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ESTIMATION OF EXPOSURE TO AGENT ORANGE AND OTHER DEFOLIANTS AMONG AMERICAN TROOPS IN VIETNAM
A Methodological Approach

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ABSTRACT

Two pivotal problems in determining whether exposure to herbicides has caused disease in Vietnam veterans or their offspring are definition of which troops were exposed and extent of exposure. The DoD HERBS tape is the most complete publicly available record of herbicide spraying in Vietnam. It contains about 17,000 records consisting of coordinates of spray missions, dates, chemical agent, quantity and area sprayed, and mission purpose. We have developed a set of discrete and continuous indexes of exposure to herbicides for individual veterans. These indexes are based upon HERBS tape spray data, and upon locations and dates of service derived from a place-and-date matrix completed by the veteran. They can take into account environmental persistence of herbicide using first-order exponential decay kinetics with an estimated half-life of dioxin.

Mean values for the continuous exposure indexes were significantly greater among veterans judged to be exposed according to self-reported job titles and specific military experiences, compared to men judged unlikely to have been exposed. Exposure indexes based upon the HERBS tape for classification of exposure to herbicides in South Vietnam during 1965 - 1971 appear to be well suited for use in epidemiologic studies.

The possible human health effects associated with the systematic spraying of large portions of South Vietnam with defoliating chemicals carried out by the United States during 1962 to 1971 are a matter of great public and professional debate and concern. During that time nearly six million acres of land were sprayed. Agent Orange, a 1:1 mixture of the n-butyl esters of 2,4-D and 2,4,5-T, was the main herbicide used. Agents White (2,4-D and picloram) and Blue (cacodylic acid) were also used but in lesser amounts [Young et al., 1978].

The ingredients of Agent Orange are known to be toxic. 2,4,5-T is embryotoxic and teratogenic to the mouse [Courtney and Moore, 1971; Neubert and Dillman, 1972; Hood et al., 1979], causes fetal anomalies in hamsters [Collins and Williams, 1971], and induces a variety of genotoxic effects in numerous animal and plant species [Grant, 1979]. 2,4-D in large doses can poison experimental animals and livestock [Rowe et al.,1954; Fenton, 1984], and is neurotoxic to humans [Goldstein et al., 1959]. When given orally to rats, 2,4-D was found to be embryotoxic and fetotoxic, but not teratogenic [Schwetz et al., 1971].

The 2,4,5-T used in Agent Orange was also heavily contaminated with 2,3,7,8-tetrachloro-p-dibenzodioxin (TCDD) and its congeners [Young et al., 1978]. The mean concentration of TCDD in Agent Orange was 2 ppm. Individual concentrations ranged from 0.05 to about 30 ppm [Young et al., 1978]. In laboratory animals, TCDD was found to be extremely toxic [Huff et al., 1980]. The LD-50 for guinea pigs is less than 2 ug/kg of body weight [Huff et al., 1980; Schwetz et al., 1973]. At subacute doses it produces many other systemic effects. TCDD is also embryotoxic and teratogenic to several strains of rats and mice [Courtney and Moore, 1971], and has been found carcinogenic by several routes of administration [International Agency for Research on Cancer, 1977; Van Miller et al., 1977; Kociba et al., 1978].

The effects of TCDD on humans are not so well established as those for animals. Human health effects are known chiefly from studies following industrial accidents and other occupational exposures. Clinical evaluation of workers and others exposed to dioxins has produced a wide range of dermatological, metabolic, neurological, and behavioral effects [Huff et al., 1980]. The best known and most widely recognized of these is chloracne, which is often described as the "hallmark" of dioxin exposure. However, many of these other conditions can result from exposure without chloracne being present [May, 1973; Oliver, 1975; Pazderova-Vejlupkova et al., 1981].

These and other observations have led to the hypothesis that soldiers exposed to Agent Orange during military service in Vietnam may be at increased risk for various acute and chronic diseases and for fathering children with birth defects.

Currently a number of studies are being conducted on the health of Vietnam veterans and their offspring. The majority are planned as long-term investigations and will not be completed for some years [American Medical Association, 1981]. A preliminary account of the Baseline Morbidity Study of Air Force personnel who conducted aerial herbicide dissemination missions in Vietnam (Operation Ranch Hand) showed no significant differences compared to control groups in conception outcomes such as prematurity, miscarriages, stillbirths, or "severe" birth defects, but did observe an excess of "minor" defects," as well as a significant excess of neonatal deaths and physical handicaps [Lathrop et al., 1984].

Among the studies now complete, a case-control study of babies born in the metropolitan Atlanta area concluded that Vietnam veterans in general did not have an increased risk of fathering babies with defects (all types combined) [Erickson et al., 1984a]. However, veterans judged to be "exposed" to Agent Orange had significantly higher risks of having children with birth defects including spina bifida, cleft lip with or without cleft palate, and a miscellaneous constellation of neoplasms. Donovan et al. [1984] have reported that the risk for Australian Vietnam veterans to have fathered a child with a birth defect was no different from that of other Australian men.

In all of these studies, one of the most difficult problems has been that of defining exposure. Accurate data on individual exposure is not available. Information on general herbicide usage exists but has so far proved difficult to translate into individual exposures.

Lathrop et al. [op. cit., Chapter VIII] computed an average exposure index for each Ranch Hand subject by dividing the total gallonage of TCDD-containing herbicide sprayed in the entire Vietnam theater during the subject's tour of duty by the number of airmen with duties equivalent to that subject during the same time period. This measure does not take into account individual exposures at specific times and places. Yet, even this index was largely ignored by the authors in their analysis. Instead, most epidemiological comparisons were made between the entire group of soldiers in Operation Ranch Hand and various non-Ranch Hand control groups, in effect assuming a single presumably high average level of herbicide exposure for all those in Operation Ranch Hand and another, lesser level for the control group.

Erickson et al. also used two different exposure indices. The first was a self-report obtained by asking the subject "Do you think you were ever exposed in any way to herbicides, like Agent Orange?" [Erickson et al., 1984b, p. 228] A more objective "Exposure Opportunity Index" (EOI), was also developed, whereby a "panel of specialists familiar with existing records of herbicide spraying in Vietnam used a mixture of objective and subjective methods" to estimate possible exposures for individual veterans [Erickson et al., 1984b, p. 23]. Two separate

EOI scorings were done, one based on occupation, location, and time recorded in military records ("records-based score"), and one based on similar information obtained from direct interviews with the veterans ("interview-based score"). Despite this incorporation of external information, the EOI scoring system was judged by authors of the study to be "a generally subjective evaluation." Furthermore, Erickson et al. have commented that the mixture of effects reported could easily have resulted from errors of misclassification [Erickson et al., 1984a].

Thus, in contrast to the highly technology-intensive techniques for evaluating the medical status of veterans, the methods of estimating exposure to herbicides have remained fairly crude. Future studies of health and reproductive outcomes of Vietnam veterans will require development of more objective, valid exposure evaluation methods.

