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Post-Vietnam military herbicide exposures in UC-123 Agent Orange spray aircraft

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ABSTRACT

Background: During the Vietnam War, approximately 20 million gallons of herbicides, including ~10.5 million gallons of dioxin-contaminated Agent Orange, were sprayed by about 34 UC-123 aircraft that were subsequently returned to the United States, without decontamination or testing, to three Air Force reserve units for transport operations (~1971–1982). In 1996, observed dioxin contamination led to withdrawal of these UC-123s from public auction and to their smelting in 2009. Current Air Force and Department of Veterans Affairs policies stipulate that "dried residues" of chemical herbicides and dioxin had not lead to meaningful exposures to flight crew and maintenance personnel, who are thus ineligible for Agent Orange-related benefits or medical examinations and treatment. Sparse monitoring data are available for analysis.

Methods: Three complementary approaches for modeling potential exposures to dioxin in the post-Vietnam war aircraft were employed: (1) using 1994 and 2009 Air Force surface wipe data to model personnel exposures and to estimate dioxin body burden for dermal–oral exposure for dried residues using modified generic US Environmental Protection Agency intake algorithms; (2) comparing 1979 Air Force 2,4- dichlorophenoxyacetic acid and 2,4-5-trichlorophenoxyacetic acid air samples to saturated vapor pressure concentrations to estimate potential dioxin exposure through inhalation, ingestion and skin contact with contaminated air and dust; and (3) applying emission models for semivolatile organic compounds from contaminated surfaces to estimate airborne contamination.

Results: Model (1): Body-burden estimates for dermal–oral exposure were 0.92 and 5.4 pg/kg body-weight-day for flight crew and maintainers. The surface wipe concentrations were nearly two orders of magnitude greater than the US Army guidance level. Model (2): measured airborne concentrations were at least five times greater than saturated vapor pressure, yielding dioxin estimates that ranged from 13.2–27.0 pg/m^3, thus supporting the likelihood of dioxin dust adsorption. Model (3): Theoretical models yielded consistent estimates to Model 2, 11–49 pg/m^3, where the range reflects differences in experimental value of dioxin vapor pressure and surface area used. Model (3) results also support airborne contamination and dioxin dust adsorption.

Conclusions: Inhalation, ingestion and skin absorption in aircrew and maintainers were likely to have occurred during post-Vietnam use of the aircraft based on the use of three complementary models. Measured and modeled values for dioxin exceeded several available guidelines. Deposition–aerosolization–redeposition homeostasis of semivolatile organic compound contaminants, particularly dioxin, is likely to have continually existed within the aircraft. Current Air Force and Department of Veterans Affairs policies are not consistent with the available industrial hygiene measurements or with the widely accepted models for semivolatile organic compounds.

Abbreviations: 2, 4-D, 2,4-dichlorophenoxyacetic acid; 2,4,5-T, 2,4,5-trichlorophenoxyacetic acid; A, aircraft interior surface; AT, Averaging time; BW, body weight; CF_a, area conversion factor; CF_{wt}, weight conversion factor; C_s, contaminant surface concentration; ED, Exposure duration; EF, exposure frequency; Fom_part, volume fraction organic matter in airborne particles; FT_{ga}, decimal fraction absorbed from gastrointestinal tract; FT_{re}, decimal fraction contaminant removed from skin-to-mouth; FT_{sm}, decimal fraction of contaminated skin touched to mouth; FT_{ss}, decimal fraction contaminant transferred surface to skin; FT_{we}, decimal fraction of contaminant collected onto wipe; h, convective mass-transfer coefficient; I, systematic intake; K_{oa}, octanol/air partition coefficient; K_p, airborne particle/air partition coefficient; NIOSH, National Institute of Occupational Safety and Health; OSHA, Occupational Safety and Health Administration; Q, ventilation rate; RH, probability of Ranch Hand aircraft; SA, exposed skin surface area; UC-123, Ranch Hand aircraft, known as the "Provider"; WD, type of worker; y_o, gas-phase concentration in contact with the emission surface; $\rho_{particle}$, density airborne particles

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1. Introduction

1.1. Historical context

Between 1962 and 1971, the United States Air Force carried out Operation Ranch Hand in which approximately 20 million gallons of herbicides were sprayed by Fairchild UC-123 aircraft over a relatively small area (~16%) of the Republic of South Vietnam in order to defoliate vegetation used for concealment and to destroy crops used by enemy combatants. Approximately 10.5 million gallons were a 50:50 mixture of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), popularly known as Agent Orange. The 2,4,5-T was contaminated with 2,3,7,8-tetrachlorodibenzodioxin, which will be referred to here as dioxin. The herbicides were shipped in color-coded drums, which accounts for their nicknames. Table 1 summarizes the known quantities of herbicides sprayed and number of aircraft (sorties) associated with each mission and Table 2 shows the distribution of missions by agent used and number of aircraft in the mission (Stellman et al., 2003). Some Operation Ranch Hand aircraft also sprayed the insecticide malathion. Table 2 provides data on the number of sorties (individual airplanes flown per mission) that were required to carry out this vast operation. The last Agent Orange Ranch Hand mission was on April 16, 1970 and missions using other herbicides ended January 7, 1971 (U.S. Department of Defense, 1970).

