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Exposure of Workers to Pesticides

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IN ORDER to evaluate the hazard to the health of workers using pesticides, it is important to know the amount of exposure which workers undergo while carrying out various jobs related to the preparation and use of these compounds. Both direct and indirect methods are available for measuring exposure. The direct methods are those which utilize some mechanism to entrap the toxic material as it comes in contact with the workman or to remove the retained toxicant at the end of the exposure period. The amount of toxicant trapped or removed is then a direct measure of the particular exposure being studied. The indirect methods involve the detection of the pesticide or its metabolite(s) in body tissue or excreta or the measurement of some pharmacologic effect of the toxicant on the exposed individual.

The indirect methods have been quite extensively employed in studying exposure of workers to pesticides. Thus, the exposure of workers to DDT has been estimated on the basis of their body fat content of DDT and DDE[1,2] or of urinary excretion level of the metabolite DDA.[3,4] Exposure of subjects whose occupations involved use of dieldrin has been determined from excretion levels of dieldrin-derived material in urine.[5] A number of surveys of exposure of workers to organic phosphorous insecticides using blood cholinesterase activity level as the have been reported.[6-12] Exposure thion has been estimated from ur. cretion of the hydrolytic product *p*-nitrophenol.[13-15]

The indirect methods for measuring exposure to pesticides have been less used. The first study of this type was apparently carried out by Batchelor and Walker[16] who determined the exposure of orchard spraymen to parathion. These investigators used α-cellulose pads on the exposed skin area and in the respirator to entrap the pesticide and, thus, serve as an indicator of contamination. Later work has followed this general procedure although some refinements have been introduced. The methodology has been reviewed in detail by Durham and Wolfe.[17] The published studies of exposure of workers to pesticides which have been carried out using direct methods are summarized in Table 1.

The present paper reports the results of pesticide exposure studies using direct methods for a number of agricultural and public health vector control work situations. The effect of a number of factors on the level of exposure has been determined. Factors studied include wind, type of activity, method and rate of application, duration of exposure, route of exposure, and attitude of workmen. The hazard to workers of various activities involving different pesticides is evaluated.

Materials and Methods

Samples to permit measurement of exposure were collected in the field while the workmen

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were carrying out their usual duties. There were 31 different work activities studied, involving ten different pesticides. Although the results for ten of these work activities have been partially reported in previous publications from this laboratory, they are included here along with additional recent data to give the best available exposure values for these situations.

Estimation of the amounts of pesticide exposure that workers would potentially incur followed the techniques and procedures described in detail by Durham and Wolfe.[17] Potential dermal contamination was measured primarily by attaching absorbent α-cellulose pads for spray exposure, or layered gauze pads for dust exposure, to various parts of the body or clothing of workers and allowing them to become contaminated during a timed interval of work. Contamination of the hands was measured either by rinsing in a suitable solvent in a polyethylene bag or by swabbing with solvent-impregnated gauze swabs.

Respiratory exposure was estimated from the contamination of filter pads held in special single or double-unit respirators or from air concentration values determined by use of impinger-type air samplers or both.

The dermal and respiratory exposure pads were extracted with a suitable solvent in a Soxhlet apparatus.

Chemical analysis for the various compounds was done using the following methods: azinphosmethyl, Meagher et al;[18]; Chlorthion, a modification (Chemagro Corporation, unpublished data) of the Averell-Norris procedure;[19] DDT, a modification by Mattson et al[20] of the method of Schechter et al[21]; demeton and TEPP, a total phosphorus method[22]; dieldrin, O'Donnell et al[23]; DNOC (sodium salt of dinitro-*o*-cresol), Wolfe et al[24]; endrin, the paper chromatography procedure described by Mitchell[25] malathion, electron-capture gas chromatography[26]; and parathion, Averell-Norris.[19]

A total of 3,555 analyses of dermal pads and 333 analyses of respirator pads were carried out in the present study.

Dermal exposure values were calculated on the assumption that the exposed person wore a short-sleeved, open-necked shirt, no gloves or hat, and that his clothing gave complete protection of the areas covered. This amount of clothing was elected since it represented just about the smallest amount of protection which was observed in the field. However, some spraymen wore additional protective clothing such as a hat or cap, long-sleeved shirt, or even a jacket or coveralls. It was considered advisable to calculate potential exposure based on the lesser amount of protective clothing so that safety recommendations derived from these calculations would tend to be on the conservative side. The surface areas of the usually unclothed body parts (face, back of neck, "V" of chest, forearms, and hands) were determined using Berkow's[27] values for surface area. The total calculated dermal exposure was the sum of the exposures of the usually unclothed body parts.

