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SUBJECT: CHLOROPICRIN SOIL FUMIGATION OCCUPATIONAL EXPOSURE DATA

Two study reports containing occupational exposure monitoring data (breathing-zone chloropicrin concentrations) from soil fumigations have been submitted to the California Department of Pesticide Regulation (DPR) by the Chloropicrin Manufacturers Task Force (CMTF). The first study monitored broadcast and bedded, tarped and non-tarped shank applications in Arizona, Washington, and Florida (Beard *et al*., 1996). The second study was entirely conducted in California, and monitored tarped and non-tarped shank applications, as well as tree replant injections and surface tarped drip applications conducted in fields and greenhouses (Rotondaro, 2004). I have previously reviewed Rotondaro (2004), and verified that it was a well-conducted study with acceptable quality assurance (Beauvais, 2005). In the attachment to this memo, I review Beard *et al*. (1996), summarize occupational monitoring results from both CMTF studies, and recommend exposure estimates for occupational scenarios associated with soil fumigation.

Beard *et al.* (1996) is also a well-conducted study with acceptable quality assurance. Twenty-two applications at ten different sites were monitored. Each application consisted of treating approximately 4 acres, draining the system, disconnecting empty cylinders (apparently two to four at a time), and transferring the empty cylinders to the supply truck. Work cycles ranged from 18 minutes (a tarp splitter following a tarped broadcast application in Florida) to 475 minutes (7.92 hrs; a tractor driver during a tarped bedded application in Arizona). Results ranged from below the quantification limit of 0.07 µg/tube (equivalent to 5.93 µg/m^3 (0.882 ppb) for a 2-hour monitoring interval) to 4,250 µg/m^3 (632 ppb) for a tarp splitter monitored for 44 minutes in association with a broadcast tarped application in Washington.

Rotondaro (2004) monitored 27 applications, three replicate applications for each of nine application methods. Broadcast shank applications were made to plots ranging between 2.7 and 9.7 acres; bedded applications ranged 1.11 – 8.4 acres; drip applications ranged 0.7 – 9.6 acres; and handwand replant applications ranged 0.11 – 0.22 acres. Work cycles ranged from 194 minutes for a handwand replant applicator to 779 minutes for an applicator during a surface tarped drip application. Reentry workers disturbing the soil were also monitored for the first hour of the work cycle, and task-specific monitoring was conducted while handlers disconnected chloropicrin cylinders. Results ranged from below the quantification limit of 0.2 µg/tube

(equivalent to 8.01 μg/m^3 (1.19 ppb) for a 4-hour monitoring interval) to 685 μg/m^3 (102 ppb) for a handwand replant applicator monitored for 4.5 hours.

Occupational exposure estimates for soil fumigation incorporate data from both Beard *et al.* (1996) and Rotondaro (2004). Exposures were estimated for short-term (one-time exposures and exposures lasting up to one week), seasonal (lasting from one week to one year), and annual exposures. For short-term exposures, DPR estimates the highest exposure an individual may realistically experience during or following legal chloropicrin uses. In order to estimate this "upper bound" of short-term exposure, DPR generally uses the estimated population 95th percentile of daily exposure, assuming daily exposures have a lognormal distribution. Seasonal, annual, and lifetime exposures are based on the arithmetic mean of daily exposure.

For each exposure scenario, reported chloropicrin concentrations were adjusted for site-specific field spike recoveries. Additionally, short-term exposures were adjusted for maximum allowed application rates and for the earliest post-application day that aeration and reentry are allowed, when monitoring was conducted on later post-application days. Omitting task-specific concentrations, recommended mean exposures range 8.76 – 906 μg/m^3 (1.30 – 135 ppb), and 95th percentile exposures range 11.7 – 4,930 μg/m^3 (1.74 – 734 ppb).

Mean and 95th percentile concentrations exceed 100 ppb for several handler scenarios, when product labels require use of respirator protection. Such concentrations suggest that monitoring of chloropicrin air concentrations is needed to ensure that handlers know when concentrations exceed 100 ppb.

