UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF CHEMICAL SAFETY
AND POLLUTION PREVENTION

MEMORANDUM

Date: [date placeholder], 2019

SUBJECT: **DRAFT** Review of "Determination of Dermal and Inhalation Exposure to Workers during Mixing, Loading and Application of Pesticides in Managed Horticultural Facilities using Powered Handgun Equipment" (AHE600)

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This memorandum presents EPA's review of the analytical and field phase reports contained in AHE600 (Canez and Baugher, 2019), an Agricultural Handler Exposure Task Force (AHETF) study that monitored dermal and inhalation exposure for workers who mixed, loaded, and sprayed pesticides in managed horticultural facilities using powered handgun equipment. It reflects comments and advice provided by the Human Studies Review Board following its April 2019 review[1]. This study meets EPA standards for occupational pesticide exposure monitoring and is considered acceptable and appropriate for use in assessing exposure and risk for workers applying pesticides with handgun equipment in facilities such as greenhouses and nurseries. The scenario monograph (Bruce and Holden, 2019), which incorporate the monitoring data from AHE600 into a single/composite dataset and includes statistical analysis of study objectives, is reviewed separately (Crowley, 2019; Dxxxxxx).

[1] [placeholder for reference to April 2019 HSRB meeting]

1.0 Executive Summary

The Agricultural Handler Exposure Task Force (AHETF) monitored dermal and inhalation exposure for 27 workers[2] while mixing, loading, and applying pesticide spray solutions in managed horticultural facilities (e.g., greenhouses and nurseries) using powered handgun equipment. Monitoring was conducted across 17 U.S states over the course of 4 years. The workers' activity consisted of opening liquid or dry flowable pesticide products, manually mixing and/or loading the product into a spray solution tank, then spraying the solution on ornamental potted/hanging/bench plants or vegetables using gas-, electric-, or battery-powered handheld spray guns or wands.

Monitored on actual days of work, workers loaded between a few teaspoons to less than a gallon of concentrated liquid product or from less than 1 to 6 pounds of dry flowable formulation, corresponding to a range of 0.0023 to 5.85 lbs of active ingredient (ai) handled. Notably no worker handled a wettable powder formulation. On each monitoring day workers mixed and loaded product in 1 to 6 separate loads, spraying between 15 and 600 gallons of spray solution over approximately 1 to 4 hours.

Table 1 presents a high-level summary of the exposure monitoring.

Table 1. AHE600 Summary

Worker ID	Type of Equipment	Facility	Spray Orientation	U.S. State	Monitoring Date
1	Hand wand	Greenhouse (enclosed)	Horizontal and down	OR	10/10/2013
2	Hand gun	Hoop house and Shadehouse (open and closed)	Horizontal and down	OR	10/30/2013
4	Hand gun	Greenhouse (enclosed)	Horizontal and down	FL	11/20/2013
5	Hand gun	Hoop house (enclosed) and Greenhouse (open)	Horizontal and down	FL	11/22/2013
6	Hand wand	Hoop house (open and closed)	Horizontal and down	FL	12/11/2013
7	Hand wand	Greenhouse (enclosed)	Horizontal and down	TX	1/28/2015
8	Hand wand	Greenhouse (enclosed)	Horizontal and down	MI	3/8/2015
9	Hand wand	Greenhouse (enclosed)	Horizontal, down, and overhead	IL	3/9/2015
10	Hand gun	Hoop house (enclosed)	Horizontal and down	NC	3/26/2015
12	Hand wand	Hoop house (enclosed)	Horizontal and down	IL	4/25/2015
13	Hand gun	Greenhouse (enclosed)	Horizontal and down	NC	4/30/2015
14	Hand gun	Nursery and shadehosue (open)	Horizontal, down, and overhead	FL	6/5/2015

[2] Monitoring was planned for 30 workers. See Section 2.3 for more information on 3 invalid results.

Table 1. AHE600 Summary					
Worker ID	**Type of Equipment**	**Facility**	**Spray Orientation**	**U.S. State**	**Monitoring Date**
16	Hand gun	Greenhouse and Nursery (open and closed)	Horizontal, down, and overhead	PA	10/7/2015
17	Hand gun	Shadehouse (enclosed)	Horizontal and down	FL	2/10/2016
18	Hand gun	Greenhouse (enclosed)	Horizontal and down	MI	9/7/2016
19	Hand gun	Greenhouse (enclosed)	Down	MI	9/8/2016
20	Hand gun	Nursery and Hoop house (open and enclosed areas)	Horizontal and down	MA	10/5/2016
21	Hand wand	Hoop house (enclosed)	Horizontal and down	NH	10/12/2016
22	Hand gun	Greenhouse (enclosed)	Horizontal and down	OH	11/2/2016
23	Hand gun	Nursery, Greenhouse, and Hoop house (open and enclosed areas)	Horizontal and down	AL	2/1/2017
24	Hand wand	Greenhouse (enclosed)	Horizontal, down, and overhead	MO	2/28/2017
25	Hand wand	Greenhouse (enclosed)	Down	WI	3/3/2017
26	Hand gun	Nursery (open)	Horizontal and down	SC	3/8/2017
27	Hand wand	Greenhouse (enclosed)	Horizontal, down, and overhead	TN	3/25/2017
28	Hand wand	Greenhouse (enclosed)	Horizontal, down, and overhead	VA	4/5/2017
29	Hand wand	Greenhouse (enclosed)	Horizontal and down	OH	4/13/2017
30	Hand wand	Greenhouse (enclosed)	Horizontal and down	NJ	4/21/2017

Dermal exposure was measured using hand washes, face/neck wipes, socks, and whole-body dosimeters (100% cotton union suits) for the remainder of the body (torso, arms, and legs). Per the study protocol (AHETF, 2012), in cases where workers wore eye protection and/or respirators (e.g., due to product label requirements) dermal exposures were extrapolated to areas covered by that equipment. Inhalation exposure was measured using personal air sampling pumps and OSHA Versatile Samplers (OVS) mounted on the shirt collar. Additionally, when an application was to include overhead spraying, the AHETF supplied chemical-resistant hats; monitoring patches were included both on top of the hats as well as underneath the hat covering the top of the worker's head. In those cases, the combination of the results for the inner and outer patches are used to represent exposure without head protection[3]. Thus, exposure monitoring results represent workers wearing long-sleeved shirts, pants, shoes/socks and chemical-resistant gloves with no respiratory protection.

[3] Using the results for the head patches, the AHETF plans additional analysis to characterize exposure for workers while wearing chemical-resistant hats, however that is not included in this review.

The study followed the applicable and most up-to-date AHETF standard operating procedures (SOPs) (AHETF, 2015) and the corresponding protocol (AHETF, 2012). Protocol amendments and deviations were appropriately documented. Analytical field and laboratory recovery results were acceptable, generally averaging between 70 and 120% recovery, with coefficients of variation largely less than 25%.

A high-level summary of dermal and inhalation exposures is provided in Table 2 below. This study meets EPA standards for occupational pesticide exposure monitoring and is considered acceptable and appropriate for use in assessing exposure and risk for workers applying pesticides with handgun equipment in facilities such as greenhouses and nurseries. For more formal use and application of the data in exposure assessment beyond simply the data results presented in this review, users are directed to a separate EPA review (Crowley, 2019; DXXXXXX).