The respiratory exposure was assumed to be equivalent to the contamination of the respirator pad or pads. Alternatively, air concentration values taken as near the breathing zone as possible were multiplied by an assumed value for lung ventilation rate of 1,740 liters/hr[28] during the light work involved in spraying to obtain respiratory exposure.

Calculation of the total exposure in terms of the percentage of the toxic dose was made by the procedure described by Durham and Wolfe.[17] The calculations were based on comparison between the dermal and respiratory exposure values determined here and values by Gaines (unpublished data) for doses toxic to the rat.[20]

Results and Comment

The values of dermal and respiratory exposure and for total exposure in terms of fraction of toxic dose per hour of work as determined in the present study are shown in Table 2.

Factors Affecting Level of Exposure.—There were wide ranges in exposure level for a given work activity with a specific pesticide depending on the environmental conditions, technique of the operator, and, perhaps, other factors. These variations ranged up to about 200-fold for dermal exposure associated with applying parathion to fruit trees with an air blast dilute spray machine and up to almost 300-fold for respiratory exposure associated with spraying parathion on fruit trees using a concentrate spray machine.

Wind.—The most important environmental condition studied with regard to effect on exposure was wind. Wind was thought to be an important factor in determining the 552 mg/hr exposure to parathion for an operator spraying parathion in a fruit orchard with an air blast machine. This level was the highest potential dermal exposure determined in the present study. This exposure

Table 1.—*Summary of Published Studies on Potential Exposure of Workers to Pesticides Using Direct Methods*

Compound	Activity	Exposure: Dermal (mg/hr)	Exposure: Respiratory (mg/hr)	Exposure: Total (% Toxic Dose/hr)	Reference
Azinphosmethyl	Checking cotton for insect damage	5.4	el*	(0.04)†	51
Azinphosmethyl	Air blast spraying fruit orchards during night	541	0.47	6.5 (3.5)‡	34
Azinphosmethyl	Air blast spraying fruit orchards during day	755	0.54	8.4 (4.9)†	34
Azinphosmethyl	Air blast spraying fruit orchards	12.5	0.26	(0.1)	30
Azinphosmethyl	Air blast spraying fruit orchards	9.9	0.1	0.15	46
Azinphosmethyl	Air blast spraying fruit orchards	27.2	0.04	0.18	This paper
Azinphosmethyl	Filling spray tank	52.9	1.27	0.72 (0.46)§	30
Azinphosmethyl	Working in formulating plant	10.1	0.56	(0.1)	30
Benzene hexachloride	Spraying forests	(70.3)	(3.06)	(0.29)	52
Benzene hexachloride	Hand spraying for mosquitoes	(10.2)	(4.29)	(0.15)	Wassermann M. et al, unpublished data
Carbaryl	Air blast spraying fruit orchards	25.3	0.29	0.03	33
Carbaryl	Air blast spraying fruit orchards	24.9	0.48	0.02	46
Chlorthion	Operating aerosol machine for mosquitoes	(3)	(0.3)	(0.003)	53
DDT	Indoor house spraying	543	...	(>0.31)	54
DDT	Indoor house spraying	1,755	7.1	(1.02)	48
DDT	Outdoor house spraying	~ 84	...	(>0.05)	54
DDT	Outdoor house spraying	243	0.11	(0.14)	48
DDT	Spraying forests	(212)	(4.92)	(0.15)	52
Dieldrin	Hand-spraying of dwellings for disease vector control	(18.6)	...	(>0.33)	55
Dieldrin	Spraying pear orchards	14.2	0.25 (0.03)‖	0.24	56
Dieldrin	Operating power air blast machine spraying fruit orchards	15.5	0.03	0.25	This paper
Dieldrin	Power hand gun spraying fruit orchards from portable machine	15.1	0.03	0.25	This paper
DNOC	Spray-thinning apples	63.2	0.4	(0.25)	47
DNOC	Spray-thinning apples	57.5	2.75	0.20	34
DNOC	Spray-thinning apples	24.4	0.03	(0.1)	24
DNOC	Chemical thinning apple blossoms by power hand gun spraying	55.1	0.13	0.13	This paper
DNOC	Chemical thinning apple blossoms by power air blast spray machine	22.5	<0.05	0.05	This paper
DNOSBP	Herbicide spraying corn and pea fields with boom ground sprayers	88.7	0.12	(0.57)	24
Endrin	Spraying orchard cover crops for mouse control	2.6	0.01	0.21	56
Endrin	High pressure power hand gun spraying orchard cover crops for mouse control	3	0.01	0.25	This paper
Endrin	Operating power air blast or boom sprayers treating orchard cover crops for mouse control	2.5	0.01	0.21	This paper
Endrin	Dusting potatoes	18.7	0.41	1.5	56
Endrin	Spraying row crops	0.15	el	(0.01)	33
Endrin	Piloting airplane during air application	1.18	0.08	0.29 (0.16)‡	33
Malathion	Operating aerosol machine	(6.6)	(0.3)	(0.003)	53
Malathion	Air blast spraying fruit orchards	2.5	0.08	0.002 (0.001)‡	33
Malathion	Air blast spraying fruit orchards	30	0.11	0.01	This paper
Malathion	Persons outdoors during air application to populated area.	(0.89)	(0.055)	(<0.001)	57
Malathion	Persons indoors during air application to populated area	(0.25)	(0.012)	(<0.001)	57

