Paper

MORTALITY OF VETERAN PARTICIPANTS IN THE CROSSROADS NUCLEAR TEST†

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Abstract—**Operation CROSSROADS, conducted at Bikini Atoll in 1946, was the first post World War II test of nuclear weapons. Mortality experience of 40,000 military veteran participants in CROSSROADS was compared to that of a similar cohort of nonparticipating veterans. All-cause mortality of the participants was slightly increased over nonparticipants by 5% ($p < .001$). Smaller increases in participant mortality for all malignancies (1.4%, $p = 0.26$) or leukemia (2.0%, $p = 0.9$) were not statistically significant. These results do not support a hypothesis that radiation had increased participant cancer mortality over that of nonparticipants.**
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Key words: Marshall Islands; health effects; radiation, low-level; mortality

INTRODUCTION

In November 1983, the Congress of the United States passed Public Law 98-160 that directed the Veterans Administration (VA) to provide for the conduct of epidemiological studies of the long-term adverse health effects of exposure to ionizing radiation from detonation of nuclear devices. In response, the Medical Follow-up Agency (MFUA), then in the Commission on Life Sciences, National Academy of Sciences (NAS), proposed to compare the mortality experience of veteran participants in the CROSSROADS nuclear test to a similar group of nonparticipants. Operation CROSSROADS involved approximately 40,000 military personnel, mostly Navy, and occurred in July of 1946 at Bikini Atoll in the Marshall Islands.

The VA convened an *ad hoc* scientific committee to review the NAS proposal, which recommended that it be funded‡ to "enlarge the growing body of information relating to the effects of low levels of radiation on human populations." The study was begun in September 1986, and, in 1988, a committee of the Institute of Medicine was organized to provide guidance and advice to the MFUA staff on the conduct of the study. The study was interrupted by the untimely death of the principal investigator, Dennis Robinette, in 1992. In 1994, the study was resumed culminating in the October 1996 publication of the report (Johnson et al. 1996).

MATERIALS AND METHODS

Mortality experience was evaluated for the approximately 40,000 U.S. Navy personnel who participated in Operation CROSSROADS, a 1946 atmospheric nuclear test series that took place at Bikini Atoll in the Marshall Islands (DNA 1984). To judge whether that mortality experience was influenced by CROSSROADS participation, those personnel were compared to a control group assembled to be similar to the participants in all ways (age, paygrade, military service, time of service, location of service) possible except for Operation CROSSROADS participation.

A roster of CROSSROADS participants was assembled and provided to the Medical Follow-up Agency (MFUA) by the Nuclear Test Personnel Review (NTPR) program of the Defense Nuclear Agency.§ A validation study by MFUA examining other sources of information regarding participant status‖ found that the final roster captured between 93 and 99% of the military personnel who participated in Operation CROSSROADS. The

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§ In June 1996, the Defense Nuclear Agency became the Defense Special Weapons Agency.

‖ Comparisons were made with a roster of CROSSROADS participants from the National Association of Atomic Veterans and a roster compiled from direct solicitation of information from veterans by MFUA.

mortality data gathered from Department of Veterans Affairs (VA) records were validated by sample comparisons with other national data sources.[¶] By the study cut-off date, 31 December 1992, 31.3% of the participants and 30.8% of the comparison cohort were known to have died. Cause of death was available for 86.3% of the participants and 89.3% of the controls.

Adjusting for remaining differences between the cohorts in distributions of age and paygrade, we compared, using proportional hazards analysis, the survival times of the two groups (SAS Institute 1992). Because available dosimetry data were not considered suitable for epidemiologic analysis (IOM 1995), we based this study on exposure surrogate groups. We looked at three principal causes of mortality: all-cause, all-cancer, and leukemia, hypothesizing that increases in the latter two could result from radiation exposure. For descriptive purposes, we also compared mortality for participants and the comparison group for 44 other disease categories.

