ± 2.1	1,421 ± 525	45.5 ± 13.4	4,554 ± 1,340	
Case Group 2 ($n = 9$)	4	134	12.0	1,204	Infant death
	10	252	31.3	3,130	Hip dysplasia
	13	385	42.6	4,264	Hip dysplasia
	6	314	19.3	1,926	Multiple developmental delays
	13	372	42.4	4,238	Infant death
	6	568	32.3	3,234	Anomalies of skull, motor delay
	11	874	43.8	4,378	Hip dysplasia
	3	809	11.6	1,164	Developmental delay
	11	1,162	48.7	4,873	Cerebral palsy
Mean ± sem	8.6 ± 1.3	541 ± 1.3	31.6 ± 4.7	3,157 ± 473	
(p value)[h]	(1.00)	(0.19)		(0.49)	
Case Group 3 ($n = 1$)	13	728	48.9	4,888	Death/respiratory distress
Mean	13	728	48.9	4,888	
All cases ($n = 14$)					
Mean ± sem	8.9 ± 1.0	806 ± 187	36.8 ± 5.0	3,680 ± 495	
All controls ($n = 11$)					
Mean	8.1 ± 1.4	559 ± 156	30.7 ± 6.5	3,074 ± 653	
(p value)[h]	(0.66)	(0.46)		(0.40)	
Grandfathers:					
All cases ($n = 8$)[g]					
Mean ± sem	6.4 ± 1.5	884 ± 302	28.8 ± 9.0	2,881 ± 898	
All controls ($n = 3$)					
Mean ± sem	3.7 ± 1.7	400 ± 255	13.5 ± 7.4	1,345 ± 741	
(p value)[h]	(0.30)	(0.26)		(0.26)	

[a] Years prior to birth of case or control infant or prior to birth of parent.
[b] WLM = working level month.
[c] millisievert = 100 millirems.
[d] millirem = 0.01 millisievert.
[e] sem = standard error of the mean.
[f] Maternal age was 42 y in both cases of Down's syndrome.
[g] Cases for grandchildren were all in Groups 1 and 2.
[h] Wilcoxon rank sum test was used to determine p values. P values were computed for the following:
Fathers: Case Group 1 vs. Case Group 2
All cases vs. all controls
Grandfathers: All cases vs. all controls.

those mothers who had reported exposures. While the odds ratios for fathers' exposures were not significant, there were trends suggesting a response by duration of exposure. The lack of significance could reflect low statistical power in the small population being studied. Power sufficient to detect a 50% increased incidence with .80 probability and with $p < .05$ within the outcome groups would have required a five-fold larger number of case-control pairs than were available, given the rates of occupational and environmental exposure found in this study.

Estimated gonadal exposure using actual measurements of cumulative WLM did not strongly support the hypothesis of association of adverse outcomes with higher exposures in cases compared with controls whose fathers or grandfathers had worked in uranium mines and for whom such data were available.

Data associations and limitations

The lack of any significant effects in Group 3, the subgroup of cases thought least likely to be related to radiation (outcomes likely to have been related to known teratogenic exposures, to perinatal or obstetrical events, or to prematurity) is consistent with an environmental basis for the effects noted in the other subgroups.

The positive associations identified in this study must be interpreted with caution. Multiple comparisons will eventually yield significant results purely by chance in a negative data set. Type I error must be considered in this analysis based on 20 computations of the odds ratio. The case-control study design is open to bias from inadvertent but systematic differences in selection of cases and controls or in eliciting responses. For example, recruitment of case and control respondents both by home visits and by radio solicitation might have introduced selection bias. This was examined by stratifying positive results by method of recruitment. No differences were found across the two recruitment methods; however, other sources of selection bias cannot be ruled out.

It is possible, among the cases, that parents who had radiation exposure were relatively more inclined to participate than parents without such exposure and that such differentiation was less among controls. Response bias in the exposure variables dealing with uranium operations is possible but was viewed as not likely in that the odds ratios for cases in Group 3 were not consistently or significantly increased. Neither field interviewers nor responding parents would likely have distinguished across the different subgroups of cases. The effects of response bias would be expected to have emerged across all of the subgroups.

Case and control comparison of computed gonadal radiation exposures among fathers and grandfathers who had worked in the mines is limited by the small numbers of mine workers in our study for whom data were available from NIOSH. Exposures in the fathers of cases were not significantly greater than those of controls at cumulative gonadal exposures in the range from 0.01–0.07 Sv (1–7 rem).

Another methodologic concern arises from the use of the three groups to classify the outcomes. There is the possibility of error in the diagnosis available in the medical record, and misassignment to a group. Also, the assignment of diagnostic categories to groups that purport to reflect likelihood of possible association with effects of radiation is judgmental.

For example, the assignment of deaths in association with respiratory distress syndrome to Group 3 may have been inappropriate. That syndrome, associated with prematurity and low birth weight, could conceivably be associated with effects of radiation. In this instance, we reanalyzed the groups with this diagnostic category removed and also with it placed with Group 2. These results did not substantively change the original odds ratios.

The finding of increased odds ratios for parental exposure from work at the electronics plant is difficult to interpret. The electronics plant used safeguards to protect workers from ^{85}Kr and ^{60}Co emissions. The two isotopes were probably not used in the main work area. Concern about solvents cannot be as readily dismissed. After the plant moved from Shiprock to California in 1975, solvent wastes leaking from an underground storage tank appeared in well water supplying a nearby area. The California Department of Health Services failed to find evidence that the solvent leak caused increases in congenital cardiac defects, spontaneous abortions, and Down's syndrome identified in the area at that time.[##] The associations for the electronics plant exposure were strongest in Group 2 and particularly in Group 3, and less apparent in Group 1. This points away from a biogenetic explanation. While there may indeed have been a risk associated with work at the electronics plant, the findings from Group 3 may signal some sort of general methodologic bias.

CONCLUSIONS

Overall, the present observations on a Navajo uranium mining population show trends that lend limited support for the hypothesis of adverse genetic outcomes resulting from radiation exposure. It was unlikely that our small study population would have demonstrated a real effect in terms of statistical significance. The increased odds ratios that were documented in this case-control study need to be interpreted with caution. While selection and response biases could not be confirmed, they could not be ruled out. In a community that had been involved in extensive mining operations for decades, including radiation exposures at levels greatly exceeding what would be allowed today, the lack of clear evidence for an increase in risk to miners should be reassuring.

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