Table 1.—*Summary of Published Studies on Potential Exposure of Workers to Pesticides Using Direct Methods (Continued)*

Compound	Activity	Exposure: Dermal (mg/hr)	Exposure: Respiratory (mg/hr)	Exposure: Total (% Toxic Dose/hr)	Reference
Methyl Parathion	Checking cotton for insect damage	0.7	el	(0.02)	51
Parathion	Air blast spraying fruit orchards	77.7	0.16	(5.4)	16
Parathion	Air blast spraying fruit orchards	2.4	0.03	0.43 (0.18)‡	33
Parathion	Air blast spraying fruit orchards	19	0.02	1.33	45
Parathion	Concentrate air blast spraying fruit orchards	28	0.06	1.95	45
Parathion	High pressure power hand gun spraying fruit orchards	55.8	0.19	(3.9)	16
Parathion	Hand knapsack mist spraying tomato bushes	9.1	0.29	(0.82)	58

* el indicates "below the experimental limits of the chemical method."
† All values shown in parentheses were not included in the original paper but were calculated by the present authors.
‡ Calculations based on the original authors' published dermal and respiratory exposure data indicated that the correct total exposure as a percentage of the toxic dose per hour should be the values shown in parentheses rather than the figures originally published.
§ These original values were calculated on the basis of maximum exposure. The recalculated values shown in parentheses are based on mean exposure.
‖ Study of the original data on which the published respiratory value (0.25 mg/hr) was based indicated that this figure was derived in error and should have been 0.03 mg/hr.

indicated that the sprayman was receiving 37% of the toxic dose per hour of work. However, the operator was wearing very effective protective clothing and probably actually absorbed only a small fraction of the estimated potential exposure.

Type of Activity.—There appeared for each given pesticide to be a significant variation in hazard depending upon the type of activity in which the worker was engaged. In the case of DDT, as shown in Tables 1 and 2, indoor house spraying was about 4 times as hazardous as flagging for airplane dusting of fruit orchards, approximately 7 times as hazardous as outdoor house spraying, and over 30 times as hazardous as operating an air blast spray machine in a fruit orchard.

Various phases of an operation determined different rates of exposure. For example, in airplane application of 1% TEPP dust to a fruit orchard, the loader received about 3 times as much exposure as the pilot and about 4½ times as much as the flagman. A similar finding has been reported by Jegier[30] who noted for orchard air blast spraying considerably higher rates of dermal and respiratory exposure to azinphosmethyl during loading than during the spray cycle as a whole.

Activities which did not involve direct contact with insecticides were generally associated with relatively low levels of exposure. For example, entomologists observing mosquito control operations with Chlorthion or malathion incurred 0.002% of the toxic dose per hour. Workers picking pole beans one and two days after application of malathion dust sustained 0.001% and less than 0.001% of the toxic dose, respectively. The exposure levels (as the percentage of toxic dose) for these two activities were the lowest of all work activities studied.

Loaders and flaggers for air applications received relatively high levels of exposure, particularly by the dermal route. For example, a flagman in aerial application of DDT to a fruit orchard had a dermal exposure rate of 517 mg/hr. It is possible that in this instance the worker, knowing that DDT was a relatively nontoxic compound, made little effort to keep out of the drift. Airplane loaders—particularly those working with dusts—often became heavily contaminated as shown by the maximum (135 mg/hr) value for TEPP exposure, which corresponded to about 83% of the toxic dose.