References

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Rotandaro, A. 2004. Monitoring of Chloropicrin Emissions from Field and Greenhouse Drip Irrigation Applications, and Implied Worker Inhalation Exposure from Applications of Chloropicrin by Shank Injection, Drip Irrigation Systems and at Tree Replant Sites. Unpublished study submitted by the Chloropicrin Manufacturers Task Force, Mojave, California. Laboratory Study ID PRS02004. MRID 464202-01. DPR Data Volume 199-112, Record No. 209842

CHLOROPICRIN SOIL FUMIGATION OCCUPATIONAL EXPOSURE DATA: ATTACHMENT

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Review of Beard *et al*. (1996)

Applications

Each application consisted of treating approximately 4 acres, draining the system, disconnecting empty cylinders (apparently two to four at a time), and transferring the empty cylinders to the supply truck. Beard *et al.* (1996) referred to each application interval as a "replicate," although each included the same crew and equipment on the same plot.

The study was done in two phases, with the first phase conducted on four plots in Phoenix, Arizona, in April and May, 1995. Details of Phase I applications are summarized in Table 1. Tractors used in the applications had overhead mounted driver fans visible in photos included with the study report; however, the fans were turned off during the applications. Each tractor had a roof, but no windows; thus, the tractors did not have enclosed cabs.

The Phase I applications were begun at the centerline dividing each plot into east and west halves, with the eastern half treated first followed by the western half. No information was given about wind direction during the applications, and it is possible that second replicates were exposed to volatilizing chloropicrin from the earlier applications. Although the replicates were considered as separate applications for exposure monitoring, Beard *et al.* (1996) calculated the amount of chloropicrin applied and the application rate by site rather than by replicate.

The broadcast non-tarped shallow application (Plot 1) was done with four chisel shanks and two wing-shaped shanks; shanks were spaced 12 inches (30 cm) apart and injected at a depth of 12 to 13.5 inches (30 to 34.4 cm). The application rig was followed by a second tractor with a disc and cultipacker soil sealer, to move loose soil over the openings (known as "vents" or "chimneys") created by the shanks.

The bedded non-tarped shallow application (Plot 2) was done with four backswept type shanks at a depth of 11 inches (28 cm) from the bed surface and about 12.5 inches (31.8 cm) from the original soil surface; four beds were treated with each pass, with a shank approximately at the bed center. Bed width was 23 inches (58 cm) and bed centers were 40 inches (102 cm) apart in Plot 2; thus, the beds reduced the treated area to 57.5% of the gross acreage. The photo of this application shows four flat weights behind the tractor, one on top of each bed. These soil sealers were possibly flat metal bars or boards, but they were not described in the report.

The bedded tarped shallow application (Plot 3) had two backswept type shanks at a depth of about 11 inches (28 cm) from the bed surface; two beds were treated with each pass, with a shank approximately at the bed center. Bed width was 20 inches (51 cm) and bed centers were 40 inches (102 cm) apart in Plot 3, and the beds reduced the treated area to 50% of the gross acreage. The "1.5-mil plastic mulch tarp" was placed over bed tops by a second tractor that closely followed the application rig.

Table 1. Phase I Chloropicrin Applications Conducted by Beard *et al.* (1996) [a]

Plot	Application Method	Plot Size (acres) [b]	Date	Application Interval (hours) [c]		Application Rate (lbs AI/acre) [d]	
				Replicate 1	Replicate 2	Nom	Act
1	Broadcast non-tarped	8.10	April 13	07:18-10:15 (3.0)	10:56-12:45 (1.8)	175	171
2	Bedded non-tarped	8.46	April 14	10:43-12:00 (1.3)	12:32-14:12 (1.7)	175	149
3	Bedded tarped	5.92	May 2	06:25-13:30 (7.1)	13:45-18:45 (5.0)	350	377
4	Broadcast tarped	7.97	May 8	07:13-09:27 (2.2)	09:59-11:55 (1.9)	350	332

[a] All Phase I applications conducted in Phoenix, Arizona, in 1995.
[b] Two replicates each applied on a sub-plot comprising about half the plot. Multiply value by 2.471 to get area in hectares (ha).
[c] Time range on a 24-hour clock. Number of hours in parentheses. Each of these applications was considered separately for exposure monitoring, but the applied chloropicrin was determined for both together.
[d] Nom = Nominal application rate. Act = Actual application rate. Both nominal and actual rates are from Table 20 in Beard *et al.* (1996). Multiply value by 1.123 to get rate in kilograms per hectare (kg/ha). Application rates for bedded applications are based on treated area only; gross actual rates for bedded non-tarped and bedded tarped were 86 lbs AI/acre and 189 lbs AI/acre, respectively. Beds reduced treated area to 57.5% and 50%, respectively, of the plot size.

