

## HEALTH STATUS AND RELATIVE EXPOSURE OF MULE DEER AND WHITE-TAILED DEER TO SOIL CONTAMINANTS AT THE ROCKY MOUNTAIN ARSENAL

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**Abstract**—We evaluated the health of 18 radio-collared deer [13 mule deer (*Odocoileus hemionus*) and 5 white-tailed deer (*O. virginianus*)] from the Rocky Mountain Arsenal, near Denver, Colorado, USA, a Superfund site contaminated with a variety of materials, including organochlorine pesticides, metals, and nerve gas production by-products. Radio-collared deer were tracked for 1 to 3 years (1989–1992) to identify relative exposure to contaminants based on telemetry locations plotted on grid maps depicting known soil contaminant concentrations. At the end of the study, all animals were in fair or good body condition at the time of necropsy. Mean ages of mule deer and white-tailed deer were 7.4 (range 4–12) and 10.6 years (range 5–17), respectively. At necropsy, tissues were collected from the deer for serology, histopathology, and analysis for eight chlorinated hydrocarbons and two metals. Detectable residues of mercury were found in the kidneys of 10 deer (range 0.055–0.096 µg/g), dieldrin was found in fat ( $n = 9$ ) (range 0.02–0.72 µg/g), liver ( $n = 4$ ) (range 0.017–0.12 µg/g), and brain ( $n = 1$ , 0.018 µg/g), and DDE was found in the muscle of one animal (0.02 µg/g). Relative exposure estimates derived from telemetry and soil contamination data were correlated with tissue levels of dieldrin ( $p < 0.001$ ) and mercury ( $p = 0.05$ ). Two mule deer had severe testicular atrophy, and one of these animals also had antler deformities. The prevalence of antibodies against epizootic hemorrhagic disease serotype 2 was 85%.

**Keywords**—Mule deer White-tailed deer Environmental contaminants Dieldrin Mercury

## INTRODUCTION

The Rocky Mountain Arsenal (Arsenal), near Denver, Colorado, USA, was used for the manufacture of chemical and incendiary (inflammatory) munitions and demilitarization (destruction) of chemical munitions from 1942 until 1982. In addition, organochlorine pesticides, herbicides, and industrial chemicals were manufactured at the Arsenal by several different lease holders from 1947 to 1982. Six different disposal basins, several landfills, and trenches were constructed on the Arsenal to dispose of wastes associated with these activities.

The Arsenal was added to the U.S. Environmental Protection Agency National Priorities list in 1982 and was identified as a Superfund site in 1989 [1]. The current U.S. Army mission at the Arsenal is related to remediation and mitigation of chemical contamination. All chemical manufacturing and demilitarization of chemical ordnance has ceased. Remediation is being coordinated by the U.S. Army, and the U.S. Fish and Wildlife Service (USFWS) is currently managing the Arsenal. The Arsenal is currently considered a USFWS wildlife area and will become a National Wildlife Refuge when the clean-up is completed.

Approximately 230 mule deer (*Odocoileus hemionus*) and 70 white-tailed deer (*Odocoileus virginianus*) inhabited the Arsenal prior to the completion of a perimeter fence in 1990. Since that time, the mule deer population has more than dou-

bled, but the white-tailed deer population has remained stable [2]. Arsenal visitors are particularly interested in viewing deer, and there is much public concern regarding the health of the deer herd.

We conducted a field study to evaluate the health status of mule deer and white-tailed deer living on an area where soils contain various persistent contaminants. The objectives of this study were to evaluate the health of the deer, to determine the concentrations of selected contaminants in deer tissues, and to examine the relationship between tissue contaminants and soil contaminants, based on the relative use of contaminated areas by deer.

## METHODS

*Study area*

The Arsenal is a 6,900-ha site near the Denver metropolitan area immediately north of Stapleton International Airport and west of Denver International Airport. Urban development and agricultural land border the west and north sides, respectively. Habitat consists primarily of wetland and upland prairie ecotypes [2].