Method and Rate of Application.—The amount of potential exposure depended also upon the method of application. There was more exposure while operating equipment

Table 2.—*Potential Dermal and Respiratory Exposure of Workers to Selected Pesticides as*

Compound	Formulation	Rate of Application (Lbs Active Ingredient/Acre)	Activity	No. of Samples Analyzed: Dermal	No. of Samples Analyzed: Respirator
Azinphosmethyl	0.05% spray	3	Operating power air blast machine spraying fruit orchards	215	8
Chlorthion*	5% aerosol	...	Operating aerosol machine for mosquito control	112	10
Chlorthion*	5% aerosol	...	Entomologist field observers checking for mosquito control near aerosol machine operation	170	20
DDT	0.09% spray	8	Operating power air blast machine spraying fruit orchards	258	15
DDT	35% dust	17.5	Flagging for airplane dusting of fruit orchards	21	1
Demeton	0.03% spray	2	High pressure power hand gun spraying fruit trees in nursery	48	6
Demeton	0.03% spray	2	Driving tractor pulling high pressure power hand gun sprayer in nursery	31	3
Dieldrin*	0.02%-0.03% spray	2-2.5	Operating power air blast machine spraying fruit orchards	42	2
Dieldrin*	0.03% spray	2.5	Power hand gun spraying fruit orchards from portable machine	42	2
DNOC*	0.02%-0.04% spray	1.1-2.1	Chemical thinning apple blossoms by power hand gun spraying	25	6
DNOC*	0.02%-0.04% spray	1.1-2.1	Chemical thinning apple blossoms by power air blast spray machine	177	22
Endrin*	0.05% spray	1.2	High pressure power hand gun spraying orchard cover crops for mouse control	194	10
Endrin*	0.05% spray	1.2	Operating power air blast or boom sprayers treating orchard cover crops for mouse control	70	12
Malathion	0.04%-0.08% spray	3-4	Operating power air blast machine spraying fruit orchards	44	7
Malathion	0.03%-0.08% spray	3-4	High pressure power hand gun spraying fruit orchards	94	13
Malathion	4% dust	1.4	Operating power duster applying pesticide to pole beans	14	4
Malathion	4% dust	1.4	Picking pole beans one day after dust application	194	6
Malathion	4% dust	1.4	Picking pole beans two days after dust application	42	1
Malathion*	2.5-5% aerosol	...	Operating aerosol machine for mosquito control	166	14
Malathion*	2.5-5% aerosol	...	Entomologist field observers checking for mosquito control near aerosol machine operation	238	30
Parathion	0.05% spray	2-3	Operating power air blast machine spraying citrus groves	40	8
Parathion	0.05% spray	2-3	Driving tractor pulling portable tower hand gun power sprayer during application in citrus groves	30	5
Parathion	0.05% spray	2-3	High pressure power hand gun spraying from tower position of portable spray machine—citrus groves	41	7
Parathion	0.05% spray	2-3	High pressure power hand gun spraying from ground position near portable tower sprayer—citrus groves	76	13
Parathion	2% dust	1	Piloting airplane dusting fruit orchards	18	3
Parathion	9% spray	...	Flagging for airplane application to fruit orchards	75	12

(Table continued on pp 628-629.)

Determined by a Direct Method

Value	Dermal (mg/hr)	Respiratory (mg/hr)	Total (% toxic dose/hr)
Range	1.1-146	0.02-0.08	0.01-0.95
Mean	27	0.04	0.18
Range	1.9-12	0.08-0.5	0.01-0.02
Mean	6.8	0.28	0.01
Range	0.8-1.6	0.05-0.08	0.001-0.003
Mean	1.1	0.07	0.002
Range	3.2-392	0.02-0.27	0.002-0.23
Mean	54	0.1	0.03
Range	395-517	...	...
Mean	420	0.2	0.24
Range	1.6-5.8	0.01-0.03	0.17-0.62
Mean	3.1	0.01	0.33
Range	1-2.5	0.01-0.03	0.11-0.29
Mean	1.9	0.01	0.21
Range	6.3-31.1	0.02-0.04	0.1-0.5
Mean	15.5	0.03	0.25
Range	3.4-29.5	0.02-0.04	0.06-0.48
Mean	15.1	0.03	0.25
Range	7-90.2	<0.02-0.42	0.02-0.22
Mean	55.1	0.13	0.13
Range	2.9-131	<0.04-0.08	0.01-0.31
Mean	22.5	0.05	0.05
Range	1.5-7.1	0.001-0.03	0.12-0.59
Mean	3	0.01	0.25
Range	1.3-6.1	<0.001-0.02	0.1-0.49
Mean	2.5	0.01	0.21
Range	5.9-59	0.02-0.24	0.002-0.02
Mean	30	0.11	0.01
Range	8.4-194	0.01-0.25	0.003-0.06
Mean	67	0.09	0.02
Range	17-32	0.22-1.23	...
Mean	23	0.73	0.01
Range	<0.5-28	...	<0.001-0.01
Mean	3.9	<0.02	0.001
Range	<1.5-4.3	...	...
Mean	2.1	<0.02	<0.001
Range	3.7-53	0.02-0.10	0.001-0.02
Mean	29	0.09	0.01
Range	2.3-6.4	0.04-0.09	0.001-0.003
Mean*	4.1	0.06	0.002
Range	1.3-38	0.01-0.07	0.09-2.60
Mean	18	0.03	1.17
Range	5.5-25	0.01-0.06	0.38-1.77
Mean	12	0.03	0.84
Range	1.0-28	0.004-0.05	0.07-1.94
Mean	11	0.03	0.77
Range	20-113	0.02-0.19	1.35-7.8
Mean	47	0.09	3,3
Range	8.3-19	0.01-0.04	0.57-1.35
Mean	13	0.02	0.87
Range	9.5-306	0.003-0.08	0.65-20.8
Mean	84	0.02	5.72