Table 2. AHE600 Exposure Summary[1]

	Dermal Exposure (µg)					Inhalation Exposure (µg)[7]
Statistic[2]	Hands[3]	Head[4]	Body[5]	Feet	Total[6]	
Minimum	0.15	0.04	1.7	0.02	1.2	0.098
Maximum	868	617	3286	48.4	3891	159
Mean	53	79.4	319	4.3	442	21.3

[1] Results shown include adjustments for field fortification sampling. See Section 3.2.2.
[2] Means are simple averages (i.e., sum of values ÷ n).
[3] Exposure underneath chemical-resistant gloves.
[4] Results include extrapolation of face/neck wipe samples to non-wiped portions of the face/neck/head as well as inner and outer head patches when chemical-resistant hats were worn.
[5] Reflects the sum of six (2 arms, 2 legs, torso) inner dosimeter samples for each worker, representing exposure underneath a single layer of work clothing.
[6] "Total" does not (necessarily) correspond to the sum of the results for the individual body parts (i.e., the worker with maximum total dermal exposure may not have also had the maximum hand exposure).
[7] Inhalation exposure (µg) = Residue collected * [Breathing rate (L/min) ÷ Pump rate (L/min)]. Pump rates generally were 2 L/min; breathing rate of 16.7 L/min assumed (NAFTA, 1998).

2.0 Summary of Field Study Characteristics

This section provides summary characteristics for AHE600. While this review provides summaries in addition to EPA considerations and conclusions, the submitted AHE600 report (Canez and Baugher, 2019) should be consulted for more specific details; applicable sections, tables, and/or page numbers are provided.

2.1 Administrative Summary

AHE600 was sponsored by the AHETF and adequately followed the study protocol (AHETF, 2012), the AHETF Governing Document (AHETF, 2008 and 2010), and applicable AHETF SOPs. The study was conducted in compliance with Good Laboratory Practice Standards (GLPS) (40 CFR §160) and met the standards in EPA Test Guidelines Series 875 – Occupational and Residential Exposure (875.1100 – dermal exposure; 875.1300 – inhalation exposure). Signed copies of acceptable Quality Assurance and Data Confidentiality statements were provided.

The protocol was amended 9 times and 3 protocol deviations were reported; appropriate documentation was provided. Amendments were largely aimed at increasing the potential for employer and worker participation by expanding monitoring areas or relaxing recruitment requirements or adding possible test substances. An example protocol deviation was the initiation (but not conclusion) of monitoring of a worker who handled a product packaged in water-soluble packaging which were excluded in the protocol.

EPA considers the amendments reasonable and useful additions for obtaining results consistent with the intent of the study's purpose and original protocol; no deviation adversely affected the conduct or outcomes of the study. For a more detailed summary of protocol amendments and deviations, see Section 4.0 below and refer to AHE600 pages 12-14 as well as AHE600 Appendix A (pages 417-440).

2.2 Test Materials

The protocol specified 9 surrogate active ingredients that could be used by the monitored workers[4]. Additionally, in May 2015 protocol amendment 3 added acephate and amendment 8 in February 2017 added mefenoxam as additional potential surrogate chemicals. Ultimately, monitored workers used 7 of the possible 11 surrogates (acephate, azoxystrobin, chlorothalonil, fosetyl-Al, imidacloprid, mefenoxam, thiophanate-methyl). The various EPA-registered products containing those active ingredients are outlined in Table 4 below; AHE600 Table 2 on pages 95-96 provides more specific details. EPA agrees that the active ingredients used as surrogates have valid analytical methods and the products were handled and applied in the study in accordance with product labels and applicable EPA regulations. The range of different products and formulations (liquids and dry flowables) also adds to the overall representativeness and diversity of potential exposure. Notably, however, no wettable powder formulations were used in the study.

Table 4. AHE600 Summary of Pesticide Products Used

Product Name	Formulation	EPA Reg. No.	Active Ingredient (% product content)
Acephate 97UP Insecticide	Dry Flowable	70506-8	Acephate (97.5%)
Strobe 50 WG	Dry Flowable	53883	Azoxystrobin (50.8%)
Abound Flowable Fungicide	Liquid	100-1098	Azoxystrobin (22.7%)
Heritage Fungicide	Dry Flowable	100-1093	Azoxystrobin (49.0%)
Spectro 90 WDG Turf and Ornamental Fungicide	Dry Flowable	1001-72	Chlorothalonil (70.0%)
Daconil Weather Stik / Docket WS Fungicide	Liquid	5034-209-100	Chlorothalonil (52.8%)
Bravo Weather Stik	Liquid	5034-188-100	Chlorothalonil (55.5%)
Chlorothalonil 720 Agricultural Fungicide	Liquid	66222-154-37686	Chlorothalonil (53.6%)

[4] Azoxystrobin, carbaryl, chlorothalonil, fosetyl-Al, imidacloprid, malathion, permethrin, sulfur, thiophanate-methyl.

Table 4. AHE600 Summary of Pesticide Products Used			
Product Name	**Formulation**	**EPA Reg. No.**	**Active Ingredient (% product content)**
Echo 720 Fungicide	Liquid	60063-7	Chlorothalonil (53.8%)
Aliette WDG Fungicide	Dry Flowable	432-890	Fosetyl-Al (78.6%)
Discuss N/G Insecticide	Liquid	432-1393-59807	Imidacloprid (2.55%)
Quali-Pro Imidacloprid 2F Turf and Ornamental Fungicide	Liquid	66222-203	Imidacloprid (21.8%)
LADA 2F Insecticide	Liquid	83100-6-83979	Imidacloprid (21.5%)
Marathon II Insecticide	Liquid	432-1369-59807	Imidacloprid (21.8%)
Mallet 2 F T&O Insecticide	Liquid	228-695	Imidacloprid (21.8%)
Subdue MAXX	Liquid	100-796	Mefenoxam (21.6%)
3336 F Turf and Ornamental Systemic Insecticide	Liquid	1001-69	Thiophanate-methyl (42.4%)

Per GLP, AHETF analyzed the test substances for purity, with all tests demonstrating that the actual product active ingredient content percentages match nominal label statements. Certificates of Analysis, which formally document analysis of the test substances, are provided in AHE600 Appendix I pages 1891-1918. In terms of exposure monitoring in this study, purity analysis is important for the purposes of determining the amount of active ingredient handled (AaiH) by each worker. The amount of product and active ingredient handled by each worker is outlined in Section 2.7 below.

2.3 Sample Size, Monitored Workers, and Locations

According to the AHE600 study protocol (AHETF, 2012) and the AHETF Governing Document (AHETF, 2008 and 2010), given the anticipated variability and correlation structure for this exposure scenario, a "10 x 3" configuration was deemed adequate to meet study objectives. That is, a total of 30 "monitoring units" (MU)[5], obtained by monitoring exposure from 10 distinct study locations across the U.S. each with 3 workers per location, would likely satisfy pre-defined data accuracy benchmarks. Monitoring multiple individuals in temporal and spatial proximity is logistically more efficient and cost-effective.

This cost-effective approach was not completely achieved due to recruitment difficulties. While monitoring was conducted in the 10 originally planned geographic regions (with expansions via protocol amendments), additional spatial and temporal differences resulted in a (less cost-effective) configuration of 17 distinct locations. As a result, there was not an even distribution of 3 workers in each of 10 areas; for example, only 1 worker was monitored in the Louisiana/Texas area while 4 workers were monitored in the Northern Florida area. However, per protocol, no worker was monitored twice (no "repeat measures") and, to reduce any potential similarities

[5] Together with the conditions under which the active ingredient is handled, the workers are often referred to as monitoring units (MUs).

related to training, all workers were employed by different farms/employers. Though the final construct of the data did not exactly match the protocol, EPA believes that because of the recruitment difficulties the (less cost-effective) outcome perhaps actually resulted in a more diverse dataset than originally planned.

Additionally, the AHETF invalidated monitoring for 3 workers due to analytical issues, deviation from protocol, or deviation from normal worker activity:

- For one worker (Worker ID #3) analytical issues for hand wash, sock and outer head patch samples resulted in a lack of a complete suite of dermal exposure results. Additionally, this worker's inhalation monitoring device was turned off for some periods of time; exposure time was therefore uncertain., rendering the exposure time necessary for inhalation exposure calculations highly uncertain. EPA agrees that the lack of complete exposure results invalidates this monitoring.
- Because Worker ID 11 used a product formulated in water-soluble packaging, a specific exclusion in the protocol, monitoring was terminated. EPA agrees that because these products were excluded from the protocol, termination of the monitoring was warranted.
- During monitoring, Worker ID #15 indicated to the research team that he had deviated from some of his normal work practices, specifically starting the application in the morning rather than the afternoon and irrigating the plants shortly before monitoring began. The research team decided to terminate the monitoring. EPA agrees that activity outside normal practice – in this case, resulting in extremely wet clothing – provides reasonable cause for monitoring termination.