*Telemetry*

Thirteen adult mule deer and five adult white-tailed deer were captured on the Arsenal during the winters of 1989–1990 and 1990–1991 using clover traps [3], a Coda-Netgun® (Coda Enterprises, Mesa, AZ, USA) or darted with a Cap-Chur® gun (Palmer Chemical, Douglasville, GA, USA) and succinylcho-

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line chloride. Only those deer captured by darting were anesthetized. Deer were outfitted with activity radio transmitters (Telonics®, Mesa, AZ, USA) on collars. Expandable collars were used on males. At the time of capture, deer of both species were aged according to tooth wear and replacement [4]. Attempts were made to trap animals in areas representative of each species' distribution on the Arsenal.

Radio tracking was conducted to include a full 24-h day at least once weekly. Attempts were made to locate all telemetered individuals once during each radio tracking session. A random numbers table was used to determine the order in which animals were located. No deer was located more than once during any 24-h period to insure independence of observations.

Deer were located from a vehicle by using homing techniques [5]. A two-element yagi antenna (Telonics) was used to direct the observer to each animal. Visual identification of individuals was obtained using binoculars or a truck-mounted spotting scope. Nocturnal observation of telemetered deer was conducted using a hand-held spotlight. Triangulation techniques were used only when deer were in areas that prohibited sighting the individual or in areas where entry was prohibited. Location estimates were plotted on 1:24,000 USGS topographical maps, and universal transverse Mercator (UTM) coordinates were recorded for each location estimate.

#### Soil sampling

Soil samples were collected from 1985 to 1994 during an extensive remedial investigation (RI) [6] and subsequent sampling efforts. The RI had two phases (I and II) and produced contaminant assessment reports and site assessment reports for over 200 specific soil, sewer, and building contamination sites [6]. Soil borings were collected using a continuous core augering technique. A core barrel containing a clear polybutyrate tube was placed inside the hollow stem auger such that the soil core entered the tube as the auger advanced. For phase I, a standard sampling interval of 0 to 0.3, 1.2 to 1.5, 2.7 to 3, 4.2 to 4.5, and 6 m below ground surface was used. Phase II soil boring intervals were either identical to those of phase I or were designed to bracket phase I intervals (sample above and below intervals) [6]. Only the analytical results from the surficial soil (0–0.3 m) portion of the borings were used to estimate relative exposure of deer to contaminants. In addition, only those contaminants identified for monitoring in deer were used in the exposure estimation.

Contaminants selected for monitoring in tissues from animals on the Arsenal were contaminants that were found in elevated levels in Arsenal biota by existing studies, found in the Arsenal environment above apparent ambient concentrations, present in high volumes and/or moderately to highly toxic, and known to be persistent in the environment [1,2,7]. Selected contaminants included aldrin,  $\alpha$ -chlordane (AclDn), arsenic (As), DDE, DDT, dieldrin, endrin,  $\gamma$ -chlordane (GclDn), isodrin, and mercury (Hg).

Soil data was plotted by DP Associates (Rocky Mountain Arsenal, Commerce City, CO, USA) on a 60-m<sup>2</sup> grid cell system using a geographical information system. A total of 109,484 grid cells were available on the Arsenal. Contaminant values for each of 10 analytes were recorded for each sampling location. If more than one sample was collected in a cell, the mean soil concentration was reported for that cell. Values less than the certified reporting limit (CRL) were converted to 0. Soil contaminant values were categorized in parts per million

as 0, 1, 2 to 3, 4 to 6, 7 to 18, and >18. Cells with no data were assigned a value of 0.