which directed spray upward into the air where it was more subject to drift than when operating equipment that directed the spray downward. For example, taking into consideration the difference in dilution of the sprays being used, potential exposure while operating an air blast machine spraying fruit orchards with parathion was about 12 times as great as during application of the same compound on row crops with a boom-type sprayer that directed the spray downward and, thus, resulted in less drift. The effects of some other methods of application on exposure, particularly by the respiratory route, are discussed below under route of exposure.

Another variable which might be expected to influence exposure of applicators was rate of application. This value is shown in table 2 for each of the exposure situations studied. Very little data on the influence of changes in rate of application on exposure were obtained, however, because all operators tended to use approximately the same dosage in a given circumstance. The maximum variation in application rate which was observed in these studies was for DNOC which varied from 1.1 to 2.1 lbs of active ingredient per acre. The application rates which were generally used were those recommended by the Washington State University and the US Department of Agriculture.

Duration of Exposure.—In addition to the level of contamination incurred per hour of work, the hazard of pesticide exposure for a worker was also related to the amount of time he worked at these particular duties. Thus, it has been pointed out that, on the average, poisoning can be expected to appear most quickly, most frequently, most diversely, and most severely in those persons most extensively exposed.[31] Many work situations involving pesticide exposure did not last a full 8 hr/day and those that did usually were not continuous for many days. Particularly in the application of pesticides to agricultural crops, the work not only was usually seasonal but also was broken up into separate spraying or dusting periods of a few days each, as the pest infestation warranted. For example, air blast spraying of a fruit orchard with parathion was usually carried out only three or four times during a grow-

Table 2.—*Potential Dermal and Respiratory Exposure of Workers to Selected Pesticides as*

Compound	Formulation	Rate of Application (Lbs Active Ingredient/Acre)	Activity	No. of Samples Analyzed: Dermal	No. of Samples Analyzed: Respirator
Parathion	1% dust	0.3-0.4	Operating tractor-mounted boom ground duster in row crops	198	33
Parathion	0.09% spray	0.5	Operating tractor-mounted boom ground sprayer in row crops	48	7
TEPP	1% dust	0.5	Piloting airplane dusting fruit orchards	30	5
TEPP	1% dust	0.5	Flagging for airplane application to fruit orchards	24	5
TEPP	1% dust	0.5	Loading for airplane application to fruit orchards	34	6

* Partially reported in previous publication.

ing season. Each spray period for an individual orchardist or sprayman lasted for one to six days of eight to ten hours each, depending on the size of the orchard to be covered. These spray operations were often hampered by wind, thereby extending the period required to complete the application. However, in the case of such an extended spray period, the number of hours per day was lower. In fact, there were waiting periods of several days when adverse weather did not permit any spraying at all. These delays spread the sprayman's exposure over a relatively long period. The increase in the period over which a given amount of exposure was spread tended to decrease the toxic effect and to prevent the occurrence of illness. This has been shown to be true in various animals studied, including man. The time factor in relation to dosage is particularly important in the case of the organic phosphorus pesticides. For example, rats can withstand over a 24-hour period a dosage approximately equivalent to the acute LD_{50} level (office of Pesticides, Communicable Disease Center, unpublished data).