One valuable source of objective, specific information on the patterns and extent of herbicide usage in Vietnam is the so-called HERBS tape, developed by the U.S. Army. This data source was used to derive the "records-based score" in the Atlanta birth defect study although the exact way in which the information was incorporated into the EOI was not described [Erickson et al., 1984b, p. 23].

The purpose of this paper is to investigate the use of the HERBS tape to see whether it can be an objective, valid source for exposure classification for individual veterans. The data file contained on this tape consists of an assembly of over 17,000 records, each describing a piece of a herbicide spray mission. The information provided within each tape record is summarized in Table 1. Besides location, the tape records also contain data on dates of spraying, the type of mission, which of the three herbicides was used, the volume used and the area sprayed. The HERBS tape was kindly made available to us by the Records Management Group of the office of the Adjutant General of the U.S. Army.

MATERIALS AND METHODS

Resource: DoD HERBS Tape

The 1980 version of the HERBS tape which we analyzed contained data on 6,475 distinct missions. A mission typically consisted of several legs, each one representing a continuous spray route, possibly including jogs. Each HERBS tape record refers to a single coordinate point on the map of Vietnam. Continuity of spray runs from point to point on the map (and from one HERBS tape record to the next) is indicated by letter-numeral combinations called leg designators (1A, 1B, etc.). The numeral of the leg indicates the number of the run within the mission to which the associated coordinate belongs, and the letter designates the leg within that run. The coordinates are keyed to the Universal Transverse Mercator (UTM) system, which is a rectangular grid ruled off in 100,000 meter sub-grids.

The diagram in Figure 1 shows two legs of a mission flown near Pleiku. The plane turned its spray on at 1A, and continued to spray as it flew on to 1B, 1C, 1D, 1E, and 1F. It turned the spray off, flew to position 2A, and sprayed until 2B.

For our calculations, we used established coordinates of vertices only, rather than center-points or average locations, since low-flying spray planes were frequently fired upon and forced to deviate from a straight-line course.

Construction of Exposure Scales

The method described here consists of several approaches used separately and in conjunction to provide different exposure indices for the Vietnam veteran in question. The parts are:

(a) discrete exposure indices, C_5, C_{10}, C_{15}, which are counts of the number of times a veteran was located within a specified radius (5, 10, or 15 km) from any of the spray locations on the HERBS tape, at times when spraying occurred; this index incorporates information supplied by the veteran using a pre-coded and tested Vietnam place-and-date matrix developed for this purpose;

(b) Continuous Exposure Indices:

(i) E_1, a continuous distance-weighted measure of how close in distance to actual defoliation missions the veteran was during his tour of duty, as calculated using the HERBS tape data and the veteran's military experience and place-and-date matrix;

(ii) E_2, an integrated estimate combining both direct exposure, as in (i), and indirect exposure derived from residual herbicides, in an area of duty where spraying occurred prior to the veteran's service in that area, using the HERBS tape data and the veteran's place-and-date matrix;

(iii) E_3, an integrated exposure index combining both (i) and (ii) above which allows for direct exposure, indirect exposure through environmental persistence, and distance from spraying missions during a veteran's tour of duty;

(c) a self-reported history by the veteran of the dates and locations he served in Vietnam as recorded in the place-and-date matrix;

(d) self-reported descriptions of military service, jobs and experiences using a pre-tested, pre-coded questionnaire.

The discrete indices simply count the number of likely exposures which could have occurred within a specified radius of a veteran's location, while the continuous indices can take into account concurrent exposures plus potential exposures to residual herbicides from all previous spraying missions which took place within 15 km of a given location.

The _discrete scales_: C_r (r = 5, 10, 15) is a count of the number of spray locations, represented by records on the HERBS tape, which fell within a specified distance, r, of each place-and-date position reported by the veteran. Two hypothetical examples of this calculation are shown in Figure 1 and in Table 3. In the example of Figure 1, a veteran reported that he was present in Pleiku on the date the diagrammed spray mission took place. As shown in the Figure, three vertices fall within 5 km of Pleiku, six fall within 10 km, and all eight fall within 15 km. We call these counts the "number of hits within 5, 10, and 15 km," respectively, and our scheme assigns the veteran exposures $C_5 = 3$, $C_{10} = 6$, and $C_{15} = 8$. This type of count can be computed for any location in Vietnam whose UTM coordinates are known.

The _continuous scales_: These indices are defined by three related continuous exposure measures (E_1-E_3). The first, represented by Equation 1, defines the index of exposure, E_1, as the sum of the reciprocals of the distances of all spray locations from a given position.

$$E_1 = C_0 \sum_{ij} (1/D_{ij}) \qquad (1)$$

where C_0 represents the initial concentration of the herbicide in each of the spraying missions, D_{ij} is the distance from the veteran's ith known location to the jth coordinate on the tape, whose dates coincide with the veteran's assignment dates at location _i_. Distances closer than 10 m are counted as 10 m to prevent the sum from approaching infinity.

For the continuous index E_1, we only use spray dates included within the veteran's stay at location _i_, which do not include the effects of spraying during previous missions. The use of reciprocal distances in this index gives higher weight to closer "hits" in the summation. For computational convenience, the sum is restricted to all distances less than or equal to 15 km, since hits at greater distances contribute negligbly to the sum.

The second continuous measure of exposure, E_2, is given by Equation 2. E_2 has been constructed to consider the environmental persistence of an exposure over time.

$$E_2 = C_0 \sum_{ij} \int_{t_{1,ij}}^{t_{2,ij}} e^{-\lambda t}\, dt \qquad (2)$$

where λ is a decay constant and t is time. For an individual veteran, the expression in Eq. (2) is integrated mathematically from $t = t_{1,ij}$ to $t=t_{2,ij}$, where $t_{1,ij}$ is the first date he was stationed at location _i_ and $t_{2,ij}$ is the date he left it. The integral is evaluated for each location _j_ on the HERBS tape within 15 km of veteran location _i_, provided the herbicide spraying occurred prior to $t_{2,ij}$. If the spraying occurred after time $t_{1,ij}$, then the lower limit of the integral is set to the actual date of spraying.

E_2 takes into account explicitly the fact that once sprayed Agent Orange and other herbicides will not instantaneously "disappear" but will be present in the environment, and will be degraded as time passes. We have used a first-order exponential decay, with rate constant λ . The choice of a first order decay law in the present study, that is, a constant half-life, is conservative since it assumes a more rapid disappearance than might actually have occurred. Studies of environmental persistence of TCDD in soil surrounding Seveso, Italy, the site of a large scale environmental release of TCDD, showed an increase in half-life with time [DiDomenico et al., 1980]. However, environmental degradation of TCDD in persistence studies conducted on heavily treated soils at test sites in Utah and Florida, observed by Young et al. [1976], demonstrated decay consistent with first order kinetics. In our calculations, we have assumed a half-life of one year, as suggested by several studies of TCDD persistence in soil [DiDomenico et al., 1980; Young et al., 1976; Kearney et al., 1972].