#### Postmortem examination

In March 1993, 18 radio-collared mule deer and white-tailed deer were located using telemetry and collected by cervical gunshot. Blood was collected via heart puncture using a 3.8-cm, 18-gauge needle, a 250-ml evacuated blood collection bottle (Baxter Scientific, McGraw Park, IL, USA), and a 10-ml evacuated blood tube containing sodium heparin (Becton Dickinson, Rutherford, NJ, USA). Serum was harvested, and serologic testing was done to determine the exposure of the study animals to selected diseases. A complement fixation (CF) test was conducted for *Anaplasma* spp. Serum was tested for *Brucella abortus* and *B. ovis* using particle concentration fluorescent immunoassay (PCFIA). A serologic screen was performed for bluetongue virus (BTV) strains 2, 10, 11, 13, and 17; bovine viral diarrhea (BVD); epizootic hemorrhagic disease (EHD) strains 1 and 2; infectious bovine rhinotracheitis (IBR); *Leptospira* and parainfluenza virus type 3 (PI<sub>3</sub>) by the Wisconsin Animal Health Laboratory (Madison, WI, USA). Samples submitted for BTV and EHD were screened using agar gel immunodiffusion (AGID). Samples testing positive by AGID were tested using a serum neutralization (SN) test; 1:8 was considered indicative of exposure. Titers were not evaluated beyond 1:32.

Animals were weighed and sexed prior to necropsy. Age was determined by tooth annuli [8]. Postmortem examinations included external exam, examination of all internal organs, and histologic (microscopic) exam of selected tissues. Fetal rate (number of fetuses per doe) and fetal ages [9] were determined at necropsy. Physical condition was determined by kidney fat index [10] and coronary fat [11]. Kidney fat indexes were averaged by species for comparison. Coronary fat was rated visually on a scale of one to four, with four being excellent.

#### Contaminant analyses

Chemical analyses of soil and corresponding reporting limits varied between phase I and phase II of the RI. Also, reporting limits varied between analytical laboratories. During phase I, organochlorine pesticides (OCPs) were analyzed by gas chromatography/mass spectroscopy (GC/MS), As was analyzed by graphite furnace atomic absorption spectroscopy (GFAA), and Hg was analyzed by cold vapor atomic absorption spectroscopy (CVAA). The CRL for OCPs in soil ranged from 0.3 to 6  $\mu\text{g/g}$  dry weight. The CRL for As in soil ranged from 2.5 to 5.0  $\mu\text{g/g}$  dry weight. The CRL for Hg in soil ranged from 0.05 to 0.07  $\mu\text{g/g}$  dry weight. During phase II, gas chromatography/electron capture detection (GC/ECD) was substituted for GC/MS. The phase II CRLs ranged from 0.011 to 0.058  $\mu\text{g/g}$  dry weight [6].

Brain, liver, kidney, fat, and muscle were collected and stored frozen in acid-washed jars for contaminant analysis. Tissues were analyzed for OCPs by GC/ECD. The CRL for OCPs in tissue was 0.015  $\mu\text{g/g}$  wet weight. Arsenic was analyzed by GFAA with a CRL of 0.20  $\mu\text{g/g}$  wet weight, and Hg was analyzed by CVAA with a CRL of 0.05  $\mu\text{g/g}$  wet weight.

The chemical analyses were performed according to the Arsenal Chemical Quality Assurance Plan, including instrument calibration, percent recoveries of spiked blanks, use of internal standards, and replication of some analyses [12].

### Relative exposure

Universal transverse Mercator coordinates for telemetry location estimates were overlaid on 60-m<sup>2</sup> grid maps depicting surficial soil concentrations for each of 10 selected contaminants. Potential relative exposure to these contaminants was calculated for each deer by tabulating location estimates that corresponded with 60-m<sup>2</sup> cells for which soil concentrations were known. If a deer was located in the same grid cell on more than one occasion, each location estimate was treated as a separate data point. Grid cells were classified according to the concentration of each contaminant. Cells with no data or concentrations less than the reporting limit was assigned a value of 0. The remaining cells were categorized as containing 1, 2 to 3, 4 to 6, 7 to 18, or >18 ppm.

Location estimates occurring in cells with concentrations above the reporting limit were assigned values of 1, 2.5, 5, 12.5, or 18. Potential relative exposure for each animal was calculated by taking the sum of the values assigned to all location estimates for that animal. However, the number of location estimates were not equal for all animals. Therefore, the mean cell value for each animal was used to rank deer from 1 to 18, with 1 being the animal located most often in areas with high soil contamination. This ranking was plotted in conjunction with tissue-contaminant levels for each deer to determine the relationship between relative exposure and tissue burdens for each contaminant.