Thus, the final dataset consisted of 27 unique workers monitored while mixing, loading, and applying pesticide spray solutions in managed horticultural facilities (e.g., greenhouses and nurseries) using powered handgun equipment in 17 U.S. states from 2013-2017. Table 5 below provides a summary of the characteristics of the 27 monitored workers, while the AHE600 study report provides additional details in Table 3 on pages 97-108.

Table 5. AHE600 Worker and Location Summary

Worker ID	Gender	Age (years)	Weight (lb)	Work Experience (years)	Monitoring Location (U.S. State)	Monitoring Date
1	Female	55	147.8	10	OR	10/10/2013
2	Male	47	181.6	6	OR	10/30/2013
4	Male	31	183	3	FL	11/20/2013
5	Female	45	155.8	25	FL	11/22/2013
6	Male	45	255.2	30	FL	12/11/2013
7	Male	47	159.6	20	TX	1/28/2015
8	Female	34	174	6	MI	3/8/2015
9	Male	22	120.2	1	IL	3/9/2015
10	Male	33	127.5	10	NC	3/26/2015
12	Male	53	249	22	IL	4/25/2015
13	Female	40	148	15	NC	4/30/2015
14	Male	34	123.4	30	FL	6/5/2015
16	Male	59	195	40	PA	10/7/2015
17	Male	59	162.4	20	FL	2/10/2016
18	Male	39	160	22	MI	9/7/2016
19	Male	27	208.8	1	MI	9/8/2016

Table 5. AHE600 Worker and Location Summary						
Worker ID	**Gender**	**Age (years)**	**Weight (lb)**	**Work Experience (years)**	**Monitoring Location (U.S. State)**	**Monitoring Date**
20	Male	60	201.6	42	MA	10/5/2016
21	Male	49	224	30	NH	10/12/2016
22	Male	60	189	40	OH	11/2/2016
23	Male	56	302.2	9	AL	2/1/2017
24	Female	63	135.5	26	MO	2/28/2017
25	Female	50	193	25	WI	3/3/2017
26	Male	28	186.5	6	SC	3/8/2017
27	Male	46	194.8	20	TN	3/25/2017
28	Male	60	184	35	VA	4/5/2017
29	Male	53	247	15	OH	4/13/2017
30	Male	40	235	15	NJ	4/21/2017

2.4 Environmental Conditions

Temperature (including heat index), humidity, wind speed and direction, and rainfall were all reported. The maximum reported temperature was 110° F (greenhouse interior in FL in February 2017) and the lowest reported temperature was 35° F (OR in October 2013). No monitoring was affected or halted as a result of the ambient temperature exceeding the pre-defined threshold of concern for potential heat-related injury. Rain did not impact any of the monitoring samples. Maximum reported wind speed was approximately 14 miles per hour[6]. For more details on environmental conditions see the AHE600 report Table 11 (pages 275-284).

2.5 Clothing and Personal Protective Equipment (PPE)

Per the stated goals of the AHETF, monitoring of mixing/loading/applying with powered handgun equipment in greenhouses and nurseries was conducted to represent exposure while wearing long-sleeve shirts, pants, shoes/socks, chemical-resistant gloves and no respiratory protection. Per protocol, though not required on product labels, when workers conducted overhead spraying, the AHETF supplied chemical-resistant hats. Monitoring patches were placed both inside and outside the hats to enable estimation of exposure as if the worker was not wearing the chemical-resistant hat.

Monitoring was conducted while the workers wore their normal clothing on the scheduled monitoring day. In no instance did a worker's clothing need to be replaced, but in 3 instances small holes in worker's clothing were repaired using tape to meet the standards of the EPA Worker Protection Standard (WPS) for pesticides[7]. Per protocol, new chemical-resistant gloves were supplied by the AHETF to all workers at the beginning of the day and were available throughout the day according to WPS requirements. All chemical-resistant gloves were of made of nitrile rubber, a material consistent with requirements on the labels of all the products used (for reference see products outlined in Section 2.2 above).

[6] The AHETF confirmed that AHE600 Table 11 inadvertently reported the maximum and minimum inversely.
[7] EPA requested clarification on this issue and the AHETF responded (3/5/19) that because the holes were very small (< 1 in^2), they opted to continue to use the worker's own clothing. EPA agrees that use of the worker's own clothing provides a better representation of exposure.

Additionally, where workers wore face or head PPE such as protective eyewear, respirators, or a hood (e.g., approximately half of the workers wore protective eyewear and/or respirators; worker #2 wore a Tyvek hood for approximately 30% of his monitoring), dermal exposure without the PPE is simulated according to AHETF SOP 9.K which extrapolates from the face/neck wipe exposure measurements to those portions of the face/head covered by the face/head PPE (see Section 3.3.2). The study noted where this additional PPE was only worn for part of the day so time-weighted adjustments (prorating) could be applied. Though 3 workers wore chemical-resistant aprons[8], because they were worn only during the mixing and loading portion of their workday, no exposure adjustments were considered necessary.

More specific details on work clothing and PPE can be found in the AHE600 study report in Tables 4 and 5 on pages 109-116.

2.6 Facilities and Application Methods/Equipment

The facilities treated with pesticides in AHE600 were, as intended in the study protocol, a diverse set of horticultural facilities ranging from enclosed greenhouses to semi-enclosed shadehouses and "hoop houses" to outdoor (open) nurseries. Approximately 70% of the monitoring was characterized as being conducted in an enclosed facility. Most applications were to ornamental plants or trees on the ground or on benches (e.g., in containers or pots) of varying heights (some up to 25 feet tall) or in hanging baskets; while greenhouses and nurseries are used to also grow fruits and vegetables, only one worker sprayed vegetables (Worker ID #20 sprayed field-grown tomatoes and peppers at a nursery). Almost all workers sprayed horizontally/laterally; only 2 sprayed exclusively downward; approximately 30% of workers conducted overhead spraying (e.g., spraying hanging baskets).

All workers mixed and loaded the product into a spray tank (e.g., 500-gallon tank), then using small tractors or trailers or mobile carts moved the spray tank to the application areas. A gas-, electric-, or battery-powered motor then pumped the spray solution through a hose to the spray attachment, either a hand gun or hand wand. As the AHETF describes:

> "…a 'handgun' (also referred to as 'spray gun') is a single- or multiple-nozzle device in which the operator squeezes a trigger with his hand to start/stop the flow of liquid spray. The 'hand wand' is a lightweight, long metal extension which ends in a nozzle or cluster of nozzles that again can be turned on and off by the operator by squeezing a trigger or turning a valve." (Bruce and Holden, 2019; page 32)

The AHE600 study protocol called for specific restrictions (referred to as "similarity restrictions" (SR)) related to some of these application characteristics. For example, from AHETF, 2012:

> SR4. All three MUs must have monitoring conditions with a different degree of openness or enclosure
>
> SR6. Each pair of MUs must differ in at least one of the following characteristics:

[8] EPA confirmed with the AHETF that references to worker ID 23 wearing an apron were incorrect. Workers 13, 17, and 19 were the only ones to wear aprons during the mixing and loading portion of their work.

- Facility type/sub-type (i.e. N, OGH, or VGH)
- Method of mixing product (example: directly into spray tank or premixed and then added to spray tank)
- Hose attachment (example: handgun-type or handwand-type)
- Predominant spray orientation during monitoring period (i.e., downward, outward or upward, or some combination)
- Formulation type (i.e., liquid or solid)
- Product container size
- Performing equipment clean-up activity (i.e., yes or no)

When recruitment became difficult and participation was becoming increasingly low, the AHETF was concerned that these restrictions would significantly prolong the study. Protocol Amendment #5 (August 2016) changed the SR requirements from "must" to "preferably" will. This amendment facilitated recruitment related to SR4; diversity related to SR6 was still met.