After service in Vietnam, the UC-123 spray planes were reassigned, from 1971 to 1982, to the Air Force Reserve for aeromedical evacuation missions. They were not decontaminated or tested for herbicides or dioxin contamination levels before their return to stateside service. No personal air samples or biological monitoring for herbicide exposure are known ever to have been collected from flight crew or aircraft maintenance personnel during post-war aircraft use. A complete list of all the Operation Ranch Hand aircraft and their fate has not been made public by the Air Force. Using unofficial lists, we estimate that about 34 aircraft carried out all the Ranch Hand operations shown in Tables 1 and 2.

Operation Ranch Hand aircraft were equipped with a 1000 gallons tank and pump to force liquid herbicide under pressure into lines connected to spray booms, one under each wing and a third beneath the centerline of the aircraft (Young, 2009). On average, each aircraft flew about 6000 herbicide missions and became heavily contaminated with chemical residues during loading, maintenance, fueling and while on missions. Few precautions were taken inasmuch as the herbicides were not thought to be harmful to humans (Military Assistance Command Vietnam (MACV), 1966). Planes were usually flown with pilot and co-pilot cockpit windows and aft rear cargo door open (Meek, 1981). A typical Ranch Hand mission employed more than one aircraft flying in formation, but, as shown in Table 2, missions could include from one to twelve aircraft. Spray legs were often repeated in a single mission such that planes would fly through previously sprayed airspace. Herbicide mist would enter the aircraft and deposit throughout their interiors. If pressurized spray lines were broken through malfunction, battle damage or maintenance mishap, they would release significant amounts of liquid herbicide into the aircraft interior.

1.2. Contamination arises as an issue

In 1979, air samples for 2,4,5-T, 2,4-D and malathion, but not dioxin, were taken from the interior of the aircraft known as "Patches" at Westover Air Force Base following complaints of persistent chemical odors (Conway, 1979). Patches had flown herbicide missions in Vietnam from 1961–1965. It is uncertain whether Patches was used for herbicide missions 1965–1967; however, in 1967 it was assigned to insecticide missions only. The bulk of herbicide spraying took place after Patches ceased to spray these chemicals. In 1980, Patches was retired to the National Aviation Museum of the United States Air Force (Fairchild C-123k Provider, n.d.), then to the USAF Museum at Wright-Patterson Air Force Base, OH. At the museum, staff concerns about dioxin exposure led to another round of testing. Based on a three-sample surface wipe survey of Patches, Weisman recommended restorers use Tyvek® coveralls and full-face respirators with high efficiency particulate filters and public entry and interior storage of materials or spare parts be prohibited (Weisman and Porter, 1994).

Other planes from the spray fleet were stored at the 309th Aerospace Maintenance and Regeneration Group facilities at Davis-Monthan Air Force Base, Arizona, and subsequently offered for public

Table 2
Distribution of identified Ranch Hand missions by herbicidal agent and numbers of aircraft (sorties) flown, 1961–1971[a].

Agent	Number of Aircraft (Sorties) in Mission												
	1	2	3	4	5	6	7	8	9	10	11	12	Total
Orange	119	907	1705	392	208	279	54	50	34		2	7	3757
White	53	191	574	190	116	229	22	27	18	1			1421
Blue	20	101	224	32	16	10	2		1				406
Purple	70	108	27	22	5	7	4	2					245
Pink	1	1	4										6
Unspecified	7	18	26	3	3	4	1	1					63
Total	270	1326	2560	639	348	529	83	80	53	1	2	7	5898

[a] Adapted from Stellman et al. (2003).

Table 1
Number of Ranch Hand missions, sorties and gallons sprayed by herbicide type and year.[a]

Agent		Years	Missions	Sorties	Gallons
Orange	50% n-Butyl ester 2,4,-D; 50% n-butyl ester 2,4,5-T	1961–1965	210	564	493,525
		1966–1969	3373	11412	10,709,737
		1970–1971	186	544	510,880
White	Acid weight basis: 21.2% tri-isopropanolamine salts of 2,4-D and 5.7% Picloram	1966–1969	1362	5212	4,976,885
		1970–1971	60	201	192,250
Blue	21% sodium cacodylate + cacodylic acid to yield ≥ 26% total acid equivalent by weight	1966–1969	349	1008	897,850
		1970–1971	60	177	151,035
Purple	50% n-Butyl ester 2,4,-D; 30% n-butyl ester 2,4,5-T; 20% isobutyl ester 2,4,5-T	1961–1965	267	566	471,043
Pink	60–40% n-Butyl: isobutyl ester of 2,4,5-T	1961–1965	6	15	13,291
Unspecified	Specific agent not stated in mission records	1961–1965	4	5	5000
		1966–1969	72	161	159,680
		1970–1971	7	22	22,000

[a] Adapted from Stellman et al. (2003).