### Statistical analysis

Spearman's rank correlation coefficient with a correction for tied data was used to determine significance of the correlation between ranked data from relative exposure estimates and tissue concentrations for dieldrin and Hg [13].

## RESULTS

### Telemetry

From 1989 to 1992, 2,246 telemetry locations were collected for 18 deer. An average of 124.8 locations (range 68–161) was collected for each animal. Mean numbers of locations for 13 mule deer and 5 white-tailed deer were 115.1 and 150.0, respectively.

### Soil sampling

During the RI, more than 6,400 soil samples were collected and analyzed [6]. The number of samples collected per grid cell for those cells sampled ranged from 1 to 81. The percentage of telemetry locations that was sampled for soil contaminants varied by contaminant and ranged from 178 (7.9%) of 2,246 locations sampled for Hg to 291 (13%) of 2,246 telemetry locations sampled for surficial As.

### Postmortem examination

Of the 13 mule deer collected, 9 were female and 4 were male. Average ages of female and male mule deer were 7.4 years (range 4–12) and 5.5 years (range 4–7), respectively. Average body weight for females was 66.2 kg (range 60.0–76.8) and for males was 91.5 kg (range 85.6–94.8).

All five white-tailed deer collected were females with an average age of 10.6 years (range 5–17). Mean body weight was 63.2 kg (range 57–67.4).

On external postmortem examination, 8 of 13 mule deer had varying degrees of alopecia (hair loss). Histologically, three of these deer were diagnosed with dermatitis and hy-

perkeratosis. Additional histological examination indicated that the alopecia was caused by skin irritation due to Canada thistle (*Cirsium arvense*) spines. All five white-tailed deer had normal hair coats.

Externally, two mule deer (56 and 60) had severe testicular atrophy. Mean testicle weights for these animals were 5.9 and 7.0 g, respectively. Two other mule deer (52 and 55) had mean testicle weights of 23.3 and 27.6 g, respectively. Histological examination of the testes from mule deer 56 indicated the vas deferens and epididymis were normal. However, the testes had markedly severe chronic diffuse seminiferous tubular degeneration and atrophy with scant evidence of spermatogenesis. Histologically, the testicles from mule deer 60 had moderate atrophy with mild tubular degeneration and aspermatogenesis. Mule deer 52 and 55 had minimal multifocal seminiferous tubular degeneration and atrophy with evidence of spermatogenesis. The antlers of mule deer 56 were approximately 40-cm-long amorphous masses. The exterior resembled the early developmental stage (velvet horn) of antlers. However, the hair or velvet normally seen on growing antlers was absent. The right antler broke at the midpoint when used as a handle for lifting the animal. Decalcification and histological examination of the antler revealed that the surface had stratified squamous keratinizing epithelium with subepidermal hair and glands. The interior consisted of cortical and trabecular woven bone. Mule deer 52 had normal adult antlers, and mule deer 55 and 60 had shed their antlers prior to collection.

Musculoskeletal examination revealed that five mule deer had some type of hoof deformity or deviation. No hoof anomalies were noted in white-tailed deer. A bony abscess and thickening of the left mandible was noted in mule deer 55, and white-tailed deer 16 had a malocclusion of the mandible.

Seven of the nine female mule deer examined were pregnant. A single fetus was found in one deer, four animals had twin fetuses, and two deer had three fetuses. Fetal sex ratio was 1:1. All five white-tailed deer were pregnant. One animal had a single fetus, and four animals had twin fetuses. The male:female sex ratio of fetuses was 1:1.25. The mean ages of mule deer and white-tailed deer fetuses was 105 (range 98–113) and 106 (range 101–115) d, respectively.

Complement fixation results were negative for *Anaplasma* spp., and PCFIA results were negative for *Brucella abortus* and *B. ovis*. Results of serum neutralization tests indicated that all 18 deer were negative for leptospirosis and IBR. Agar gel immunodiffusion screening for EHD1 was positive in 12 (92%) mule deer and 5 (100%) white-tailed deer. However, EHD1 SN results were negative for all deer. Eleven (85%) mule deer and five (100%) white-tailed deer had SN titers to EHD2. Three (23%) mule deer and one (20%) white-tailed deer had SN titers to BTV 13, and one (8%) mule deer had a positive titer for BTV 11. Bovine viral diarrhea titers were found in nine (69%) mule deer and one (20%) white-tailed deer. Serum neutralization titers for PI<sub>3</sub> were found in nine (69%) mule deer and three (60%) white-tailed deer.