Table 1 in the Executive Summary provides a summary of application characteristics while AHE600 Table 6 on pages 117-120 and Table 12 on pages 285-295 provide more explicit details.

2.7 Application Rates and Amount of Active Ingredient Handled

According to the AHE600 study protocol (AHETF, 2012) and the AHETF Governing Document (AHETF, 2008 and 2010), to facilitate a data analysis objective (evaluating the relationship between exposure and the amount of active ingredient handled) the total amount of active ingredient handled (AaiH) applied should be sufficiently diversified across the dataset as well as within each study location. Specifically, each worker in a monitoring area was intended to handle within a certain range (or 'strata') of amount of active ingredient. That construct was not able to be implemented, however the overall range of active ingredient handled across all workers was approximately 3 orders of magnitude.

Workers handled between 1 and 6 lbs of dry flowable formulation products and between a few teaspoons to less than a gallon of liquid product over the course of 1 to 4 hours. Though six workers did not meet the protocol guideline of more than 2 hours of pesticide application work, it does not appear that short monitoring times consistently resulted in non-detected residues or otherwise had a significant adverse effect on the dataset overall[9]. Using the product concentration – confirmed by laboratory purity analysis (see Section 2.2 above) – and the amount of product handled, the AHETF calculated the amount of active ingredient handled for each worker. Workers handled between 0.0023 to 5.85 lbs of active ingredient.

Table 7 below provides more detail on the amount of active ingredient handled by each worker. The submitted AHE600 study report Table 12 (on pages 285-295) should also be referenced.

[9] Not all workers who worked less than 2 hours had non-detect exposures: of the six workers (# 19, 22, 24, 25, 29, 30) who worked less than 2 hours, three (workers #24, 25, 30) also had dermal exposure monitoring largely consisting of non-detects. For inhalation exposure, all 27 monitored workers had detected residues.

Table 7. AHE600 Amount of Active Ingredient Handled							
Worker ID	**Formulation**	**Loads Mixed**	**Total product loaded**	**Product conc.[a, b]**	**Amount Solution Sprayed**	**Exposure Time (hrs)**	**AaiH (lbs)[c]**
1	Liquid	3	40 oz	2.94% ai (0.262 lb ai/gal prod)	80	4.9	0.071
2	Liquid	3	100 oz	42.4% ai (4.1 lb ai/gal prod)	450	8.5	3.29
4	Dry Flowable	3	3.75 lb	78.6% ai	147.5	3.0	2.94
5	Liquid	3	24 oz	42.2% ai (4 lb ai/gal prod)	150	3.1	0.767
6	Dry Flowable	3	6 lb	70% ai	300	2.1	4.20
7	Liquid	3	36 oz	52.8% ai (6 lb ai/gal prod)	150	2.4	1.65
8	Dry Flowable	3	0.313 lb	50.7% ai	149	2.7	0.158
9	Dry Flowable	3	0.25 lb	50.3% ai	100	2.6	0.126
10	Dry Flowable	3	9.5 oz	50.8% ai	472	6.8	0.302
12	Liquid	3	21 oz	53.5% ai (6 lb ai/gal prod)	98	3.1	0.975
13	Liquid	3	28.8 oz	42.1% ai (4 lb ai/gal prod)	180	3.2	0.919
14	Dry Flowable	3	6 lb	97.5% ai	450	3.7	5.85
16	Liquid	4	2.8 oz	21.6% ai (2 lb ai/gal prod)	165	4.5	0.044
17	Liquid	3	60 oz	22.7% ai (2.08 lb ai/gal prod)	600	7.6	0.966
18	Dry Flowable	6	0.375 lb	48.8% ai	120	2.0	0.183
19	Liquid	3	13.9 oz	42.4% ai (4 lb ai/gal prod)	85	1.5	0.445
20	Liquid	1	16 oz	55.5% ai (6 lb ai/gal prod)	40	2.1	0.771
21	Liquid	2	1.7 oz	21.8% ai (2 lb ai/gal prod)	100	2.4	0.027
22	Dry Flowable	1	2.2 oz	49.1% ai	50	1.2	0.068
23	Liquid	3	33 oz	53.6% ai (6 lb ai/gal prod)	150	2.6	1.54
24	Liquid	1	0.25 oz	21.8% ai (2 lb ai/gal prod)	15	1.2	0.004
25	Liquid	1	0.152 oz	21.6% ai (2 lb ai/gal prod)	15	2.0	0.002
26	Liquid	2	66 oz	53.8% ai (6 lb ai/gal prod)	190	4.5	3.08
27	Liquid	3	1.65 oz	21.5% ai (2 lb ai/gal prod)	95	3.6	0.025

Table 7. AHE600 Amount of Active Ingredient Handled							
Worker ID	**Formulation**	**Loads Mixed**	**Total product loaded**	**Product conc.[a, b]**	**Amount Solution Sprayed**	**Exposure Time (hrs)**	**AaiH (lbs)[c]**
28	Liquid	1	0.42 oz	21.8% ai (2 lb ai/gal prod)	24	2.8	0.007
29	Liquid	1	0.5 oz	21.5% ai (2 lb ai/gal prod)	50	1.3	0.008
30	Dry Flowable	1	0.125 lb	49% ai	35	0.6	0.061

[a] See Table 4 for active ingredients.
[b] The % ai is based on the Certificates of Analysis (see AHE600 Appendix I), not the % ai on the product label.
[c] AaiH is approximated by the calculation: "product handled * % ai in product" for dry flowables and "product handled * lb ai/gallon product" for liquids. More information in Microsoft Excel file AHETF submission "AHE600 Monitoring time and AaiH calculations - Sent to EPA 2-20-19.xlsx".

2.8 Representativeness of Exposure Monitoring

As part of the study protocol, the AHETF conducted opinion polling within each monitoring area of local experts at the end of the field phase of AHE600 to evaluate whether various characteristics of the monitoring were reasonably representative of powered handgun applications in horticultural facilities in that area. Across the 10 monitoring areas (17 U.S. states), a total of 186 surveys were distributed to university extension agents, educators and local research personnel with 72 responses. They were asked to provide their opinion as to whether the following characteristics about the monitoring were representative of their area: 1) location of the monitoring event, 2) whether the study participant was an employee or owner of the greenhouse or nursery, 3) number of experienced chemical applicators at the greenhouse or nursery, 4) type of greenhouse or nursery, 5) crop or crops treated, and 6) description of the greenhouse or nursery application equipment used at that location.

Though the survey was informal, only two responses (one in NC/SC/TN and another in OH/PA) indicated the characteristics of the monitoring were outside routine practice. One respondent said that most applications were done using backpacks not powered handguns and the other stated that most applications were done by employees not facility owners. Thus, it appears based on this informal survey/poll of local experts that the participants in AHE600 were not atypical of the population of individuals who use powered handguns to apply pesticides in greenhouses and nurseries. More detail can be found in AHE600 Section 4.0 on pages 59-60.

2.9 Exposure Monitoring and Analytical Methods

Per applicable AHETF SOPs, standard passive dosimetry methods recognized by EPA as appropriate for worker exposure monitoring were utilized for all monitoring. No biomonitoring samples were required, planned, or collected.

Dermal exposure was measured as described below, and are combined (i.e., the measurement results summed together) for each worker to reflect dermal exposure underneath a single layer of work clothing (long-sleeve shirt, pants, shoes/socks) and chemical-resistant gloves.