The exposure index, E_2, therefore gives higher weight to more recent sprayings, while "remembering" past sprayings, but weighting them according to an exponential decay law. As with any first-order decay, the half-life, tau, is given by

$$\tau_{1/2} = \ln 2/\lambda \qquad (3)$$

A third index, E_3, given in Equation 4, is a composite of E_1 and E_2, which combines environmental persistence with reciprocal distance, to give higher weight to more recent sprayings as well as to closer hits.

$$E_3 = C_0 \sum_{ij} (1/D_{ij}) \int_{t_{1,ij}}^{t_{2,ij}} e^{-\lambda t} \, dt \qquad (4)$$

where the indices i and j and times $t_{1,ij}$ and $t_{2,ij}$ are defined above.

In these equations we have assigned a constant concentration C_0 to the herbicide used in all missions.

Self-Reported Exposure Data

Self-reported history and place-and-date matrix formats were developed in consultation with numerous veterans and other experts on Vietnam geography. A matrix, divided into the four Combat Tactical Zones, or Corps, in Vietnam, I,II,III,IV, was created in which major, villages, locations and areas heavily used by American troops were listed by the names used by the veterans. The printed matrix was accompanied by a map of Vietnam on which larger towns were also shown. The matrix was designed so that the respondent could indicate up to 98 specific places in Vietnam where he might have served and the dates that he was there.

Subjects were asked whether or not they had experienced any of the following: been a sprayer on a C-123, helicopter, or boat, had worked at clearing vegetation, had worked as a sprayer or handler of herbicides during shipment, or had slept in or walked through obviously defoliated areas. Subjects were then classified as "exposed" or "not exposed" to each of these spray occupations or to recently sprayed terrain.

This method of collecting location and date information data was pre-tested in 100 California veterans, and proved to be a satisfactory data collection instrument. Approximately 70% of questionnaires had sufficiently completed places and dates to calculate the above exposure measures, without assistance and without an interview. The questions used in the self-described exposure section are reproduced in Table 2.

This information allowed us to compare the measures of exposure derived from the HERBS tape against the observations, experiences and military jobs reported by the soldiers.

Application of Algorithms and Analysis of HERBS tape

We have tested the exposure indices on a sample of 478 veterans selected from a study we have been conducting with the Veterans Education Project of the National Veterans Law Center, American University. Several thousand questionnaires were mailed to veterans participating in a nationwide outreach program sponsored by the Veterans Education Project. The questionnaires solicited information on veterans' health and reproductive outcomes, and contained the exposure instruments described above. This sample was clearly highly self-selected, so that it would not be appropriate to directly generalize associations of herbicide exposures with health outcomes from this population to all Vietnam veterans. However, since our present purpose is only to investigate our proposed exposure indices, and not health outcomes, there is nothing inherently biased in using this group to test and validate the exposure algorithms, of which the respondents had no knowledge.

Finally, we have also carried out calculations on the aggregated data contained in the HERBS tape to obtain additional data on overall usage of defoliants and hence to provide more information about potential exposure of American troops in Vietnam during the 1965-1971. In addition we have made estimates of the relative concentration of herbicides used on each of the missions by calculating the ratio of gallons to area sprayed using the data recorded on the tapes.

RESULTS

Overall Patterns and Extent of Defoliation Activities

Quantities of herbicides recorded on the HERBS tape can be compared with previously published estimates of herbicide use in Vietnam, as an indicator of the completeness of data available to us. The total volume of Agent Orange recorded on the HERBS tape was 11,197,929 gallons, which differs by less than 0.7% from the quantity reported by the National Academy of Sciences [Committee on the Effects of Herbicides in South Vietnam, 1974]. Similar levels of agreement were observed for Agents Blue and White.

Defoliants were used in Vietnam for a variety of purposes. Figure 2 shows the major reported uses of the three herbicides in Vietnam, defoliation and crop destruction, while Figure 3 shows the minor uses reported, related to Vietnamese troop movement and their interdiction. More than ten million gallons of Agent Orange were sprayed, in at least 3,000 separate defoliation missions. Nearly another million gallons of Agent Orange were used in crop destruction programs. About five million gallons of Agent White and one million gallons of Agent Blue were also used for these purposes. Approximately 100,000 gallons of Agent Orange were sprayed around the perimeters of bases to deny cover to enemy troops. These latter uses of defoliants may also have led to significant exposure to U.S. troops.

For more than 80% of the missions, the calculated ratio of gallonage to area sprayed, which is a close approximation of concentration, is nearly constant. 15% of the missions with a substantially different gallon/area ratio occur among missions in the lowest gallonage classification (<500 gallons) and 5% of the missions dispensed less than 100 gallons.

Although herbicide use in Vietnam had begun by January, 1962, the HERBS tape covers only those spray missions conducted after June, 1965. Limited amounts (less than 300,000 gallons) of other dioxin-contaminated herbicides, notably Agents Pink and Purple (active ingredient 2,4,5-T), were disseminated between January, 1962, and December, 1964 [Young et al., 1978]. Since these were years before major American troop involvement, the number of U.S. servicemen exposed would be extremely small. Figure 4 shows the total herbicide usage by calendar quarter. The precipitous drop in the first quarter of 1968 coincides with the Tet Offensive. As indicated in the Figure, usage tended to be most widespread when the largest numbers of U.S. soldiers were in the field.

Application of Indices

As an example, we have summed the indices C_5, C_{10}, and C_{15}, which count the total number of "hits" within specific radii, in six towns or other places in Vietnam, where thousands of American troops were stationed: Chu Lai, Khe Sanh, Camp Evans, Pleiku, Tay Ninh, and Phuoc Vinh. Table 3 shows the total number of such hits falling within 5, 10, and 15 km of these locations, respectively, as well as the total index E_1, derived from all sprayings from 1965 through 1971. These represent upper limits to exposure indexes that would be calculated for veterans stationed at these locations for shorter periods of time. These sample calculations illustrate how the indices can differentiate exposure classification among combat troops.

The equations were then applied to our study population. Of the 543 men sampled, 478 had sufficient information to compute exposure indices, and 303 of these judged themselves "exposed" within at least one of the categories queried in Table 2. Mean scores for the various discrete and continuous scales were computed separately for men designated as "exposed" within each of these six potential exposure categories, as well as for the remaining group of 175 men who said they did not think they were exposed, and who did not indicate that they had held any of the likely exposure jobs. Results are shown in Figure 5. All six of the "exposed" groups had E_3 means higher than the mean of the "unexposed" group,average, and all categories but one (shipping handlers), a group for which we had few observations, had more "hits within 15 km", C_{15}, than the population average for that variable.

