THE VIETNAM DEFOLIATION ENVIRONMENT AND OPPORTUNITY FOR HUMAN EXPOSURE

Michael Newton

College of Forestry, Oregon State University, Corvallis OR 97331. USA

Introduction

Defoliants were applied to forested areas in South Vietnam to limit cover and concealment of forces hostile to ARVN and allied forces, mostly in the III and IV Corps areas. The principal defoliant used (1.52 million ha) was a mixture of 2,4-D and 2,4,5-T as the butyl ester in a product known as Agent Orange because of the color coding on the barrels. The 2,4,5-T component of this mixture was manufactured from 2,4,5-trichlorophenol. Traces of 2,3,7,8-tetrachlorodibenzo-para-dioxin (TCDD) formed as an unwanted byproduct of that manufacturing process. The Agent Orange used in Vietnam has been estimated to have had a content of TCDD averaging 2 to 3 parts TCDD per million parts 2,4,5-T. Potential exposure to TCDD in Agent Orange for persons handling Agent Orange varies depending on the degree of contact with 2,4,5-T and the concentration of TCDD in the product. This analysis addresses the factors that should be considered in determining whether humans may have encountered physiologically significant exposure to these materials in Vietnam in the 1962-71 period, apart from applicators and handlers.

Methods

Determination of potential human exposure to Agent Orange requires careful evaluation of the fate and transport of Agent Orange. Data and literature on each of the phases of fate and transport from the initial spraying to contact by the military troops in Vietnam are considered in terms of their cumulative effect on typical human exposure.

Results and Discussion

Defoliation and Burning: Spraying of defoliants resulted in the loss of foliage and death of a fraction of trees ranging from nearly 100 percent in repeatedly defoliated mangroves in the Rung Sat delta, to small percentages in upland forests sprayed only once, the more usual situation. Many sprayed forests dropped enough dry foliage to facilitate burning to complete the clearing process. Much of the defoliated upland forest in War Zones C and D was so burned, leading to death of most of the forest canopy. Meanwhile, additional burning was occurring on shifting farm plots in the uplands. For several years, the total area burned was very large, and resulted not only in a shift in forest cover, but also the formation of many products of combustion, among which one might find an array of dioxins. The rapid degradation of phenoxy herbicides and TCDD in this environment suggests that such burning did not materially convert any of such residues to TCDD, but other sources of TCDD from combustion may have occurred when phenolic compounds in foliage were exposed to both heat and perhaps chlorine originating in monsoonal rains.

Canopy Penetration: Areas where most of the Agent Orange was applied were mature or secondary forests with dense enough foliage to conceal enemy equipment, shelters and troops. There were openings in these forests ranging from roadways to agricultural clearings to clearings made by explosives, but the general condition in which hostile troops would be found was likely closed-canopy stands of trees and shrubs. Stands of this kind, as interpreted from mangroves in Vietnam for which I measured leaf-area and hardwood groves in western USA, showed a typical density of canopy ranging around 2-5 square meters of foliage per square meter of ground (i.e. leaf area index (LAI) is 2-5). The density of foliage expressed this way is a good estimator of penetration of spray materials coming from an aircraft to the level of ground troops or understory vegetation. One may calculate canopy penetration by the spray on the basis that each layer of foliage intercepts about half of the spray volume reaching that point. Thus, with and LAI of $2m^2/m$ of ground surface, one would expect ½ x ½ = ¼ of the deposit hitting the top of the foliage. Similarly, with LAI of 5, the deposit would be surface deposit times 2^{-5}, or 1/32 of the nominal deposit rate as the amount actually reaching the understory[5].

Transport From Canopy to Other Media: Little 2,4,5-T is expected to be transported from the canopy to other media such as soil or surface water because 2,4,5-T is difficult to dislodge in measurable amounts once dried. 2,4,5-T present on the plant canopy is susceptible to photodegradation and is considered to be a significant source of loss. Photodegradation of TCDD was 100% for leaves and 60% for grass, six hours after administration[6]. The small amount that migrates to soil or ultimately to surface water would also be degraded through a number of mechanisms including photodegradation and microbial degradation. In soil, particularly soil with a high concentration of organic matter, such as jungle soil, 2,4,5-T is strongly adsorbed to the soil particles and is not likely to migrate to other media.