The broadcast tarped shallow application (Plot 4) was made with four chisel shanks and two wing-shaped shanks; shanks were spaced 12 inches (30 cm) apart and injected at a depth of 10.5 inches (26.7 cm). The tarp roller was mounted just behind the shanks, so that the application rig could place the 1-mil thick polyethylene tarp as it injected chloropicrin.

The second phase of the study involved only broadcast shallow tarped applications, and was conducted on three plots each in Yakima, Washington, and Bradenton, Florida. The same application equipment was used on all three plots at each location. In Washington, applications were made with four chisel shanks and two wing-shaped shanks; shanks were spaced 12 inches (30 cm) apart and injected at a depth of 9 inches (23 cm). A tarp roller was mounted on the application rig just behind the shanks, and placed a 1-mil "high-barrier" polyethylene tarp as it injected chloropicrin (despite the different names, tarps used in Washington were probably similar to those used in Arizona and Florida). In Florida, applications were made with two straight shanks mounted outside of six Noble plows, each having two injection points. Shanks injected at a depth of about 10 inches (25 cm). A tarp roller was mounted on the application rig just behind the shanks, which unspooled a 1-mil thick polyethylene tarp over the injected chloropicrin. Details of Phase II applications are summarized in Table 2.

Table 2. Phase II Chloropicrin Broadcast Tarped Applications Conducted in 1995 and 1996 by Beard *et al.* (1996) [a]

Plot	Plot Size (acres) [b]	Date	Application Interval (hours) [c]			Application Rate (lbs AI/acre) [d]	
			Replicate 1	Replicate 2	Replicate 3	Nom	Act
W-1	8.35	10/17/1995	07:55-10:55 (3.0)	12:17-15:22 (3.1)	Not applicable	350	343
W-2	7.47	10/18/1995	07:44-10:00 (2.3)	10:23-12:28 (2.1)	Not applicable	350	360
W-3	5.3	10/19/1995	07:25-08:50 (1.4)	09:22-11:25 (2.0)	Not applicable	350	351
F-1	8.18	1/16/1996	07:52-10:31 (2.6)	10:39-13:22 (2.7)	Not applicable	350	346
F-2	12.41	1/17/1996	07:53-09:54 (2.0)	10:04-12:05 (2.0)	13:08-14:35 (1.4)	350	345
F-3	13.16	1/18/1996	07:31-09:01 (2.5)	09:28-10:51 (1.4)	12:17-13:44 (1.4)	350	334

[a] Phase II applications conducted in Yakima, Washington (W plots), and Bradenton, Florida (F plots).
[b] Two replicates each applied on a sub-plot comprising about half the plot. Multiply value by 2.471 to get area in hectares (ha).
[c] Time range on a 24-hour clock. Number of hours in parentheses. Most plots were treated in two intervals rather than three; only two of the Florida plots had three replicates. Each of these applications was considered separately for exposure monitoring, but the applied chloropicrin was determined only for the overall plot.
[d] Nom = Nominal application rate. Act = Actual application rate. Both nominal and actual rates are from Tables 21 and 22 in Beard *et al.* (1996). Multiply value by 1.123 to get rate in kilograms per hectare (kg/ha).

All applications monitored by Beard *et al.* (1996) were shallow shank applications, as none were deeper than 12-13 inches (30-33 cm); deep shank applications would be in the 18-24 inch (46-61 cm) depth range (Rotondaro, 2004). Actual application rates were determined in both Phase I and Phase II by weighing each chloropicrin cylinder before and after use to determine pounds applied, and measuring the plot size. Measured plot sizes and actual application rates are reported above in Tables 1 and 2. Soil characterization is summarized in Appendix 1, and equipment used in applications is summarized in Appendix 2.