- Hand exposure was measured using a hand rinse method administered at the end of the workday as well as at lunch, restroom breaks, or other instances where workers would otherwise wash their hands as outlined in AHETF SOP 8.B.
- Exposure to the face/neck was measured using a wipe technique as outlined in AHETF SOP 8.C and extrapolated to non-wiped portions of the head according to AHETF SOP 9.K. Thus, for those workers who wore additional face or head protection (i.e., eye protection, respirators, or hood) the extrapolation to the whole head renders the resulting measurement representative of face/neck/head exposure without that additional gear. Generally, 1-2 face/neck wipe samples were collected for each worker then analyzed as a composite sample.
- Exposure to feet was measured using pre-washed white, 100% cotton, lightweight, ankle-high socks as described in SOP AHETF-8.I.
- Dermal exposure to the remainder of the body (torso, arms, and legs) was measured using whole body dosimeters (100% cotton union suits), sectioned into two pieces and analyzed separately according to AHETF SOP 8.A.
- For workers who wore chemical-resistant hats, patches were used both underneath the hat attached to the top of the worker's head (a 100 cm^2 patch) and on the outside attached to the top of the hat (a 50 cm^2 patch). The patches were cut to the appropriate size from the white, 100% cotton long underwear inner dosimeter union suits per SOP AHETF-8.H.

Inhalation exposure was measured using OVS tubes (with front and back sections) mounted on the worker's collar and personal sampling pumps (set at 2 liters per minute) according to AHETF SOP 8.D and 10.G. The concentrations measured represent the chemical available in each worker's breathing zone.

Validated analytical methods specific to each active ingredient and each type of monitoring matrix (i.e., inner dosimeters, hand rinses, etc.) were used to extract residues. Protocol amendment 3 (May 2015) and 8 (February 2017) added analytical methods for acephate and mefenoxam. The analytical methods listed below are described in more detail in the AHE600 analytical reports (AHE600 Appendices B, C, D, E, F, G, and H). Though final submitted validation reports are dated after the exposure monitoring, EPA confirmed that, according to the AHE600 protocol, no sample from AHE600 was analyzed prior to validation of the method. For example, azoxystrobin-based monitoring was first conducted on March 8, 2015. Though the method validation report for azoxystrobin is dated August 2018, EPA confirmed that the method was validated in the laboratory prior to the September 2015 analysis of those March 2015 samples.

- Acephate
    - AHE06 (2004): "Validation of Methods for the Analysis of Exposure Matrices for Acephate"
        - AHETF-AM-001 (2003): "Determination of Acephate on Cotton Inner Dosimeters"
        - AHETF-AM-002 (2003): "Determination of Acephate in Face/Neck Wipe Samples"
        - AHETF-AM-003 (2003): "Determination of Acephate in Handwash Exposure Samples"

        - AHETF-AM-007 (2004): "Determination of Acephate in Sock Samples"
        - AHETF-AM-004 (2003): "Determination of Acephate in OVS Air Sampling Tubes"
- Azoxystrobin
    - AHE229 (2018): "Validation of Analytical Methods for the Determination of Azoxystrobin" (EPA MRID 50779801)
        - AHETF-AM-099 (2018): "Determination of Residues of Azoxystrobin on Six-Piece Cotton Inner Dosimeters"
        - AHETF-AM-100 (2018): "Determination of Residues of Azoxystrobin on Cotton Face/Neck Wipe Samples"
        - AHETF-AM-101 (2018): "Determination of Residues of Azoxystrobin on Cotton Head Patches"
        - AHETF-AM-103 (2018): "Determination of Residues of Azoxystrobin in Hand Wash Solutions"
        - AHETF-AM-104 (2018): "Determination of Residues of Azoxystrobin in OVS Air Sampling Tubes"
        - AHETF-AM-102 (2018): "Determination of Residues of Azoxystrobin on Cotton Socks"
        - AHE238 (2018): "Determination of the Frozen Storage Stability of Azoxystrobin in/on Worker Exposure Matrices and Fortification Solutions" (EPA MRID 50779804)
- Chlorothalonil
    - ARF004 (1999): "Validation of Method for the Analysis of Worker Exposure and Reentry Matrices for Chlorothalonil"
        - ARTF-001 (1997): "Determination of Chlorothalonil in Dermal Dosimeters"
        - ARTF-004 (1997): "Determination of Chlorothalonil in Facial/Neck Wipes"
        - ARTF-002 (1997): "Determination of Chlorothalonil in Hand Wash Solutions"
        - ARTF-003 (1997): "Determination of Chlorothalonil in OVS Air Sampling Tubes"
- Fosetyl-Aluminum
    - AHE230 (2019), "Validation of Analytical Methods for the Determination of Residues of Fosetyl-Aluminum in/on Worker Exposure Matrices" (EPA MRID 50779802)
        - AHETF-AM-105 (2018): "Determination of Residues of Fosetyl-Aluminum on Six-Piece Cotton Inner Dosimeters"
        - AHETF-AM-106 (2018): "Determination of Residues of Fosetyl-Aluminum on Cotton Face/Neck Wipe Samples"
        - AHETF-AM-108 (2018): "Determination of Residues of Fosetyl-Aluminum on Cotton Socks
        - AHETF-AM-109 (2018): "Determination of Residues of Fosetyl-Aluminum in Hand Wash Solutions"
        - AHETF-AM-110 (2018): "Determination of Residues of Fosetyl-Aluminum in OVS Air Sampling Tubes"

        - AHE239 (2018): "Determination of the Frozen Storage Stability of Fosetyl-Aluminum in/on Worker Exposure Matrices and Fortification Solutions" (EPA MRID 50779805)
- Imidacloprid
    - AHE242 (2018): "Validation of Analytical Methods for the Determination of Residues of Imidacloprid on Cotton Six-Piece Inner Dosimeters, Cotton Head Patches, and Cotton Socks" (EPA MRID 50779803)
        - AHETF-AM-072 (2018): "Determination of Residues of Imidacloprid on Six-Piece Cotton Inner Dosimeters"
        - AHETF-AM-073 (2018): "Determination of Residues of Imidacloprid on Cotton Head Patch Samples "
        - AHETF-AM-074 (2018): "Determination of Residues of Imidacloprid on Cotton Socks
    - AHETF-AM-059 (2008): "Determination of Residues of Imidacloprid, Clothianidin, Carboxin and Metylaxyl in Face Wipes, Hand Washes, and Dosimeter Garments"
    - AHETF-AM-066 (2008): "Determination of Residues of Imidacloprid, Clothianidin, Carboxin and Metylaxyl in OVS-2 Air Monitoring Tubes"
- Thiophanate-methyl
    - AHE233 (2015): "Validation of Worker Exposure Methods for the Determination of Thiophanate-methyl as its Carbendazim Hydrolysis Product in Worker Exposure Matrices"
        - AHETF-AM-086 (2015): "Determination of Residues of Thiophanate-Methyl as its Carbendazim Hydrolysis Product in Inner Dosimeter Samples"
        - AHETF-AM-088 (2015): "Determination of Residues of Thiophanate-Methyl as its Carbendazim Hydrolysis Product in Face/Neck Wipe Samples"
        - AHETF-AM-087 (2015): "Determination of Residues of Thiophanate-Methyl as its Carbendazim Hydrolysis Product in Hand Wash Solutions"
        - AHETF-AM-090 (2015): "Determination of Residues of Thiophanate-Methyl as its Carbendazim Hydrolysis Product in Socks"
        - AHETF-AM-089 (2015): "Determination of Residues of Thiophanate-Methyl as its Carbendazim Hydrolysis Product in OVS Air Sampling Tubes"
- Mefenoxam[10]
    - AHE242 (2018): "Validation of Analytical Methods for the Determination of Residues of Imidacloprid on Cotton Six-Piece Inner Dosimeters, Cotton Head Patches, and Cotton Socks"
        - AHETF-AM-072 (2018): "Determination of Residues of Imidacloprid on Six-Piece Cotton Inner Dosimeters"
        - AHETF-AM-073 (2018): "Determination of Residues of Imidacloprid on Cotton Head Patch Samples "

[10] Analysis conducted using same methods as imidacloprid, per Protocol Amendment #8: "The imidacloprid analytical methods identified in protocol section 14.2 identify four analytes, including mefenoxam."