Histological cardiovascular examination revealed that white-tailed deer 16 displayed myocardial fibrosis and myofiber degeneration. Mule deer 9 had focal sarcocystosis in the heart, and mule deer 18 had bilateral arterial worms (*Elaeophora schneideri*).

Histologic respiratory lesions were noted in three mule deer. These include a minimal bronchiolitis and focal pleural fibrosis. One lung worm (*Dictyocaulus viviparus*) was found in one mule deer.

Table 1. Frequency of detection and maximum concentration ( $\mu\text{g/g}$ ) of target analytes in deer from the Rocky Mountain Arsenal

	Arsenic	Mercury	Isodrine	Aldrin	Alcldn <sup>a</sup>	Dieldrin	Endrin	Gcldn <sup>b</sup>	ppDDE	ppDDT
Brain	NT <sup>c</sup>	NT	0/18	0/18	0/18	1/18 (0.018)	0/18	0/18	0/18	0/18
Liver	0/17	0/17	0/17	0/17	0/17	4/17 (0.12)	0/17	0/17	0/17	0/17
Kidney	0/15	10/12 (0.12)	0/17	0/17	0/17	0/17	0/17	0/17	0/17	0/17
Muscle	0/18	0/18	0/18	0/18	0/18	0/18	0/18	0/18	1/18 0.02	0/18
Fat	NT	NT	0/17	0/17	0/17	9/17 (0.72)	0/17	0/17	0/17	0/17

<sup>a</sup> Alachlordane.<sup>b</sup> Gamachlordane.<sup>c</sup> NT = not tested.

Digestive system examination showed that eight mule deer had varying numbers of canid tapeworm (*Taenia* spp.) cysticerci adhered to organs in the abdominal cavity. No larval tapeworms were noted in white-tailed deer. Histologically, one mule deer had a mild hepatitis of unknown etiology.

Histological examination of lymph nodes revealed that 10 mule deer and 3 white-tailed deer had mild lymphoid hyperplasia with sinus histiocytosis and some follicular activity. Two mule deer and three white-tailed deer had mild to moderate hemosiderosis or fibrosis of the spleen.

Internal examination revealed that, in general, white-tailed deer had greater fat reserves than did mule deer. The mean kidney fat index for white-tailed deer was 217.97 versus 128.72 for mule deer. Mean coronary fat ratings for white-tailed deer and mule deer were 2.75 and 2.27, respectively.

#### Contaminant analyses

Twelve mule deer and two white-tailed deer had tissue concentrations above the CRL for DDE, dieldrin, or Hg (Table 1). Five mule deer had fat or fat and liver concentrations above the CRLs for dieldrin and kidney concentrations above the CRLs for Hg. One mule deer had kidney concentrations above

the CRL for Hg and muscle concentrations above the CRL for DDE (Table 1).

Tissue concentrations of dieldrin were highest in fat, followed by liver and brain. Nine (69%) mule deer had fat concentrations of dieldrin above the CRL, and four (31%) mule deer had liver concentrations above the CRL. One mule deer had a brain dieldrin concentration above the CRL. No dieldrin concentrations above the CRL were reported for white-tailed deer.

Mercury analysis was conducted on muscle from all 18 deer. Mule deer liver, kidney, and fat were analyzed for 12, 10, and 7 animals, respectively. White-tailed deer liver, kidney, and fat were analyzed for 4, 2, and 4 deer, respectively. Mercury concentrations above the CRL were found in kidney tissue from 8 of 10 (80%) mule deer and 2 of 2 (100%) white-tailed deer. No aldrin,  $\alpha$ -chlordane, arsenic, DDT, endrin,  $\gamma$ -chlordane, or isodrin were detected in any of the deer tissues above the CRLs.