Exposure Monitoring

Breathing zone air concentrations of chloropicrin were monitored with air sampling tubes containing 600 mg (400 mg in front section, 200 mg in back section) of XAD-4 sorbent connected to air pumps calibrated at 50 ml per minute (Beard *et al*., 1996). Each worker being monitored wore one pump at his belt, but a tubing splitter was used to allow duplicate samples to be collected concurrently; both sampler tubes were attached to the lapel of the worker being monitored. The flow rates of the individual tubes were calibrated at the start and end of each monitoring interval using a rotameter (personal communication from Aaron Rotondaro, study scientist, May 28, 2008). Back-up pumps, each with two tubes calibrated at 100 ml per minute, were placed on one or two tarp removers at each site in Washington and Florida.

Replicates were defined by Beard *et al.* (1996) as follows (p. 32):

> A replicate consisted of monitoring worker air concentration during one work cycle. An application work cycle was defined as those work activities performed during field application starting with loading the chloropicrin cylinders onto the tractor, application and then unloading the empty cylinders. For the tarp removers, a work cycle was defined as those work activities performed during splitting, aerating and/or removing the tarp on a field for approximately the same size of area as one application replicate (~ four acres). One sample (in duplicate) was collected for each work interval for each worker and was considered one replication for each job description sampled.

DPR practice when reviewing exposure monitoring data is generally to consider a replicate as a single worker monitored for a full shift. However, when discussing data reported by Beard *et a*l. (1996), the term "replicate" is used as defined above.

Work cycles ranged from 18 minutes (a tarp splitter following a tarped broadcast application in Florida) to 475 minutes (7.92 hrs; a tractor driver during a tarped bedded application in Arizona). In addition to the full work cycle monitoring, task-specific monitoring was conducted of a tractor driver doing equipment repairs during a non-tarped broadcast application in Arizona for a 16-minute interval. No other task-specific monitoring was conducted by Beard *et al.* (1996).

Background levels of chloropicrin were determined prior to four of the applications by monitoring air concentrations adjacent to the fields (sampling stations were within 18 m of field edge). The four applications with pre-application monitoring included the broadcast non-tarped and bedded non-tarped applications in Arizona during Phase I, and Plot 1 (the "flux plot") in both Washington and Florida during Phase II. All pre-application samples were below the detection limit of 0.02 µg chloropicrin per tube.

Analytical Method

Sorbent in the front and back sections of the air sampling tubes was extracted with hexane, and the amount of chloropicrin in each sorbent section was determined using gas chromatography (GC) with an electron capture detector. The limit of quantification (LOQ) was 0.07 µg chloropicrin per tube (Beard *et al*., 1996).

The method was validated for linearity of responses of the GC system within the range of 0.01-0.2 µg chloropicrin/ml of solvent (0.05-1 µg chloropicrin/tube). Samples containing higher amounts of chloropicrin were diluted with hexane and re-analyzed as needed. Additional validation studies investigated effects of various factors on recovery of chloropicrin from sorbent, including loading levels of chloropicrin, air flow rates, relative humidity, total sample volume (amount of air passing through sorbent during sampling), and storage time. No significant effect of any of these factors on the recovery of chloropicrin on sorbent was reported. The maximum loading level tested was 500 µg chloropicrin, the maximum air flow was 50 ml/min, and the maximum sample volume was 36 L (which would be achieved following 12 hours at 50 ml/min).

Quality Assurance

Quality assurance samples consisted of solvent blanks, control samples, procedural fortified tubes and field fortified tubes (FFs). Control tubes were set up at each site and air was drawn through them in the same way as the sample tubes attached to workers. At the Arizona site, all 61 controls had chloropicrin < LOQ of 0.07 µg/tube. At the Washington site, all but three of a total of 42 controls had chloropicrin residues < LOQ; the exceptions were near the LOQ, in the range of 0.10 – 0.20 µg/tube. At the Florida site, all but one of the 45 controls had chloropicrin < LOQ; the exception contained 0.07 µg/tube. The controls for all sites are considered acceptable.