- AHETF-AM-074 (2018): "Determination of Residues of Imidacloprid on Cotton Socks
- AHETF-AM-059 (2008): "Determination of Residues of Imidacloprid, Clothianidin, Carboxin and Metylaxyl in Face Wipes, Hand Washes, and Dosimeter Garments"
- AHETF-AM-066 (2008): "Determination of Residues of Imidacloprid, Clothianidin, Carboxin and Metylaxyl in OVS-2 Air Monitoring Tubes"

Limits of quantification and detection (as defined in AHETF SOP 9.A) are presented in Table 9 below.

Table 9. Analytical Limits (µg/sample) for AHE600

Monitoring Matrix	Limit of Detection (LOD)							Limit of Quantification (LOQ)						
	ACE	AZOX	CTH	F-Al	IMID	MEF	TPM	ACE	AZOX	CTH	F-Al	IMID	MEF	TPM
Inner Dosimeter	0.05	0.19	0.30	0.35	0.15	0.15	0.17	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Face/Neck Wipe	0.25	0.05	0.30	0.12	0.30	0.30	0.06	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Head Patch	0.05	0.15	0.075	--	0.10	--	0.20	0.5	1.0	0.25	--	1.0	--	1.0
Socks	0.08	0.04	0.075	0.05	0.05	0.05	0.04	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Hand Rinse	0.04	0.25	0.30	0.11	0.30	0.30	0.20	0.2	1.0	1.0	1.0	1.0	1.0	1.0
OVS air sampler (per section)	0.003	0.0007	0.0015	0.0009	0.0015	0.0015	0.0010	0.01	0.005	0.005	0.005	0.005	0.005	0.010

Chemical legend: ACE = acephate; AZOX = azoxystrobin; CTH = chlorothalonil; F-Al = fosetyl-aluminum; IMI = imidacloprid; MEF = mefenoxam; TPM = thiophanate-methyl

3.0 Results

This section provides a discussion of quality assurance and quality control sampling and the actual field monitoring measurements of workers.

3.1 Quality Assurance

All phases of each study were subject to appropriate quality assurance processes according to EPA's GLPs which included an audit by the AHETF Quality Assurance Unit (QAU) per AHETF SOPs (AHETF SOP Chapter 5: A-K). The inspected phases were: Protocol, Application/Sampling, Study Data, and Draft Final Report. The study contains a signed quality assurance compliance statement as required by GLPs. Protocol amendments or deviations were addressed appropriately per GLP guidance and are described further in Section 4.0.

3.2 Quality Control

AHETF instituted various quality control measures to ensure proper field conduct including preparation and handling of exposure measurement matrices, evaluation of test material, and field observations (AHETF SOP Chapter 10: A-G). Analytical methods were validated appropriately ensuring that all exposure matrices could be measured for the surrogate active ingredients proposed. Analytical quality control measures for ensuring the integrity of measurements captured in the research were also instituted according to AHETF SOP 9.J.

Exposure monitoring matrices (inner whole body dosimeters, hand washes, face/neck wipes, socks, head patches, OVS tubes) were fortified with known amounts of active ingredient to assess their stability during field, transit, and storage conditions (and analyzed when necessary) according to AHETF SOP 8.E. Laboratory control samples were also fortified at the level of quantification and at levels capturing the range of expected field exposures for each matrix. Generally, field fortification samples were collected in triplicate at each of 3 levels (high, middle, and low) on each sampling day. Travel fortifications were generally conducted on each day of sampling in duplicate only at the high fortification level. Untreated control samples – included to determine if there are significant background sources or contamination during sample processing – were generally conducted in duplicate on each day of sampling.

The following sections provide results for all quality control sampling across all exposure measurement matrices for all chemicals used.

3.2.1 Field and Laboratory Control Samples

There were several instances where field control samples contained detectable residues, likely the result of in-field contamination (e.g., spray drifting to research area). Also, approximately 7% (16 of 224) of concurrent laboratory controls had residues above the matrix LOD. EPA does not believe that either outcome indicates there were systematic analytical issues. Per AHETF practice, monitoring matrix samples were not adjusted/reduced for presence of the chemical in control samples. More detailed results can be found in AHE600 Appendix B Tables 9-16 on pages 485-492, Appendix C Tables 9-21 on pages 623-648, Appendix D Tables 23-36 on pages 935-993, Appendix E Tables 7-12 on pages 1299-1305, Appendix F Tables 9-21 on pages 1437-1470, Appendix G Tables 9-21 on pages 1657-1679, and Appendix H Tables 7-12 on pages 1814-1823.

3.2.2 Field Fortification Recoveries

Field fortification sampling matrices are spiked with known amounts of chemical, then placed under similar conditions and duration as the actual sampling matrices used on the workers (including drawing air through OVS samplers). The intent of these samples is to quantify potential residue losses due to the sampling methods used under actual field conditions. Additional samples are also fortified to assess degradation of the sample during transit from the field to the lab and during sample storage but are only analyzed when necessary; travel/storage samples were analyzed by the laboratory for chlorothalonil to confirm some anomalous results.

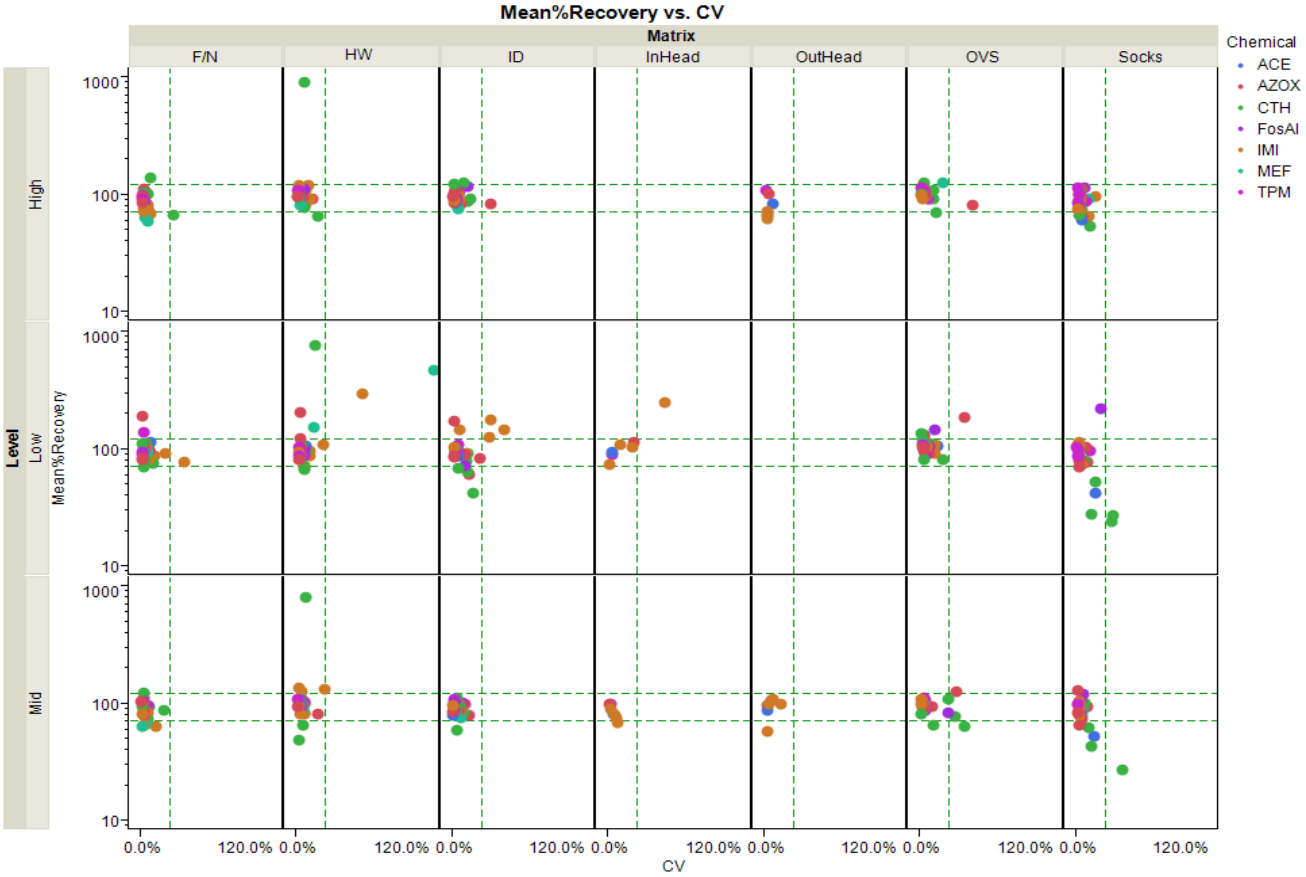
Field fortifications are conducted at 3 levels to capture the expected range of results, with triplicate samples taken on each day at each fortification level. Once analyzed, the average recovery results (expressed as a percentage of known amount applied) are used as multipliers to adjust, or correct, all measured field samples to 100%.