RESULTS

Among Navy personnel, the primary analysis group for this study, we found that participants at the CROSSROADS nuclear test experienced higher mortality than a comparable group of nonparticipating military controls. The increase in all-cause mortality was 4.6% [relative risk (RR) = 1.046, 95% confidence interval, 1.020–1.074] and was statistically significant ($p < 0.001$). For malignancies, the elevation of mortality was lower—RR = 1.014 (0.96–1.068)—and was not statistically significant ($p = 0.26$). Similarly, leukemia mortality RR was elevated to 1.020 (0.75–1.39), but not significantly ($p = 0.90$) and by less than all-cause mortality. The increase in all-cause mortality did not appear to concentrate in any of the disease groups we considered. Of the 44 other specific cancers and disease categories we examined, there were no statistically significant increases in mortality. The overall elevation of mortality rate ratios for malignancies and leukemias in the participants were not statistically significant and, in fact, were lower than for many other causes of death.

Navy mortality due to all malignancies and leukemia did not vary substantially among our exposure surrogate groups (i.e., those who boarded target ships after a detonation vs. those who did not, and those enlisted personnel who had an Engineering & Hull occupational specialty vs. those in other specialties).

Participants who boarded target ships were thought to be more highly exposed than the rest of the participant group. Relative to the controls (nonparticipating comparison group), boarding participants experienced a 5.7% increase in all-cause mortality, RR equal to 1.057 (1.014–1.10), $p = 0.0093$, whereas the nonboarders (less exposed participant group) experienced a 4.3% increase [RR = 1.043 (1.015–1.073), $p = 0.0028$]. Aside from all-cause mortality, risks for boarding participants did not significantly exceed those for controls for any of the disease categories, and risks relative to controls were similar for boarding and nonboarding participants. The increase in risk for all-malignancies among the participants was 2.6% [RR = 1.026 (0.94–1.12), $p = 0.55$] for boarders and 1% [RR = 1.010 (0.95–1.068), $p = 0.73$] for nonboarders. For leukemia, the increase in mortality risk for boarders was 0.7% [RR = 1.007 (0.61–1.66), $p = 0.98$] and for nonboarders 2.4% [RR = 1.024 (0.737–1.422), $p = 0.89$]. In all cases the 95% confidence intervals overlap, suggesting the difference between boarders and nonboarders could well be due to chance.

Those Navy participants holding an Engineering & Hull (E&H) occupational specialty were thought to be more highly exposed to radiation than their non-E&H counterparts. However, the E&H participants had essentially the same risk of mortality from all causes as non-E&H participants [RR = 0.99 (0.95–1.038), $p = .81$]. For all malignancies and leukemias, the rate ratios were somewhat higher, 1.051 (0.97–1.14) and 1.51 (0.94–2.44), respectively, but both could be attributed to chance ($p = 0.25$ and 0.088, respectively). Risk ratios for leukemia and malignancies among E&H controls showed a similar elevation relative to non-E&H controls, suggesting that a factor specifically associated with CROSSROADS was not likely to have been the cause.

DISCUSSION AND CONCLUSIONS

These findings do not support a hypothesis that exposure to ionizing radiation was the cause of increased mortality among CROSSROADS participants. Had radiation been a significant contributor to increased risk of mortality, we should have seen significantly increased mortality due to malignancies, particularly leukemia, in participants thought to have received higher radiation doses relative to participants with lower doses and to unexposed controls. We did not observe any such effects. We note, however, that this study was neither intended nor designed to be an investigation of low-level radiation effects, *per se*, and it should not be interpreted as such.

In comparing the findings and methods employed in this study with those of other investigations of atomic veteran mortality (Robinette et al. 1985; Darby et al. 1988, 1993; Watanabe et al. 1995), we have identified a possible self-selection bias in the participant cohort: participants who died of a disease (particularly cancer) may have been more likely than healthy participants to have identified themselves to the NTPR, and hence become a part of this study. Such a bias would have resulted in an apparent increase in death rates among the participants. We do not have data with which to make a good quantitative estimate of this potential bias. However, the roster of participants is nearly complete, and mortality from all malignancies and leukemia was lower, not higher, than the increase in all-cause mortality. These factors suggest that a self-selection bias was not entirely

[¶] We used data from the Health Care Financing Administration and the National Death Index, National Center for Health Statistics. All statistical tests are two-sided.

responsible for the finding of increased all-cause mortality in study participants.

The elevated risk of all-cause mortality in CROSSROADS participants relative to a comparable military comparison group is probably the result of two factors. The first is an unidentified factor, other than radiation, associated with participation in, or presence at, the CROSSROADS test. The second is a self-selection bias within the participant roster. However, the relative contributions of these two explanations could not be accurately determined.

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