The procedural fortified tubes (laboratory spikes) were prepared during sample analysis, and consisted of sample tubes that were spiked with chloropicrin then extracted and analyzed along with samples. The mean percent recovery ± standard deviation (SD) of the procedural fortified tubes was 87 ± 17% during analysis of Arizona samples; 93 ± 24% during analysis of Washington samples; and 85 ± 21% during analysis of Florida samples. These recoveries are acceptable.

With respect to FFs, Beard *et al*. (1996) stated that: "Quality assurance spikes were prepared as close as possible to the treated field in an area that was believed to be free of background chloropicrin but with the same ambient conditions as the field samples." FFs were stored, transported to the laboratory, and analyzed along with samples from each site.

FF recoveries are summarized in Table 3. Data from the three sites were considered separately because monitoring was conducted at different times; additionally, at the Arizona site monitoring of non-tarped and tarped applications occurred at different times and those FFs are considered separately.

FF recoveries were generally acceptable at the Arizona and Florida sites, where mean FF recoveries ranged 78 – 107%. At the Washington site, mean FF recoveries were acceptable for the mid- and high-level spikes, at 118% and 109%, respectively. The mean percent recovery ± SD of low-level FFs at the Washington site was 164 ± 65%, and the range was 79.5 – 384%. Ranges of mid- and high-level spikes at the Washington site were 44.2 – 193% and 39.4 – 223%, respectively.

Table 3. Summary of Field Fortification (FF) Recoveries for Chloropicrin [a]

Study Site	Number of FFs	Level [b]	Mean Recovery (%) [c]	SD	CV
Arizona, Non-Tarped Plots	45	0.23	83 (47.8 – 108.7)	15	18.1
	45	4.81	107 (30.6 – 166.9)	24	22.4
	45	278	96 (56.1 – 199.3)	25	26.0
Arizona, Tarped Plots	63	0.21	78 (57.1 – 123.8)	9.9	12.7
	62	6.01	78 (50.4 – 101.8) [d]	13	16.7
	62	248	101 (71.8 – 131.5) [e]	12	11.9
Washington	42	0.151	164 (79.5 – 384.0)	65	39.6
	42	4.73	118 (44.2 – 193.0)	35	29.7
	42	229	109 (39.4 – 223.0)	33	30.3
Florida	43	0.219	99 (59.4 – 173.5)	26	26.3
	44	5.62	96 (63.9 – 161.0)	20	20.8
	45	297	88 (54.5 – 142.4)	19	21.6

[a] Summary of data from soil fumigation exposure monitoring study (Beard *et al.*, 1996), Table 4 – Table 19. Mean and standard deviation (SD) calculations reported by Beard *et al.* (1996) were spot-checked, and coefficient of variation (CV) was calculated from reported mean and SD (CV = 100*SD/mean).
[b] Fortification level in µg/tube.
[c] Range of individual FFs in parentheses.
[d] Beard *et al.* (1996) omitted one FF, with recovery 288.7%, as a double-spike.
[e] Beard *et al.* (1996) omitted one FF, with recovery 173.4%, as a double-spike.

Beard *et al.* (1996) adjusted sample residues for FF recoveries < 100%, with residue range intervals defined by mid-points between FF levels. DPR practice is in general agreement with U.S. EPA policy, in which samples are corrected for field fortification recoveries below 90% (U.S. EPA, 1992; U.S. EPA, 1998). Adjustment factors used by Beard *et al.* (1996) and in estimating exposures reported in this memo are summarized in Table 4. The two adjustment factors used by Beard *et al.* (1996) that differ from DPR practice are marked with bold text in Table 4. The first of these adjustment factors was for the high-level FF for Arizona non-tarped applications; however, no samples were in the range of this FF. The second adjustment factor was for the low-level FF at the Florida site. Beard *et al.* (1996) adjusted concentrations to 1.00, which resulted in slightly higher concentrations than those calculated according to DPR practice. Results in this memo were adjusted for FF recovery according to DPR practice.