Since a number of men belong to more than one nominally "exposed" category, the groups are not independent, so that it is not meaningful to make statistical comparisons between the group means. However, the mean values of the discrete exposure index, C_{15}, as well as of the continuous indices E_1, E_2, and E_3, in exposed and unexposed groups as a whole are compared in Table 4. Mean values for E_2 and E_3 were significantly higher in the exposed compared to the unexposed: mean E_2 was 41% higher ($p<.01$) and mean E_3 was 32% higher in the exposed. Using a Mann-Whitney U test for the discrete variable C_{15}, the mean rank among the exposed was significantly higher than in the unexposed ($p<.05$).

DISCUSSION

As illustrated in Figure 5 and Table 4, HERBS tape-derived exposure indices vary widely among individual troops, ranging from no exposure to a high probability of having been directly sprayed upon, and are consistent with likely exposures associated with specific military jobs and experiences in Vietnam.

It is particularly noteworthy that there is little difference in mean E_3 values for men whose self-reports indicated that they cleared vegetation, slept, or walked through fields, and men who reported no exposure. We believe this to be reflective of the uncertainty and confusion which exists in the minds of many veterans about whether or not they were exposed to Agent Orange. Many sources of defoliation in Vietnam in addition to chemical herbicides have been documented by the National Academy of Sciences [Committee on the Effects of Herbicides in South Vietnam, 1974], such as bombing and shelling, use of Rome plows (super-bulldozers), resettlement, cutting of trees for lumber and firewood, and local agricultural practices (swidden agriculture); it is difficult to see how a soldier under the stress of combat could be expected to distinguish one cause of defoliation from another. Our method can sort out those individuals who erroneously believe themselves to have been exposed and whose misclassification might thereby dilute any potentially observable effect in an epidemiological study.

On the other hand, a self-report might miss important sources of contact with defoliants because the soldier was unaware of previous spraying in the area. Note, for example, the statistically significant differences in E_2 and E_3 between groups in Table 4, which take into account prior spraying at a given location, compared to the lack of statistical significance of differences among values for E_1, which includes only current exposure. This demonstrates the importance of considering the residual effects of herbicide spraying encountered by troops long after the actual date of herbicide application.

In a previous survey of veterans [Stellman and Stellman, 1980] we recorded reports of hundreds of servicemen who had entered freshly denuded forests, and who camped within defoliated areas, either in the jungle or near the perimeters of their base camps, in areas which were recently sprayed. In addition, men could have been exposed by spending time in areas long after spraying took place. Men on extended jungle patrols often swam in and drank water from streams that drained defoliated areas. The possibility of exposure from the latter source cannot be ruled out. Tissue samples from rodents, birds, fish, and reptiles trapped several years after spray tests were halted at a Florida test site for Agent Orange (Table 5) contained traces of dioxin [Young et al.,1978, p. III-19].

It is precisely for these reasons that it is impossible to give credence to any health effects study in which assignment of herbicide exposure levels to individual veterans is based solely upon self-reports.

We are aware, of course, of limitations associated with surveys of self-selected individuals. In health surveys subjects can be self-selected for a variety of reasons, including concern over possible exposure to Agent Orange, and concern about their own health. For this reason, any studies relating exposures to health outcomes in this population are likely to be highly biased. However, since no veteran could possibly know the thousands of dates and places of missions on the tape, there can be very little selection bias in this measure.

Therefore, we believe this to be an independent and objective source of exposure information, despite the fact that our data was elicited from participants who selected themselves to participate in our survey. Furthermore, from the wide variability of the aggregated indices for these specific locations, we infer that it would be quite difficult for a subject to deliberately fabricate a high score for himself. That is, a subject is highly unlikely to be able to identify places at random, and expect that the scores for those places, restricted to the time period he served in Vietnam, would be especially high.

Because questionnaires are all self-administered, there is the usual problem of how to handle missing or obviously incorrect information. Our evaluation algorithms are biased towards minimizing exposure by truncating Vietnam location dates according to overall dates of service in Vietnam, and eliminating records with no dates at all. The majority of respondents took great pains to fill out the exposure related section and the Vietnam location and date section with care. Fewer than five questionnaires from obviously unreliable subjects were eliminated. Recent experience with another, non-self-selected group, comprising a random sample of several state membership lists of the American Legion, convinces us that veterans possess and utilize many resources to recall just where they were in Vietnam and what they did there. (Study in progress.)

A still more accurate exposure method would, in addition, assign different exposure values to each mission, according to the actual number of gallons dispersed, the area sprayed, the rate of dispersion and even the meterological conditions, if this data were available. For the great majority of missions the results obtained here would not change because, as indicated above, the ratio of gallons to area was nearly constant. Without taking differing concentrations into account, the method is, at worst, a conservative approach to exposure estimation because the small number of concentration outliers are concentrated in the missions carried out over the smallest acreage, hence possibly representing the most intense exposure.

It is probable that we are underestimating exposure arising from backpacking and other small, but intense uses of herbicides since we know that most of the missions with a substantially different gallons/area ratio from the calculated average fall in the low gallonage category. Refinement of the method, with variations in concentration and in different types of spray missions taken into account, is currently underway. The U.S. Army is revising the 1980 HERBS tape to provide still more accurate data on backpacking missions. This new information will be incorporated into our method as soon as it becomes available.

It may, of course, be possible for other researchers, particularly those engaged in large, government-sponsored studies, to obtain complete military records of troop movements in Vietnam, as has been attempted by Erickson et al. [1984b], and to apply this or similar methods to derive still more accurate exposure information, thereby possibly eliminating many of the drawbacks associated with personal recall and use of self-administered questionnaires and approximations of concentration. On a more modest level, the method outlined in this article can be readily applied at minimal expense by the many registries and projects now being carried out by state agencies and private research groups.

The obvious next step is to examine the prevalence of adverse health conditions in relation to the values of the herbicide exposure indices described in this paper. Such studies are now in progress.

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TABLE 1

DATA CONTAINED ON HERBS TAPE

Date (Month/Day/Year)

Combat Tactical Zone (I, II, III, IV)

Mission Number

Agent (Orange, White, Blue)

No. of Gallons

Type of Mission (Defoliation, Crop
Destruction, etc.)

Area Sprayed (Hectares)

Leg Designator: 1A, 1B, etc.

UTM Coordinate of Leg

TABLE 2

Wording of Questions on Self-Described Exposure to Agent Orange

In this section we are interested in finding what you remember about being exposed to defoliating herbicides, such as Agent Orange, which were used to kill jungle cover in Southeast Asia. If you believe you were exposed to such a chemical agent, either by directly loading it, spraying it, or entering a freshly sprayed area, we would like you to describe how you were exposed and when.

If you don't remember being directly exposed to herbicides, check here: ____ and go on to next page.