#### Relative exposure

Tissue concentrations of target analytes and relative exposure rankings to dieldrin (Fig. 1) and Hg (Fig. 2) were

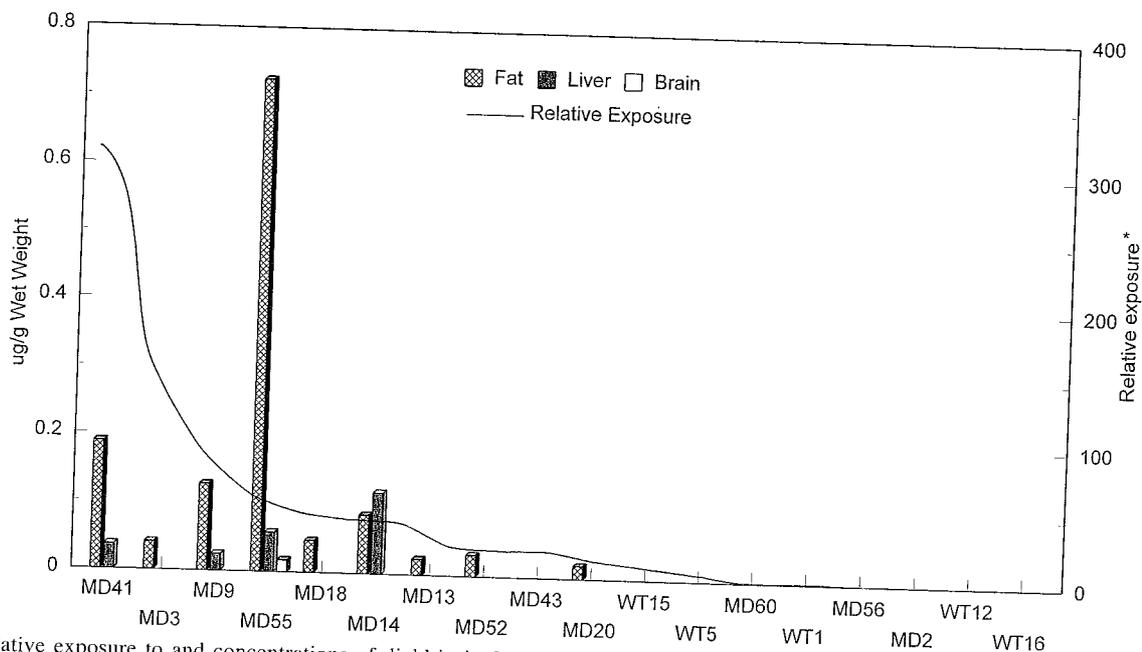


Fig. 1. Relative exposure to and concentrations of dieldrin in fat, liver, and brain of mule deer and white-tailed deer on the Rocky Mountain Arsenal.