Table 4. Field Fortification (FF) Recovery Adjustment Factors for Samples [a]

Study Site	Residue Range Used by Beard *et al.* (1996) [b]	Beard *et al.* (1996) Adjustment Factor [c]	Residue Range Used by DPR [d]	DPR Adjustment Factor [e]
Arizona, Non-Tarped Plots	0 – 2.3	0.83	< 2.52	0.83
	2.3 – 140	1.00	2.52 – 141	1.00
	> 140	**0.96**	> 141	1.00
Arizona, Tarped Plots	0 – 127	0.78	< 3.11	0.78
	NA [f]	NA	3.11 – 127	0.78
	> 127	1.00	> 127	1.00
Washington	< 2.45	1.00	< 2.45	1.00
	2.45 – 117	1.00	2.45 – 117	1.00
	> 117	1.00	> 117	1.00
Florida	0 – 150	**0.98**	< 2.92	1.00
	NA	NA	2.92 – 151	1.00
	> 150	0.88	> 151	0.88

[a] Summary of FF recovery reported in exposure monitoring study (Beard *et al.*, 1996), Table 4 – Table 19.
[b] Residue in µg/tube. Samples within each range are divided by the adjustment factor shown in the next column. Ranges span FF levels.
[c] Beard *et al.* (1996) adjusted samples for field fortification recoveries less than 100%, and reported adjustment factors as values by which results were multiplied. In this table, the adjustment factors are reported as the amount by which results were divided. Adjustments differing from DPR practice are marked with bold text.
[d] Residue in µg/tube. Ranges are selected using midpoints between successive FF levels.
[e] Department of Pesticide Regulation (DPR) practice is to adjust residues for samples with corresponding field fortification recoveries of less than 90%.
[f] NA = Not Applicable. Beard *et al.* (1996) combined the first two levels, as recoveries did not differ significantly.

Breakthrough (chloropicrin residues recovered from back sorbent section as well as front section) occurred in several sorbent tubes, and is summarized in Table 5. Huey and Materna (2002) defined breakthrough in air sampling tubes as “a condition in which the mass of a collected gas or vapor in the backup section is greater than 10% of the mass in the front section." If a chemically significant amount of analyte passes through the front section of a tube, this is an indication that the tube did not quantitatively capture the analyte. Breakthrough is a concern in exposure monitoring because it could result in underestimating chloropicrin concentrations to which workers may be exposed.

Table 5. Breakthrough in Chloropicrin Field Fortifications (FFs) [a]

Study Site	FF Level [b]	FF Tubes with Breakthrough > LOQ [c]	Highest Breakthrough (%) [d]	Range for FF (µg/tube) [e]	Number of Tubes in Range [f]
Arizona, Non-Tarped Plots	0.23	0/45	0	< 2.52	14
	4.81	0/45	0	2.52 – 141	0
	278	26/45	6.6	> 141	0
Arizona, Tarped Plots	0.21	0/63	0	< 3.11	60
	6.01	2/62	1.7	3.11 – 127	6
	248	53/62	14.7	> 127	0
Washington	0.151	0/42	0	< 2.45	40
	4.73	0/42	0	2.45 – 117	48
	229	4/42	0.1	> 117	0
Florida	0.219	0/43	0	< 2.92	104
	5.62	0/44	0	2.92 – 151	22
	297	11/45	0.2	> 151	0

[a] Summary of breakthrough reported in exposure monitoring study (Beard *et al.*, 1996), Table 4 – Table 19.
[b] Residue in µg/sample, except for air sampling tubes, where level is µg/tube. Ranges are selected using midpoints between successive field fortification levels.
[c] The limit of quantification (LOQ) is 0.07 µg/tube. Ratio is the number of FF tubes with quantifiable residues in the back section divided by the total number of FFs at that level.
[d] Breakthrough as percent of amount fortified on tube.
[e] Residue range used by the Department of Pesticide Regulation: samples in range were corrected for recovery of the FF.
[f] Number of samples in range of FF (range given in previous column). Most workers wore two tubes attached to a single pump during a monitoring period; each tube was counted separately for this total. The number of sample tubes analyzed totaled 294 tubes, not including quality assurance tubes.