Route of Exposure.—The potential dermal exposure to each compound in every work situation studied was much greater than the potential respiratory exposure. The respiratory exposure for the various work situations studied ranged from 0.02% to [illegible] (mean, 0.75%) of the total (dermal plus respiratory) exposure. The fact that the skin receives a higher dose than the lungs has been noted in other work situations studied by direct methods at this laboratory[illegible] and by other investigators.[30,32,34]

In general, it is true that chemicals given at equivalent doses are absorbed more rapidly and more completely from the respiratory tract that through the skin and that studies with volunteers revealed a lack of toxic effect from large dermal doses of parathion.[35] However, parathion applied to the skin of laboratory animals has shown high toxicity[29,36] and a number of authors[37-44] have attributed instances of parathion poisoning in people to dermal contact.

In the various situations studied the average potential respiratory exposure tended to be higher in agricultural dusting operations than during agricultural spraying operations. For example, in the ground application of parathion to row crops, the average respiratory exposures were 0.16 mg/hr with dust and less than 0.01 mg/hr with spray. The respiratory exposure in these instances represented 1.6% and less than 0.2% of the total exposure with dust and spray, respectively. A relatively high respiratory exposure (0.73 mg/hr; 3.2% of the total exposure) was also noted in the ground application of malathion dust to pole beans. The potential dermal exposure was found to be about the same for a given pesticide application regardless of whether the material was applied as a spray or as a dust formulation. Thus, ground application of parathion to row crops gave skin contamination levels of 4.7 and 8.8 mg/hr with spray and dust formulations, respectively.

Disproportionately high respiratory exposure values in relation to dermal exposure levels were also found in two spray operations—use of Chlorthion aerosol for mosqui-

Determined by a Direct Method (Continued)

	Exposure		
Value	Dermal (mg/hr)	Respiratory (mg/hr)	Total (% toxic dose/hr)
Range	1.4-17	0.03-0.41	0.12-1.43
Mean	8.8	0.16	0.71
Range	2.2-11.3	...	0.15-0.72
Mean	4.7	<0.01	0.33
Range	10-53	0.02-0.47	6.29-34.5
Mean	24	0.17	15.4
Range	16-21	0.03-0.12	9.67-12.9
Mean	16	0.07	10.2
Range	43-136	0.03-0.43	25.7-83.4
Mean	73	0.15	44.2

toes (respiratory exposure, 0.28 mg/hr or 3.9% of the total exposure) and, to a smaller degree, low-volume concentrate spraying of parathion in fruit orchards (respiratory exposure, 0.06 mg/hr or 0.2% of the total exposure). These latter values were about three times as great as the respiratory exposure for similar parathion applications using conventional high-volume spray. These disproportionately high respiratory exposures were probably due to the fact that the spray in these two instances was made up of particles of significantly smaller size than was usually the case with sprays. The small particles tended to remain suspended in the air longer and, thus, presented a greater opportunity to be inhaled. Also, the path of the smaller droplets was more easily changed by the influx of air into the nose, thus diverting these particles from their normal extracorporal path into the respiratory tract. The question of exposure levels involved in concentrate spraying has been dealt with more thoroughly elsewhere.[45]

The data on relative respiratory exposure (expressed as percentage of total [ie, dermal plus respiratory exposure] for workers applying different types of pesticide formulations is summarized in Table 3 for all the exposure situations measured in the present study. These results indicate that relative respiratory exposure is higher for aerosol (2.87% of total exposure) and dust (0.94% of total exposure) formulations than for dilute spray formulations (0.23% of total exposure).

Attitude of Operator.—Although it is a rather difficult concept to document with specific exposure data, observations made in the present study suggest that, for a given operation, considerably lower exposure was sustained by a careful operator than by a careless one. Among the factors noted were differences in avoiding contact with both concentrated and dilute formulations during loading and mixing, washing before eating or smoking, and wearing protective clothing and respirator when needed. In addition, the careless operators sometimes sprayed on windy days or under other adverse conditions while the careful spraymen waited for better conditions.

Comparison of Present Results With Previous Studies of Exposure.—In table 1 are listed results of previously published studies using direct methods to determine dermal and respiratory exposure of workers to pesticides. In a number of instances, the original workers did not calculate total exposure on the basis of fraction of toxic dose per hour. However, these values have been calculated by the present authors and inserted where indicated. Also included in the Table are some exposure values from the present paper (excerpted from Table 2) for comparison with previously published results. Papers in which authors have merely determined air concentrations of pesticides in work areas and made no calculations of actual respiratory intake have not been included in the tabulation. The results from the present study were generally in good agreement with those published previously, in those instances in which direct comparisons were possible.