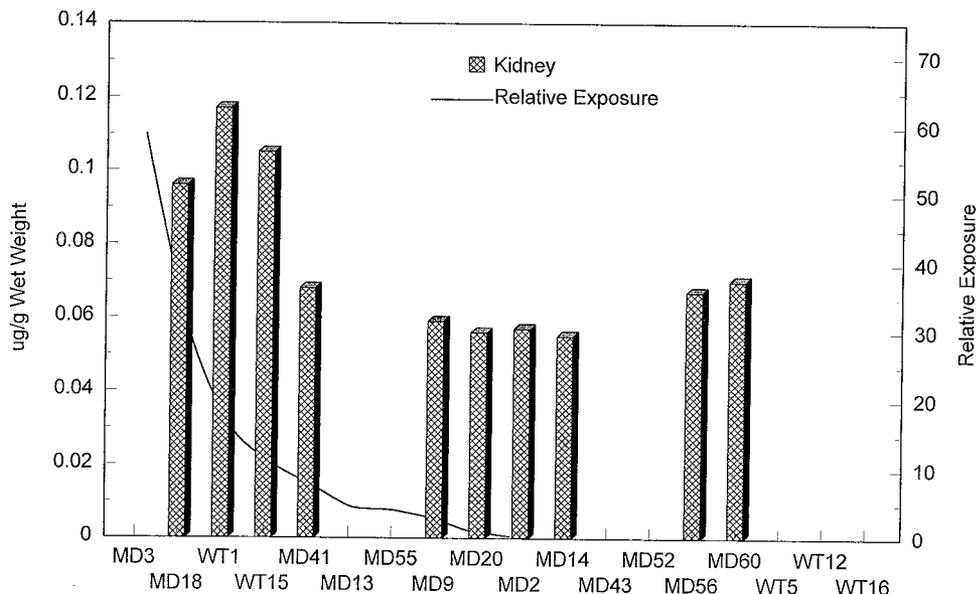


Fig. 2. Relative exposure to and concentrations of mercury in kidneys of mule deer and white-tailed deer on the Rocky Mountain Arsenal.

calculated for all 18 deer. Tabulation of telemetry locations in relation to known soil concentrations of contaminant categories indicates that dieldrin had the highest mean (62.84) relative exposure value. Mercury had a mean relative exposure value of 8.95.

Mule deer had higher mean relative exposure values for both contaminants than did white-tailed deer. The mean dieldrin relative exposure value for mule deer was 76.12 compared with 12.52 for white-tailed deer. Mean Hg exposure values for mule deer and white-tailed deer were 9.92 and 6.39, respectively.

There was a significant ( $p < 0.001$ ) correlation between relative exposure values and tissue concentrations of dieldrin for both species. Estimates of relative exposure and corresponding tissue concentrations of Hg were correlated at  $p = 0.05$ .

## DISCUSSION

Soil and telemetry analyses indicate that mule deer and white-tailed deer on the Arsenal are subject to varying degrees of long-term exposure to contaminants. Concentrations of soil contaminants were not evenly distributed throughout the study site. The majority of contamination was within close proximity to the manufacturing and disposal facilities occupying the central core area of the site consisting of approximately six contiguous square miles. Telemetry results indicate that mule deer tended to occupy areas near these facilities, whereas white-tailed deer frequented areas along riparian zones with less human activity [14]. That tissue levels of dieldrin were higher in mule deer than in white-tailed deer while the reverse was true of Hg levels may reflect habitat preferences for these species. Half of the deer from our study had tissue levels of dieldrin above the CRL. All of those animals were mule deer, and 56% of those deer spent the majority of their time in the contaminated core area of the Arsenal. Tissue levels of Hg were higher in white-tailed deer than in mule deer, although white-tailed deer rarely used areas near manufacturing facilities. However, water from lakes on the Arsenal was used as process cooling water at some of the manufacturing facilities.

This cooling water was then returned to Arsenal lakes to be reused. Sediment and soil samples from these and other riparian areas frequented by white-tailed deer indicate substantial Hg contamination [6].

Postmortem examination of deer on the Arsenal showed that overall herd health appeared to be relatively good. In general, white-tailed deer were in better physical condition than were mule deer. Postmortem examinations were timed to coincide with the late winter seasonal period in which the deer herd would be in its poorest physical state. The late winter period prior to spring green-up is a time when the effects of breeding and winter stress are most evident [15].

Murphy and Korschgen [16] fed white-tailed deer diets containing 5 and 25 ppm dieldrin for up to 3 years. Mean dieldrin levels in brain tissue of deer fed 5 ppm for 214 and 1,096 d were 0.16 and 0.14 ppm wet weight, respectively. When fed 25 ppm, dieldrin brain residues were 0.85 ppm at 216 d and 1.20 ppm at 1,097 d. Mean tissue levels of dieldrin could not be calculated for our study because concentrations less than the CRL of 0.015 ppm were not reported. However, one mule deer had a brain dieldrin concentration of 0.018 ppm, and the remaining 17 animals had levels below the CRL.