Direct Contact to Military Troops: Direct exposure of military personnel might have occurred to troops assembled in the open when spraying took place, or to troops under cover of some kind. Troops exposed to Agent Orange while under cover of a vegetative canopy would be minimally exposed, with at least 75 percent of the spray contacting the upper layers of the canopy. However, given the measures taken to avoid spraying troops and the infrequency of spraying in most areas, it is unlikely that direct exposure to Agent Orange spraying is significant for military troops not directly involved in handling or spraying.

If some military troops were directly exposed to Agent Orange from spraying, the actual exposure would be very low. Application rates of Orange averaged 28 liters/ha of product containing about 14 kg/ha 2,4,5-T with TCDD deposits ranging from .027 to .042 g/ha. Deposits of 2,4,5-T and TCDD per square meter were 1.4 g 2,4,5-T. This is a barely discernible deposit of liquid that dries or absorbs very quickly. Such deposits of 2,4,5-T may have initially contained 2.7 to 4.2 *micro*grams of TCDD on the average.If troops were situated under tree cover, the range of chemical concentrations that could deposit on the skin would be only ¼ to 1/32 of the above quantities. Newton and Norris[4] measured dermal absorption of 2,4,5-T (PGBE) ester on human skin at the rates of considerably less than 1% of the actual 2,4,5-T in contact with skin for an unbroken two-hour period, or less, when applied to skin directly by 900 cm^2 cloth patch saturated with emulsions of 2,4,5-T ester in concentrations normally used in ground-based and aerial sprays. The percentage absorbed was inversely related to the concentration in contact with skin, hence this percentage is probably higher than would have been experienced by persons exposed to identical quantities of 2,4,5-T as undiluted Agent Orange. Therefore, more than 99% of 2,4,5-T in contact with the skin would not be absorbed. The concentrations that could be absorbed in such circumstances would be well below the concentration associated with any known toxic effect. In light of the procedures employed for spraying of Agent Orange in Vietnam, direct spraying of friendly forces rarely occurred. Potential exposures were extremely low and infrequent.Thus, the Vietnam experience is one in which chronic exposure models would be inappropriate.

Direct exposure to the herbicide after the deposit has dried on foliage or soil is virtually nil because these materials are difficult to dislodge once dried. Occurrence of dislodgeable Orange was episodic and brief, as evidenced by Lavy and co-workers[3], who reported little dislodgement of 2,4,5-T upon contact with clothing only hours after application in a forest, and by records that show applications were typically once per year or less. Therefore, this is not a significant source of exposure to Agent Orange.

Indirect contact to Military Troops: All other environmental exposures would be even lower than those resulting from direct exposure to bare skin. If troops used water previously sprayed with Agent Orange for drinking or washing, the herbicide itself and TCDD would largely have biodegraded or migrated to sediment. The role of sunshine in degrading TCDD[1,2], and the affinity of TCDD for silt, organic matter and any other surfaces capable of removing it from solution, significantly reduces the opportunity for a measurable post-application environmental exposure to TCDD under tropical forest conditions. Any bioaccumulation of TCDD in fish would occur in the organs and skin of the fish, so consumption of fish flesh would not result in substantial potential exposure to TCDD. Given the fact that most areas were only sprayed once, the available environmental concentrations of dioxins would reduce over time. The various mechanisms of degradation and migration all suggest that environmental exposure would be far lower than direct personal contact.

Relative Exposure and Toxicity: Thousands of spray workers in several western countries were heavily exposed while spraying tall vegetation with hand application equipment, often on a daily basis. Many such workers were showered with sprays, not just once in a lifetime, but many times a day for months at a time and most did not wear masks or respirators. Serum levels of TCDD increase only after several years of such heavy exposure to 2,4,5-T.[7] Reports of the health of these people are fragmentary, but provide no reason to assume their health is different from those exposed or not exposed in Vietnam.

Conclusion

In summary, it may be stated that relatively few military personnel in the field received significant direct exposure to 2,4,5-T or TCDD. This conclusion is consistent with studies reporting that military troops who served in Vietnam have normal background levels of TCDD comparable to those seen in veterans not involved in the spraying or handling of Agent Orange.

References

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