	No	Yes	If yes, No. of weeks
Sprayer on C-123	___	___	___
Sprayer on Helicopter	___	___	___
Sprayer on boat	___	___	___
Loader/handler of spray on any of the above	___	___	___
Job involved clearing vegetation and/or patrolling around camp, roads, or clearing free-fire zones	___	___	___
Slept/walked through sprayed areas. Exposed to herbicides used near camp or on roads you traveled on	___	___	___
Handler of spray during storage or shipment	___	___	___

TABLE 3

Number of Herbicide Spray "Hits" within 5, 10, and 15 km of Six Selected Sites in Vietnam (1965-1971)

Place	No. of spray hits within: 5 km	10 km	15 km	Exposure Index E_1*
Tay Ninh	0	5	33	2.814
Chu Lai	2	33	55	6.304
Khe Sanh	15	23	55	8.264
Camp Evans	3	35	110	10.609
Phuoc Vinh	27	144	356	38.958
Pleiku	69	74	121	43.600

*Defined by Eq. (1)

TABLE 4

Statistical Comparisons Between Mean Exposure Indices For Veterans Self-Described as "Exposed" and "Not Exposed" to Agent Orange

VARIABLE	Average Value of Variable for Veterans Reporting Exposure	Average Value of Variable for Veterans Not Reporting Exposure	$\underline{p}$
	(Numbers of veterans are given in parentheses)		
E_1	8.94 (303)	8.39 (175)	N.S.
E_2	8.25 (303)	5.85 (175)	<.01
E_3	0.98 (303)	0.74 (175)	<.05

	Mean Rank	Mean Rank	Mann-Whitney U	$\underline{p}$
C_{15}	248.9 (303)	223.2 (175)	2364.5	<.05

TABLE 5

Levels of TCDD Found in Animals 3 to 8 Years After Heavy Spraying of Agent Orange at Eglin Air Force Base, Florida

SPECIES	TISSUE	CONCENTRATION (ppt)
Mammals:		
Beachmouse	Liver	300 - 2400
Hispid Cotton Rat	Liver	<10 - 210
Birds:		
Meadowlark	Liver	100 - 1020
Mourning Dove	Liver	50
Savannah Sparrow	Liver	69
Fish:		
Spotted Sunfish	Liver	86
Mosquito Fish	Whole Body	12
Sailfin Shiner	Whole Body	12
Amphibia:		
6-Lined Racerunner	Muscle	360 - 430

Source: Young et al., 1978

CAPTIONS FOR FIGURES

Figure 1. Representation of a typical spray mission flown near Pleiku. Plane sprayed continously from 1A to 1F, flew without spraying to 2A, then sprayed from 2A to 2B. Number of vertices or "hits" falling within radii of 5, 10, and 15 km are 3, 6, and 8, respectively.

Figure 2. Quantities of Herbicides Orange, White, and Blue used in Defoliation and Crop Destruction missions in South Vietnam, 1965-1971.

Figure 3. Quantities of Herbicides Orange, White, and Blue use in five minor types of missions in South Vietnam, 1965-1971.

Figure 4. Quantities of three herbicides used in South Vietnam, 1965-1971, by calendar quarter.

Figure 5. (a) Mean discrete exposure index C_{15} computed for men with six different job categories with probable Agent Orange exposure, and for men not likely to have been exposed. (b) Same for continuous exposure index E_3.