As the fortification samples are conducted at levels to capture the range of expected field sample results, adjustments to field samples are done using the average percent recovery for the

fortification level closest to the measured field sample[11]. The mid-point between each fortification level is used as the threshold in determining the average recovery percentage for use in adjusting the field sample.

With some exceptions, field fortification averages for each fortification level and each monitoring matrix were in the range of 70-120% with coefficients of variation (CV) generally less than 25%. Figure 1 below shows the field fortification results (CV by Mean % Recovery) across all fortification levels, dosimetry matrices and chemical, overlaid with the 70-120% and 25% benchmarks (green dashed lines). For more details on field fortification results see AHE600 Table 8 on pages 124-170. A summary for each matrix is then provided in the sections below.

Figure 1 - Field Fortifications (CV vs Mean; Fortification Level by Matrix by Chemical)



Matrix legend: F/N = Face/neck wipe; HW = hand wash; ID = inner dosimeter; InHead = inner head patch; OutHead = outer head patch; OVS = inhalation sampler
Chemical legend: ACE = acephate; AZOX = azosystrobin; CTH = chlorothalonil; FosAl = fosetyl-aluminum; IMI = imidacloprid; MEF = mefenoxam; TPM = thiophanate-methyl

[11] Per AHETF standard procedure, if average recovery is > 120% the maximum ("downward") adjustment value applied is 1.2.

3.2.2.1 Inner Dosimeters

Results for inner whole-body dosimeter (WBD) field fortification samples were acceptable, with recoveries averaging from 70% to 120% with few exceptions and coefficients of variation less than 25%. About 15% (12 of 81 WBD fortification samples) were outside the 70-120% recovery range (mostly chlorothalonil, then imidacloprid and azoxystrobin) and 5% (4 of 81) were above a CV of 25% (mostly imidacloprid, then azoxystrobin).

3.2.2.2 Face/Neck Wipes

Results for face/neck wipe field fortification samples were acceptable, with average recoveries ranging from approximately 70% to 120% and coefficients of variation less than 25% with a few exceptions. About 15% (12 of 81 face/neck fortification samples) were outside the 70-120% recovery range (thiophanate-methyl, imidacloprid, azoxystrobin, mefenoxam) and 2% (2 of 81) were above a CV of 25% (chlorothalonil and imidacloprid).

3.2.2.3 Hand Washes

Results for hand wash field fortification samples were acceptable, with average recoveries ranging from approximately 70% to 120% and coefficients of variation less than 25% with a few exceptions. About 20% (17 of 81 hand wash fortification samples) were outside the 70-120% recovery range (mostly chlorothalonil, then azoxystrobin, imidacloprid, and mefenoxam) and 2% (2 of 81) were above a CV of 25% (mefenoxam and imidacloprid).

In the case of the chlorothalonil samples with consistent recoveries close to 1000% of the fortification level (applicable to worker #6), the results likely indicate improper fortification and these results were not used for adjustment of field monitoring. Adjustments for field control samples will instead be based on chlorothalonil fortification results from other monitoring days.

3.2.2.4 Socks

Results for sock field fortification samples were acceptable, with average recoveries ranging from approximately 70% to 120% and coefficients of variation less than 25% with a few exceptions. About 20% (17 of 81 sock fortification samples) were outside the 70-120% recovery range (per Figure 1, mostly lower than 70% and mostly chlorothalonil, then azoxystrobin, acephate, imidacloprid, and fosetyl-Al) and 4% (3 of 81) were above a CV of 25% (chlorothalonil).

3.2.2.5 Head Patches

Results for head patch field fortification samples were acceptable, with average recoveries ranging from approximately 70% to 120% and coefficients of variation less than 25% with a few exceptions. About 20% (6 of 28 patch fortification samples) were outside the 70-120% recovery range (all imidacloprid) and 3.5% (1 of 28) were above a CV of 25% (imidacloprid).

3.2.2.6 OVS Air Samplers

Results for OVS fortification samples were acceptable, with average recoveries ranging from approximately 70% to 120% and coefficients of variation less than 25% with a few exceptions. About 12% (10 of 81 OVS fortification samples) were outside the 70-120% recovery range (chlorothalonil, fosetyl-Al, azoxystrobin, mefenoxam) and 6% (5 of 81) were above a CV of 25% (azoxystrobin and chlorothalonil).

3.3 Field Measurements

The following sections summarize the exposure monitoring results, conducted as described in Section 2.8. Exposure values reflect total exposure for workers across their monitoring periods, not normalized by any exposure metric. All measurements were appropriately adjusted for applicable field fortification recoveries (see Section 3.2.2). Face/neck wipe measurements were extrapolated to un-wiped portions of the face and head according to AHETF SOP 9.K and head patches were extrapolated to head surface area as described in Section 2.8 above. For samples below the LOQ or LOD, ½ LOQ or ½ LOD was used.

3.3.1 Inner Dosimeters

Without field fortification adjustments, WBD sections ranged from < LOD to 1911 µg. Out of a total of 162 inner dosimeter samples, 52 were < LOQ (17 of which were < LOD). After adjusting for field fortification recoveries and summing the six separate body sections, the total dermal exposure underneath the long-sleeve shirt and pants ranged from 1.7 – 3286 µg with an average of 319 µg.

3.3.2 Face/Neck Wipes

Without field fortification adjustments, face/neck wipe samples ranged from < LOD to 80.9 µg. Out of a total of 27 face/neck wipe samples, 10 were < LOQ (7 of which were < LOD). Because some workers wore eye protection and/or respirators, and because measurements cannot be easily conducted on hair, extrapolations from those portions of the face/neck that are wiped need to be made to portions of the head that are not measured. Specifics on these adjustment factors can be found in AHETF SOP 9.K[12]. After adjusting for field fortification recoveries and extrapolating to non-wiped portions of the head described above, total head exposure ranged from 0.03 – 86 µg with an average of 8.8 µg.

3.3.3 Hand Washes

Per protocol, hand wash samples were collected at the end of each work day and at points where workers would normally wash their hands such as during restroom or lunch breaks. The number

[12] PPE adjustment factors: 1 = no adjustment; 1.1 = goggles/safety glasses; 1.1 = half-face respirator w/thin straps; 1.2 = half-face respirator w/thick straps; 1.4 = eye protection + half-face respiratory w/thick straps.
PPE-adjusted value (µg) = collected residue (µg) X PPE adjustment factor.
Extrapolated Total Head (µg) = Total Face/Neck Residue (µg) + {Total Face/Neck Residue (µg) X [(Ratio Face/Neck SA (cm^2): Total Body SA (cm^2)) ÷ (Ratio "Rest of Head" SA (cm^2): Total Body SA (cm2))]}.

of hand wash samples ranged from 1 to 6: 18 workers had only one sample (at the end of the day), 6 workers had 2 samples, 2 workers had 3 samples, and 1 worker had 6 samples.