Liver concentrations of dieldrin in deer fed 5 ppm for 214 and 1,096 d was 4.15 and 3.72 ppm, respectively [16]. When diets contained 25 ppm, liver residues of dieldrin were 15.87 ppm at 216 d and 16.92 ppm at 1,097 d. Five of 17 deer in our study had liver concentrations of dieldrin (range 0.017–0.12 ppm) greater than the CRL. Liver and brain residues from the Arsenal study were slightly higher than those found by Murphy and Korschgen [16] (0.01–0.02 ppm) in control deer fed commercial feeds containing small amounts (0.01 ppm) of dieldrin. However, brain dieldrin residues from deer on the Arsenal were well below the 4.0- to 5.0-ppm level considered to be indicative of poisoning [17]. Kocan et al. [18] analyzed kidneys for Hg from 64 free-ranging, white-tailed deer in Oklahoma. The mean concentration for these animals was 0.176 ppm. By comparison, 8 of 10 mule deer from the Arsenal had Hg levels from kidney tissue above the CRL (range 0.055–

0.096 ppm). Mercury levels from kidneys of the two white-tailed deer sampled were 0.105 and 0.117 ppm. The Hg levels in white-tailed deer were higher than those from mule deer, but all animals sampled from the Arsenal had lower concentrations of Hg than the average of free-ranging deer collected from 10 counties in Oklahoma.

Greenwood et al. [19] analyzed DDE residues in fat from 23 white-tailed deer and 13 mule deer from various counties in South Dakota. Residues of DDE >0.02 ppm were found in 52% of the white-tailed deer and 46% of the mule deer sampled. The maximum tissue concentrations found were 0.05 ppm for both species. In comparison, only one mule deer from the Arsenal had a DDE concentration (0.02 ppm) in muscle tissue above the CRL.

Testicular atrophy and associated antler anomalies have been reported in white-tailed deer in Texas [20], from mule deer in Colorado [21], and from black-tailed deer in California [22]. One mule deer had testicular atrophy and uncalcified velvet covered antlers. This same deer had similar antlers when captured at the beginning of the study, although the capture occurred in April. A second adult male that had testicular atrophy had shed his antlers. When initially captured, this deer had shed his antlers in an apparently normal completion of the antler cycle. This condition has been seen in other mule deer from the Arsenal (R. Roy, personal communication). Possible causes of testicular atrophy include chromosomal anomalies, Zn deficiency, circulatory disturbances, localized or systemic infection, nutritional deficiencies, toxic plants, or hormone imbalances [23]. Further research is needed to determine the cause of this condition on the Arsenal.

Results of serological tests indicate that both mule deer and white-tailed deer are exposed to a number of diseases on the Arsenal. Epizootic hemorrhagic disease is primarily a disease of white-tailed deer and to a lesser extent mule deer, whereas BTV affects both species of deer [24]. The prognosis for deer acutely ill with EHD or BTV is poor. Mortality rates often reach 90%. In our study, coronary band lesions related to chronic EHD2 or BTV infection are the probable cause of the hoof deformities seen during necropsy. Serological evidence of EHD2 and BT indicates that the deer on the Arsenal have been exposed to these diseases, but their effect on the population cannot be determined without additional surveillance. Titers were also found for BVD, PI<sub>3</sub>, and IBR. Richards [25] reported that 85% of the mule deer tested in one study in Colorado had antibodies to BVD compared with 69% during our study. Cases of acute BVD resulting in deer mortality are rare. However, chronic forms of the disease can be debilitating, and herd immunity can only be obtained by exposure to the disease. Parainfluenza virus type 3 and IBR are both primarily viral diseases of cattle, and limited studies of these agents in deer suggest that only nonfatal clinical manifestations occur [25]. A 1991 serologic survey of mule deer for BVD (85%) and PI<sub>3</sub> (54%) conducted on the Arsenal showed results similar to those for our study. These data suggest that BVD and PI<sub>3</sub> may be endemic on the Arsenal.

Our results indicate that 7 of the 10 contaminants analyzed were generally found below CRLs in both species of deer. Only concentrations of dieldrin and Hg appeared to be related to relative exposure. A variety of postmortem anomalies occurred in a small portion of the deer and likely had no population impact on either species. Most animals appeared healthy, although they were collected during their most physiologically stressful period. In addition, Whittaker

[14] observed increasing (mule deer) or relatively stable (white-tailed deer) populations on the Arsenal during the period of study. Therefore, it appears that exposure to contaminants does not have a significant physiological or demographic impact on mule and white-tailed deer on the Arsenal.

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