Figure 1

NUMBER OF "HITS"		
5 km	10 km	15 km
3	6	8

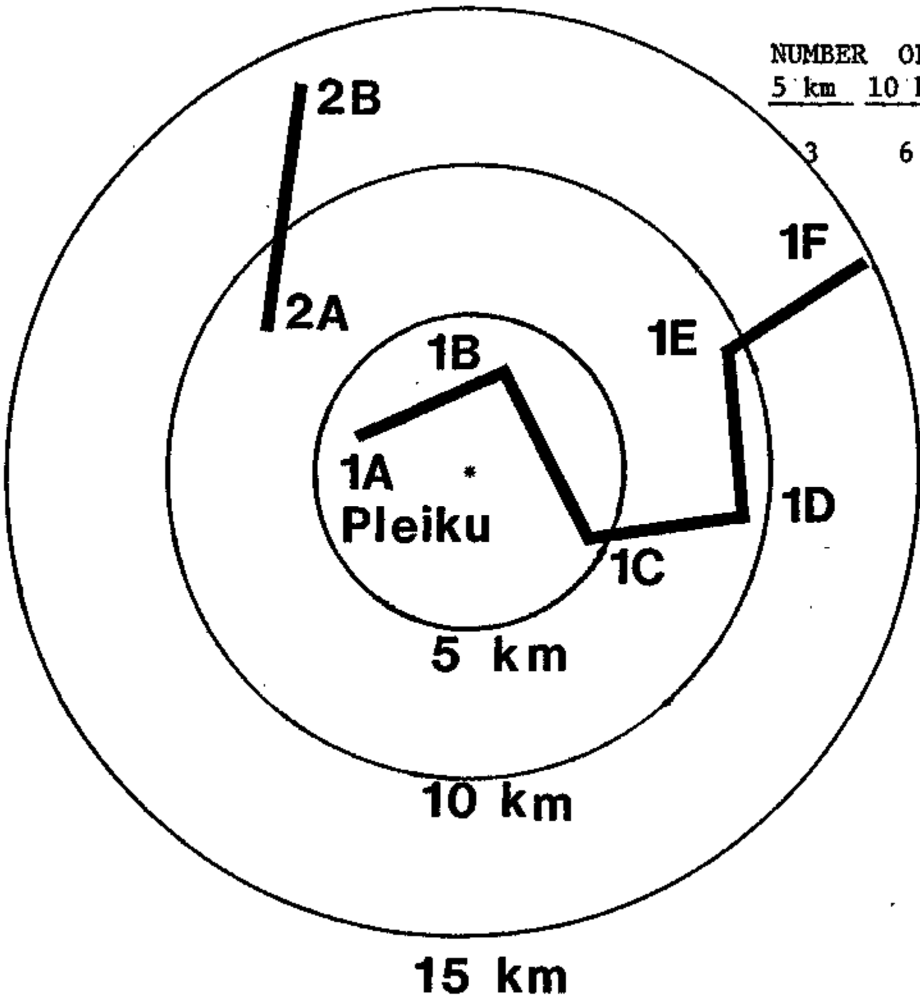


Figure 2

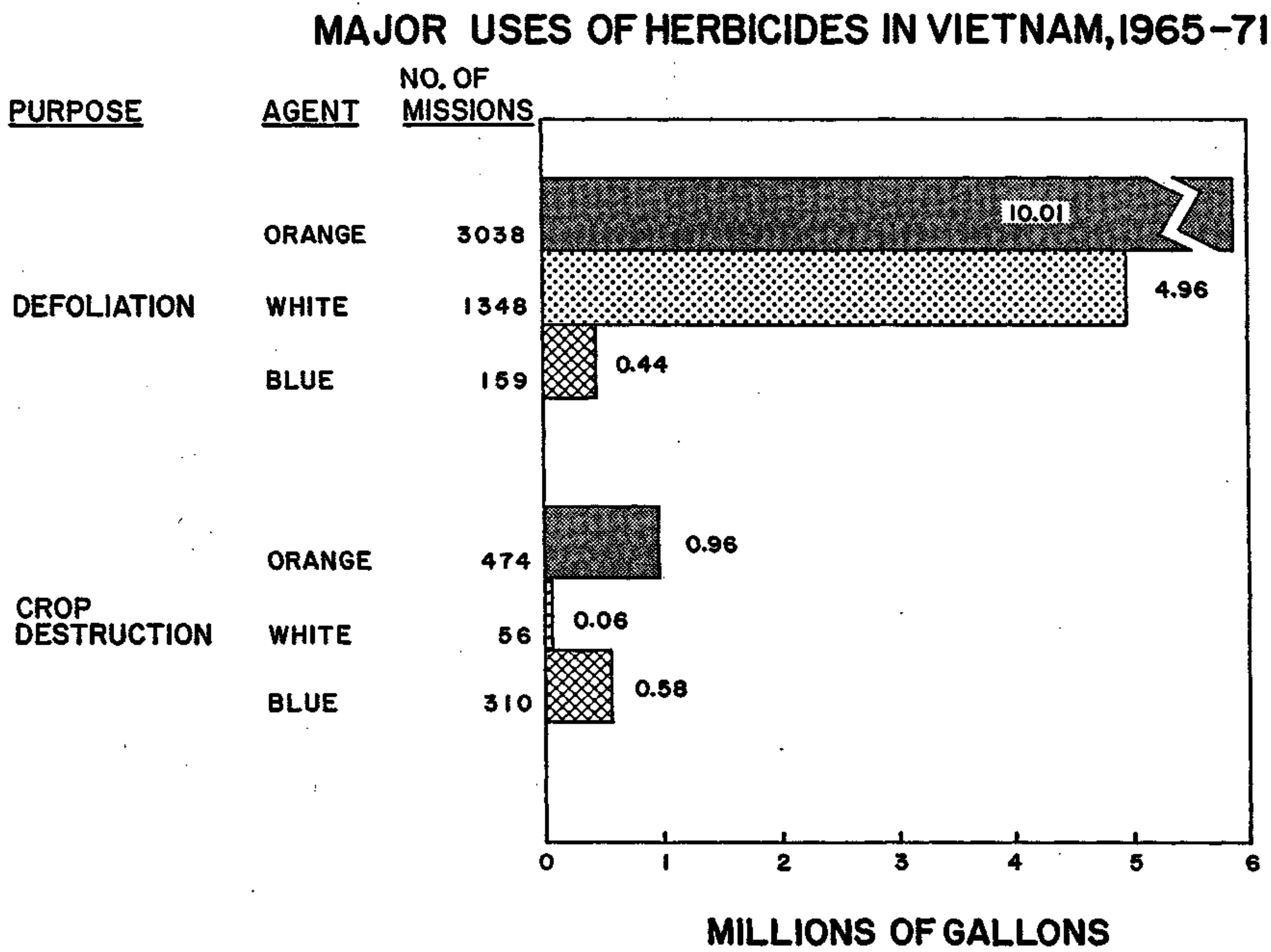
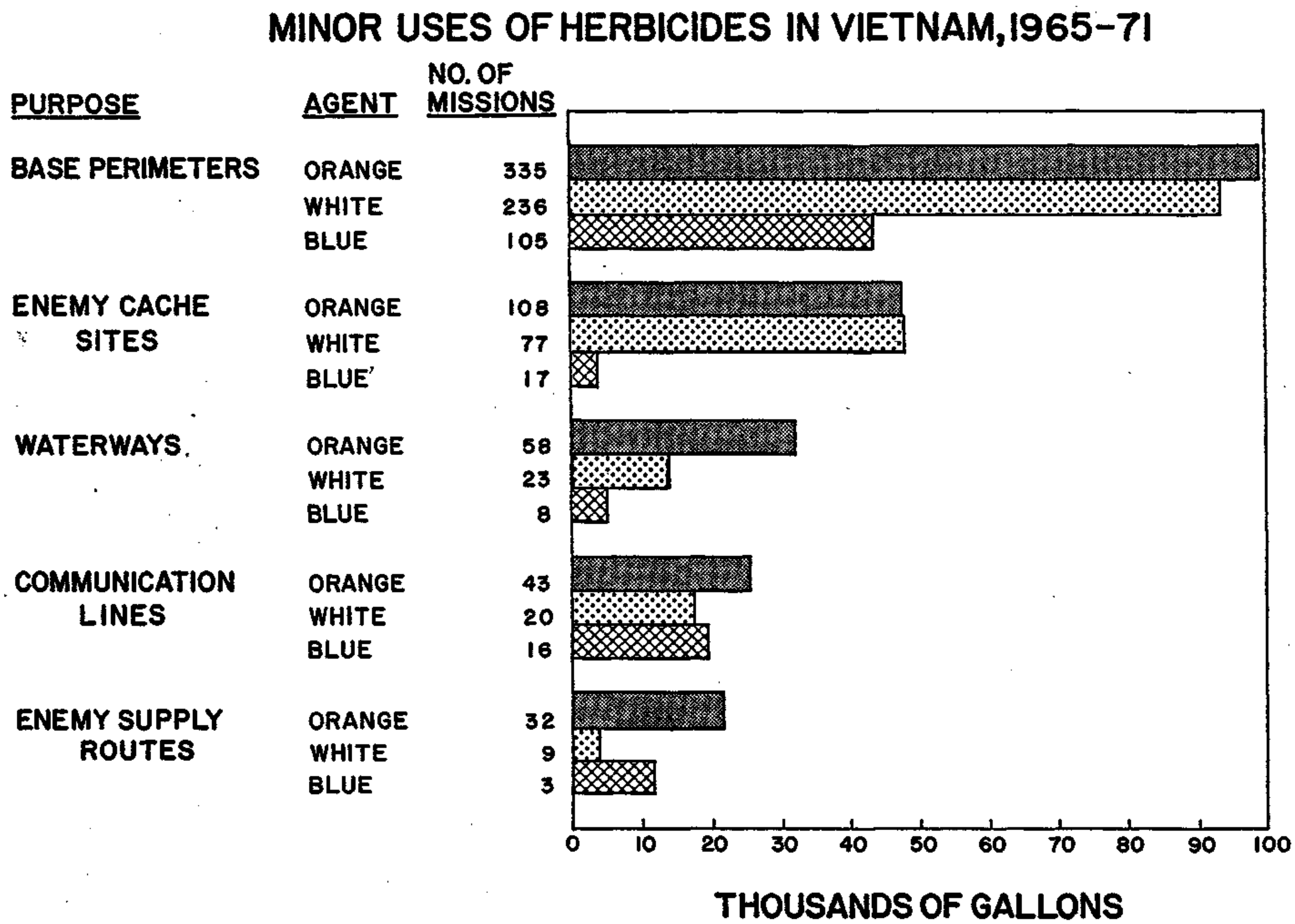