Without field fortification adjustments, individual hand wash samples ranged from < LOD to 312 µg. Out of a total of 42 hand wash samples, 10 were < LOQ (3 of which were < LOD). After adjusting for field fortification recoveries and summing each worker's hand wash samples, hand exposure (representing use of chemical-resistant gloves) ranged from 0.15 – 868 µg with an average of 53 µg.

3.3.4 Socks

Without field fortification adjustments, sock samples ranged from < LOD to 32.4 µg. Out of a total of 27 sock samples, 13 were < LOQ (5 of which were < LOD). After adjusting for field fortification recoveries, the total dermal exposure on worker's feet underneath shoes and socks ranged from 0.02 – 48.4 µg with an average of 4.33 µg.

3.3.5 Head Patches

As previously described, head patches were used to assess exposure as if workers who wore chemical-resistant hats were not wearing them. Patches were worn both on the inside and outside of the chemical-resistant hats; the patches' "per cm^2" results are summed and then extrapolated to the worker's head surface area (excluding that which was measured using the face/neck wipe sampling). Without field fortification adjustments, head patch samples ranged from < LOD to 44.3 µg. Out of a total of 7 inner head patches, 4 were < LOQ (1 of which was < LOD); out of 7 outer head patches 1 was < LOQ (but > LOD). After adjusting for field fortification recoveries, the total head patch results ranged from 0.05 – 51 µg.

3.3.6 OVS Air Samplers/Inhalation Exposure

Front and back sections of the OVS tube were analyzed separately. All front section samples had quantifiable residues while 14 of 27 back section samples were < LOQ (9 of which were < LOD). Without field fortification adjustments, front sections ranged from 0.0123 to 15.8 µg and back sections ranged from < LOD to 0.353 µg. Normally, residues are not expected to be found in the back sections of OVS tubes and could potentially indicate that the chemical collected from the air by the sampling pump penetrated or broke through the OVS tube sampling media; were that true, inhalation exposure could be underestimated. As the AHETF describes, almost all back-section OVS results were less than 10% of results found in front sections, likely indicating that any further breakthrough out of the back section would be very minimal. After adjusting for field fortification recoveries, the total (front section + back section) collected active ingredient amounts ranged from 0.012 – 19 µg with an average of 2.54 µg.

To calculate worker inhalation exposures from the OVS samples, the measured (mass) amounts are adjusted based on the sampling pump's air flow rate (in liters per minute) and a typical worker's breathing rate for this type of activity. The AHE600 report – as it is mainly a presentation of field and analytical results – presents only total mass of active ingredient collected by the air sampling units. A separate AHETF submission describing the mixing,

loading and applying using handgun equipment in greenhouses and nurseries (under separate EPA review; Crowley, 2019; DXXXXXX) presents worker inhalation exposures based on an assumed breathing rate. For workers mixing, loading and applying using handgun equipment in greenhouses and nurseries, a breathing rate of 16.7 liters per minute was used, representing light activities (NAFTA, 1998). The calculation is as follows:

*Inhalation exposure = Adjusted residue (µg) * [Breathing rate (LPM) ÷ Pump flow rate (LPM)]*

Based on these calculations, worker inhalation exposures ranged from 0.098 – 159 µg with an average of 21.3 µg.

3.4 Field Observations

Field researchers observed each worker and recorded their behavior throughout the work day. These can be found in the AHE600 report in Table 10 on pages 198-274.

Many of the observations detailed routine loading procedures. For example: worker 7 at 8:48 am –"At end of row, MU07 turns around and walks N spraying continuously on right side. Moves wand slightly side to side to cover ~5ft rows of plants". Other observations can potentially provide clues as to determinants of exposure – examples of these types of observations include:

- Worker 19 at 5:11 pm: "MU 19 started spraying section 1. Note: MU 19 holds spray gun at chest level and sprays walking backwards in a sweeping motion. He holds the spray gun with one hand and the hose which is being pulled out of the reel with the other."
- Worker 22 at 9:05 am: "Reaches end of row, moves backwards again spraying same plants. MU22 does not have any contact with foliage as rows are wide between plants."

Data users are recommended to review the field observations to get a sense of the variation in worker practices within the dataset.

4.0 Protocol Amendments and Deviations

Amendments to the study protocol and protocol deviations are copied below from AHE600. For additional details, see AHE600 Appendix A (pages 417-440). The 7 protocol amendments outlined were reasonable accommodations to accomplish the research and did not adversely impact the study conduct or the exposure monitoring results.

- Amendment 1 (December 11, 2012):
    - Amended the recruiting procedure to confirm the address of the survey respondent and to inform the potential participant that the Study Director or designee may contact them in the future.
- Amendment 2 (March 4, 2014):
    - Amended the contact and business affiliation information associated with two of the Principal Field Investigators associated with the study.
    - Updated the analytical methods and references for azoxystrobin, fosetyl-aluminum, imidacloprid, and permethrin (which was never used as a surrogate).

- Amendment 3 (May 27, 2015):
    - Added dry formulations of acephate as acceptable surrogates and identified the analytical methods to be used for residue analysis.
- Amendment 4 (May 27, 2015):
    - Identified the wet bulb/globe/dry bulb temperature (WBGT) as an alternative method of heat stress management.
- Amendment 5 (September 6, 2016):
    - Changed Study Director's address.
    - Changed participant inclusion criteria regarding Worker Protection Standard (WPS) training.
    - Added the requirement to review the product label with the participant prior to monitoring.
    - Changed the requirement for certain similarity restrictions from "must" to "preferably will".
- Amendment 6 (October 17, 2016):
    - Monitoring areas were expanded to include all counties in named states and states contiguous to certain states in the original monitoring areas to increase the pool of potential cooperators. Monitoring areas for which the targeted three MUs have been collected may be re-opened for recruiting additional MUs. This may result in some monitoring areas having more than three MUs and some fewer than three MUs.
- Amendment 7 (October 25, 2016):
    - If a grower volunteers a reference to another grower, the researcher may contact the referred grower to screen them for willingness to cooperate. Consideration of referred growers will increase the pool of potential cooperators.
- Amendment 8 (February 16, 2017):
    - Added mefenoxam as a surrogate.
- Amendment 9 (February 7, 2019):
    - Noted change of address for Study Director.

The three protocol deviations are copied below; EPA agrees they do not adversely impact the study's results:

- Deviation 1 (signed October 18, 2018):
    - At the analytical laboratory, calibration standards were used after their 1-month expiration date for the quantification of field sample residues in four sets due to an inadvertent documentation error.
- Deviation 2 (signed February 10, 2019):
    - An approved surrogate product was packaged in water soluble packets, however the protocol specified that products were to be in open pour packaging.
- Deviation 3 (signed February 10, 2019):
    - Three Monitoring Areas were expanded to include contiguous states prior to the protocol amendment allowing this expansion.

5.0 Conclusion

As the study followed the corresponding protocol as well as EPA guidelines for occupational pesticide exposure monitoring, the results are reliable for assessment of exposure and risk for workers mixing, loading, and applying pesticides using powered handgun equipment in managed horticultural facilities (e.g., greenhouses and nurseries).

Since these exposure data were collected with the intent of populating a generic pesticide exposure database, reviewers are directed to the additional information and statistical analyses in the AHETF Monograph: Mixing/Loading/Application using Powered Handgun Equipment in Managed Horticultural Facilities (AHE1023: Bruce and Holden, 2019). Review of the monograph as well as recommendations for use of the data by EPA exposure assessors is in a separate EPA review memorandum (Crowley, 2019; DXXXXXX).

6.0 References

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