Values for exposure to azinphosmethyl while spraying fruit orchards have been reported from Australia,[46] Canada,[30] Israel,[34] and the United States, as reported in this paper. The dermal exposure levels for this compound determined by Simpson (9.9 mg/hr), by Jegier (12.6 mg/hr), and that reported in the present paper (27.2 mg/hr) were similar. Known differences in procedure apparently account for some, if not all, of the variation which does occur among these results. Thus, although both Jegier and Simpson generally followed the procedures initially described by Batchelor and Walker,[16] there were some differences in technique. Jegier used α-cellulose strips only

Table 3.—Relative Respiratory Exposure (Expressed as The Percentage of Total [Dermal + Respiratory] Exposure) for Workers Applying Different Types of Pesticide Formulations

Type of Formulation	No. of Activities	Respiratory Exposure	
		Value	% of Total
Dilute Spray	19	Range	0.02-0.5
		Mean	0.23
Aerosol	4	Range	0.3-5.8
		Mean	2.87
Dust	7	Range	0.05-3.2
		Mean	0.94

on the forehead and wrists of the subject instead of on the four body areas (shoulders, back of neck, "V" of chest, and forearms) sampled in the present study. Also, both Jegier and Simpson calculated hand exposure on the basis of the wrist pad contamination while the whole hand was rinsed in the present study to determine exposure. In our experience pads placed on the wrists gave lower results for hand contamination than did washing the entire hand area, particularly in regard to exposure during mixing and loading. The much higher dermal exposure results (541 and 755 mg/hr for nocturnal and daytime spraying, respectively) obtained by Wassermann et al[34] cannot be explained at this time. The difference between nocturnal and daytime exposure levels was due to the greater amount of protective clothing worn when spraying in the cooler temperatures at night. The respiratory levels for the present study (0.04 mg/hr) were considerably lower than those obtained by Wassermann et al (0.54 mg/hr) and somewhat lower than those reported by Simpson (0.10 mg/hr) and by Jegier (0.26 mg/hr). It is particularly interesting to note that Jegier obtained good correlation for respiratory exposure determined from pads (0.26 mg/hr) and from air samples (0.30 mg/hr).

The dermal exposure level for operators thinning apple blossoms with DNOC, as determined much earlier at this laboratory (63.2 mg/hr) by Batchelor et al,[47] was somewhat higher than that found in the more recent studies (24.4 mg/hr, 22.5 mg/hr). The markedly higher respiratory level found earlier (1956 value, 0.40 mg/hr; present values, 0.13 for hand-gun and less than 0.05 for air blast equipment) was apparently due to the use at that time of uncovered respirator pads which permitted impingement of spray and apparently resulted in counting as respiratory exposure particles which would not be inhaled through the presently used funnel-covered respirator pads. These differences were discussed in detail by Wolfe et al.[24] The dermal exposure level for DNOC (57.5 mg/hr) determined in Israel by Wassermann et al[34] agrees well with the values determined here (22.5 and 55.1 mg/hr); however, the respiratory level determined by Wassermann and his colleagues (2.75 mg/hr) is very much higher than the present values (0.13 and less than 0.05 mg/hr) or even than that obtained earlier with uncovered respirators (0.40 mg/hr). In fact, the respiratory exposure level of 2.75 mg/hr is higher than that for any compound studied by other laboratories in outdoor spraying activity and approaches the level for DDT exposure during indoor house spraying (7.1 mg/hr).[48]

Dermal malathion exposure as determined in the present study (30.3 mg/hr) was higher than that (2.5 mg/hr) published by Jegier,[33] probably due at least partly to the differences in technique mentioned above. Respiratory results (present paper, 0.11 mg/hr; Jegier, 0.08 mg/hr) were comparable.

Also, for parathion spraying, the present dermal exposure level (19.4 mg/hr) was higher than that reported by Jegier (2.4 mg/hr) while the respiratory values were similar (present paper, 0.02 mg/hr; Jegier, 0.03 mg/hr).

Evaluation of Hazard to Workers.—From tables 1 and 2, it can be seen that in studies at this laboratory three compounds—endrin, parathion, and TEPP—have been involved in operations in which the mean value for the percentage of toxic dose potentially absorbed per hour exceeded 1%. All three of these compounds are known to have caused occupational poisoning. There is only one other compound (demeton) listed in the tables which is known to have caused occupational poisoning in the sort of work activities under study here. Therefore, it appears that, in general, the results of these exposure tests correlate well with use experience.