MAJOR USES OF HERBICIDES IN VIETNAM, 1965-71
PURPOSE
AGENT
NO. OF MISSIONS
DEFOLIATION
ORANGE
3038
10.01
WHITE
1348
4.96
BLUE
159
0.44
CROP DESTRUCTION
ORANGE
474
0.96
WHITE
56
0.06
BLUE
310
0.58
0
1
2
3
4
5
6
MILLIONS OF GALLONS

Figure 3



MINOR USES OF HERBICIDES IN VIETNAM, 1965-71
PURPOSE
AGENT
NO. OF MISSIONS
BASE PERIMETERS
ORANGE 335
WHITE 236
BLUE 105
ENEMY CACHE SITES
ORANGE 108
WHITE 77
BLUE 17
WATERWAYS
ORANGE 58
WHITE 23
BLUE 8
COMMUNICATION LINES
ORANGE 43
WHITE 20
BLUE 16
ENEMY SUPPLY ROUTES
ORANGE 32
WHITE 9
BLUE 3
0 10 20 30 40 50 60 70 80 90 100
THOUSANDS OF GALLONS

Figure 4

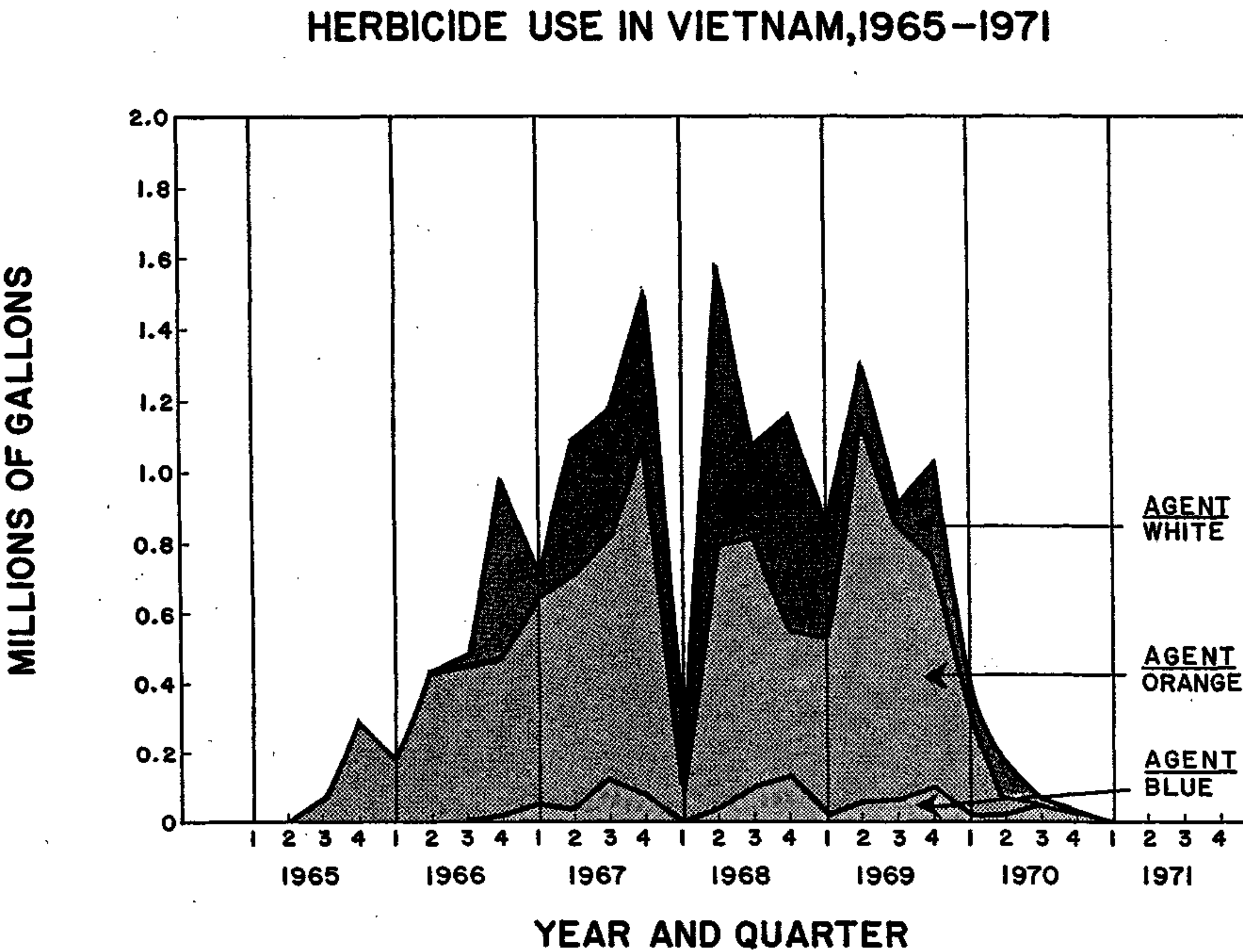
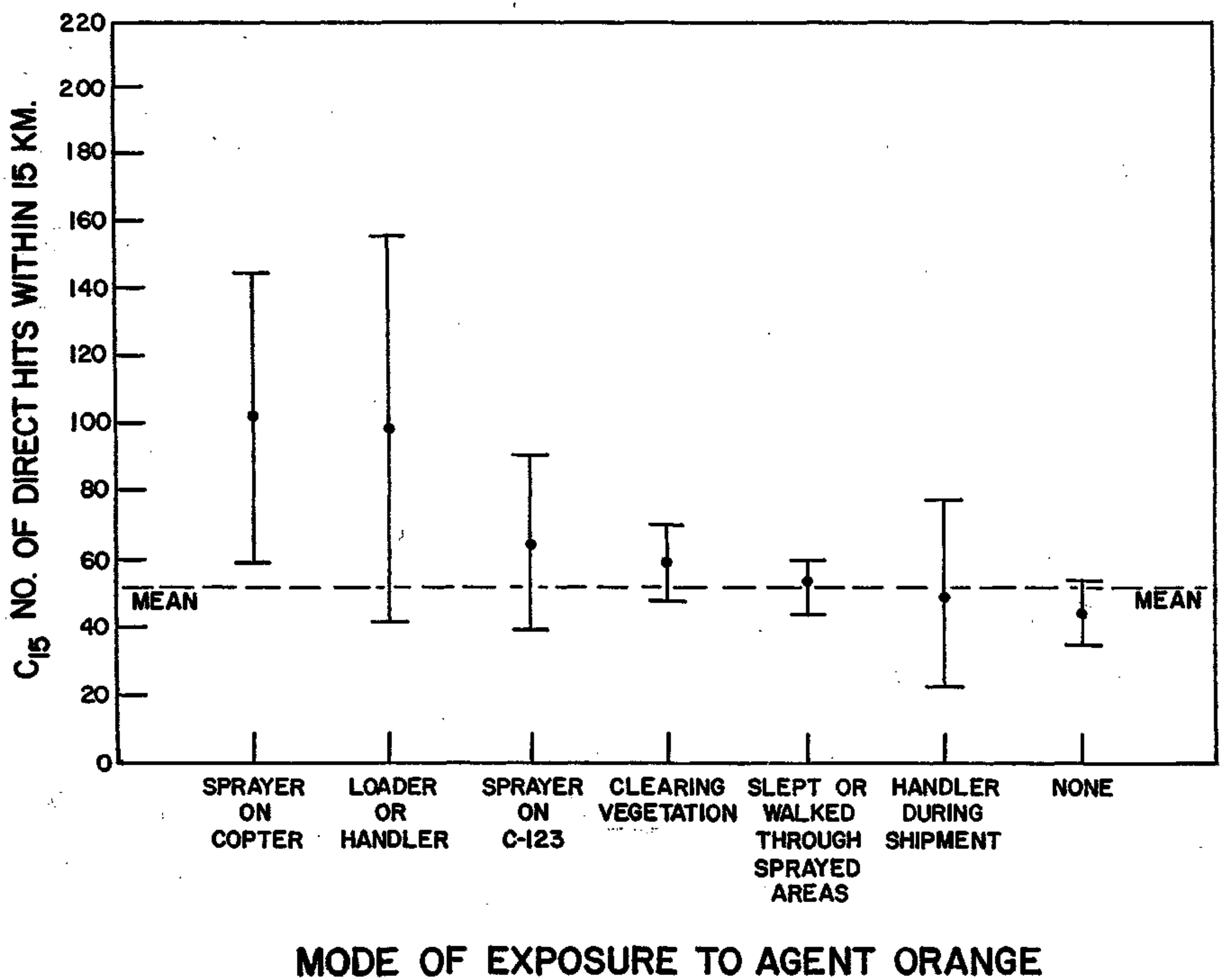
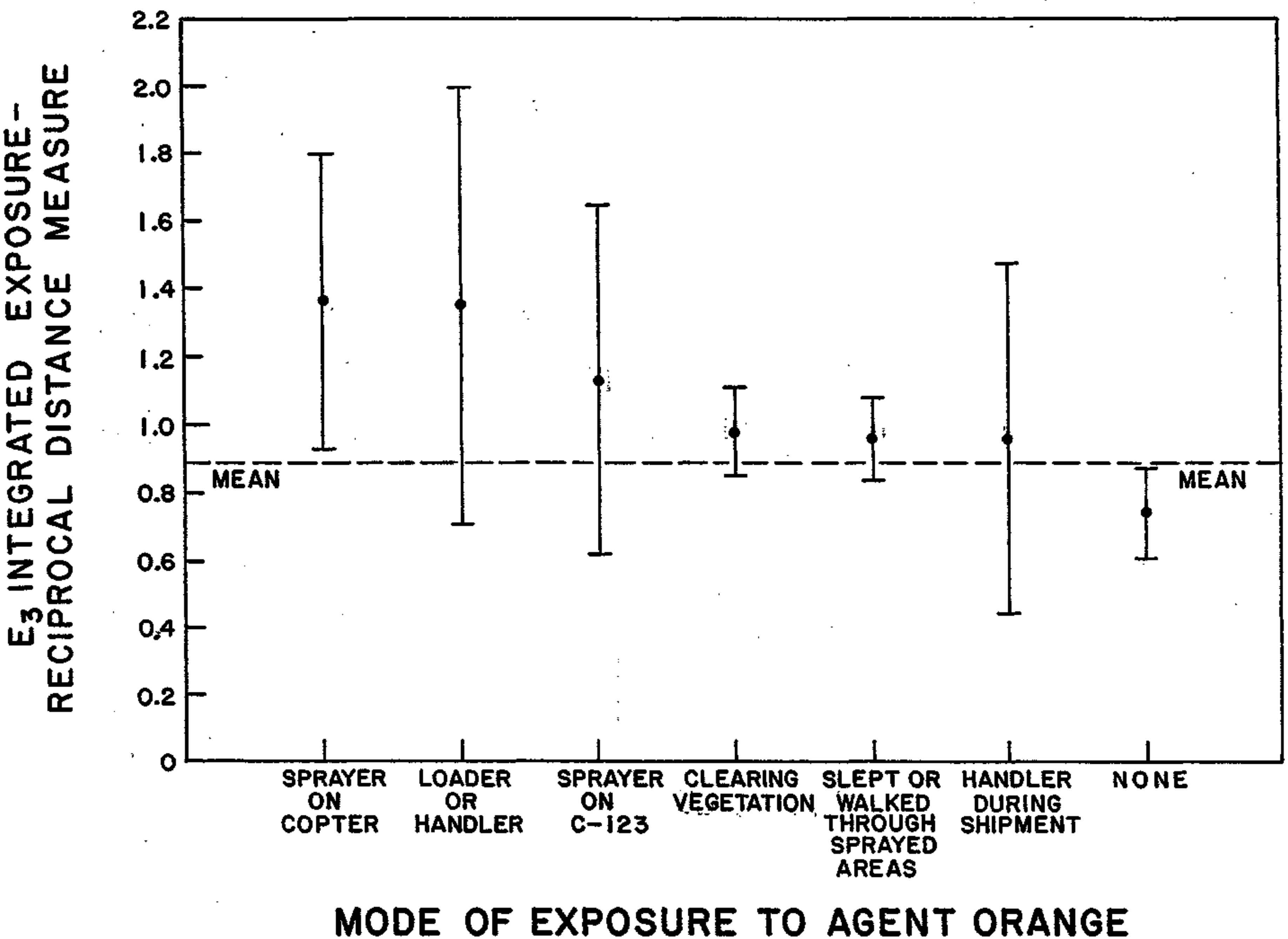

HERBICIDE USE IN VIETNAM, 1965–1971
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
MILLIONS OF GALLONS
AGENT WHITE
AGENT ORANGE
AGENT BLUE
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
1965
1966
1967
1968
1969
1970
1971
YEAR AND QUARTER

Figure 5 (a)



C_{15} NO. OF DIRECT HITS WITHIN 15 KM.
220
200
180
160
140
120
100
80
60
40
20
0
MEAN
MEAN
SPRAYER ON COPTER
LOADER OR HANDLER
SPRAYER ON C-123
CLEARING VEGETATION
SLEPT OR WALKED THROUGH SPRAYED AREAS
HANDLER DURING SHIPMENT
NONE
MODE OF EXPOSURE TO AGENT ORANGE

Figure 5 (b)



E_3 INTEGRATED EXPOSURE-
RECIPROCAL DISTANCE MEASURE
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
MEAN
MEAN
SPRAYER ON COPTER
LOADER OR HANDLER
SPRAYER ON C-123
CLEARING VEGETATION
SLEPT OR WALKED THROUGH SPRAYED AREAS
HANDLER DURING SHIPMENT
NONE
MODE OF EXPOSURE TO AGENT ORANGE