The highest mean value for fraction of toxic dose received per hour of work (44.2%) was for workers who loaded airplanes with 1% TEPP dust. Although there have been numerous illnesses among workers in this occupation, the number who become ill has been quite low considering that the workers potentially would, on the average, be subjected to almost one half the toxic dose per hour of work. Three factors may account for the low morbidity rate. First, observations have indicated that the number of hours per day or per week the worker is actually loading airplanes is quite low. Secondly, in such a situation where it is obvious that high contamination of the worker may occur, much more attention is generally given to the use of adequate protective clothing and respiratory devices than in less hazardous jobs. Thirdly, probably only a small percentage of the dry dust impinging on exposed skin areas is actually absorbed.

Although much attention has been, and rightly should be, given to prevention of exposure to compounds that are more acutely toxic, the importance of also minimizing exposure to other less toxic compounds should not be overlooked. For example, malathion, while not a compound of high systemic toxicity, has been shown to be a skin sensitizing agent and a potential cause of dermatitis in exposed individuals.[49] The fraction of toxic dose received during application of some of the less toxic chlorinated hydrocarbon pesticides may be compartively low; however, these compounds are stored in body fat following absorption. Although no adverse health effects have yet been shown in workers with continued, high-level exposure to DDT[3] or pesticides generally,[50] the continued contact with absorbed chlorinated hydrocarbon compounds resulting from fat storage and the possible additive pharmacologic effect of various related pesticides in this chemical class are factors that should be considered. Also, certain dusts, even those inert ones which do not contain pesticides or other added chemicals, may cause discomfort and even precipitate illness in some people.

The exposure studies reported in the present paper and similar studies which have been published previously from this and other laboratories (as summarized in table 1) indicate that, in general, agricultural and public health vector control workers using pesticides in various activities are exposed to relatively small fractions of the toxic dose each day. Surveys of illness, and of various physiologic manifestations of pesticide exposure, such as symptomatology, blood cholinesterase activity, fat storage of DDT and other chlorinated hydrocarbon pesticides and their metabolites, and urinary excretion of DDA, *p*-nitrophenol, and other pesticide biotransformation products confirm this impression of a generally low-level of exposure of workmen to pesticides. Both direct and indirect studies have shown that the exposure levels of workers, while higher than those for the general population, are generally relatively low in comparison to the toxic level. In many instances in which poisoning of a pesticide worker does occur, it is possible to show an obvious disregard for one or more safety recommendations to account for the illness.

Thus, the results of the present study are consistent with the idea that pesticides can be used safely provided recommended precautions are followed. In fact, a number of pesticides are so nontoxic that occupational poisoning associated with their use has not been reported and the exposure levels (as the percentage of toxic dose per hour) are so low that it is doubtful that it will occur. However, a few of the more toxic compounds (such as endrin, parathion, and TEPP) have caused occupational poisoning in the past. Their relatively high exposure values indicate that even minor lapses in adherence to safety precautions might be sufficient to allow poisoning to occur.

Summary

Values for dermal and respiratory exposure and for total exposure in terms of fraction of toxic dose were determined for 31 different work activities involving ten different pesticides.

There were wide ranges in exposure level for a given work activity with a specific pesticide, depending on the environmental conditions, particularly wind and technique of the operator; but other factors could not be excluded. Also, for a given pesticide there was a significant variation in hazard depending upon the type of work activity involved. Various phases of an operation often produced different levels of exposure. Generally, the loading operation was the most hazardous part of the spraying or dusting cycle. Exposure also depended upon the method of application. Not only was the hazard related to the length of time worked, but the use of dusts or fine aerosols rather than sprays greatly increased respiratory exposure.

As reported in previous exposure studies, the potential dermal exposure to each compound in every work situation studied was much greater than the potential respiratory exposure. However, the practical importance of this potential difference must be viewed in light of the fact that chemicals given at equivalent doses are absorbed more rapidly and more completely from the respiratory tract than through the skin.

The results from the present study were generally in good agreement with those published previously in those instances in which direct comparisons were possible.

The present results indicate that, in general, workers using pesticides in agriculture and public health vector control are exposed to relatively small fractions of the toxic dose each day. These findings are consistent with the idea that pesticides can be used safely provided recommended precautions are followed. However, the relatively high exposure values associated with a few of the more toxic pesticides (such as endrin, parathion, and TEPP) indicate that even minor lapses in adherence to safety precautions might be sufficient to allow poisoning to occur.

Some of the data reported in this paper was collected by Gordon S. Batchelor and Kenneth C. Walker. The α-cellulose was supplied by Rayonier, Inc., New York.

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