Substantial breakthrough occurred in FFs fortified at the high level (300 µg chloropicrin per tube) at the Arizona site; of 62 high-level FFs, 53 had chloropicrin residues > LOQ in the back section, with the highest amount 36.4 µg (14.7% of the spiked amount). Additionally, two tubes site fortified at the mid-level (6.01 µg chloropicrin per tube) had breakthrough above the LOQ; the highest was 0.1 µg, which was 1.7% of the spiked amount. However, at the other two sites, only limited breakthrough occurred (less than 1% of the spiked amount), and only in the high level FFs. With the exception of the high-level FFs at the Arizona site, these results are below the breakthrough criterion of 10% suggested by Huey and Materna (2002) for acceptable air sampling. Beard *et al*. (1996) concluded that the level of breakthrough was relatively low, and that the satisfactory recovery of FFs suggests that breakthrough did not significantly affect FFs. Furthermore, the high level FFs, where most of the breakthrough occurred, contained chloropicrin amounts substantially above all samples. This suggests that it is unlikely that chloropicrin concentrations in this study were underestimated due to breakthrough.

Results

Data were reported for a total of 294 tubes (Table 5). However, most workers wore two sampling tubes (some wore four tubes), and individual tubes are repeated measures rather than true

replicates. Exposure estimates are reported as mean concentrations (mean of the two or four tubes worn by each worker during a work cycle).

For each replicate, Beard *et al.* (1996) reported 8-hour time-weighted average (TWA) concentration estimates that assumed two hours of non-exposure plus six hours exposure (i.e., reported concentrations had been multiplied by 0.75). However, DPR practice is to normalize workday exposures by assuming that workers are exposed for a full 8 hours. Concentrations reported in this memo were calculated from data reported in Appendix E, and do not include the 0.75 adjustment. Sample results were adjusted for FF recoveries. Results below the LOQ of 0.07 µg/tube were not corrected for field spike recoveries; ½ LOQ (0.035 µg/tube) was substituted for results < LOQ.

Table 6 summarizes exposures from Phase I non-tarped applications in Arizona. Non-tarped broadcast and bedded applications were performed on consecutive days, two applications by each method. One individual operated the application rig for both the broadcast and bedded applications; i.e., all four tractor driver replicates reported in Table 6 monitored the same individual. A second individual drove the tractor with the soil sealer during the non-tarped broadcast application.

The same individual was used for both driver replicates; additionally, this individual was monitored for the bedded non-tarped driver replicates as well. This driver was also monitored during a 16-minute repair task, via a second pair of sampling tubes attached to a second pump. However, this task-specific monitoring resulted in chloropicrin below the limit of quantification of 0.07 µg/tube. Substituting ½ LOQ for this value would yield a concentration of 43.8 $\mu g/m^3$, which is below the full-shift estimates for the driver of 117 and 160 $\mu g/m^3$ and suggests that a separate estimate is not needed for this task.

Concentrations in Table 6 and all following tables are reported in $\mu g/m^3$, and equivalent concentrations in parts per billion (ppb), expressed as ratio of volume of chloropicrin to volume of air, were estimated using the ideal gas law. At 1 atmosphere of pressure and a temperature of 25°C, the concentration in ppb is equal to the concentration in $\mu g/m^3$, multiplied by 24.45 liter-atm/mole and divided by the molecular weight of 164.38 g/mole. As 24.45/164.38 = 0.1487, this value can be multiplied by the concentration in $\mu g/m^3$ to obtain the concentration in ppb.

Table 6. Chloropicrin Exposures During Phase I Non-Tarped Applications in Arizona [a]

Activity	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
				(µg/m^3)	ppb
Broadcast Non-Tarped					
Tractor Driver	1	4/13/1995	215	160	23.8
Tractor Driver [d]	2	4/13/1995	153	117	17.4
Soil Sealer	1	4/13/1995	215	41.6	6.19
Soil Sealer [e]	2	4/13/1995	137	42.9	6.38
Bedded Non-Tarped					
Tractor Driver	1	4/14/1995	145	35.0	5.21
Tractor Driver [f]	2	4/14/1995	127	88.6	13.2

[a] Data from Beard *et al.* (1996), Appendix E. Activity descriptions and individual identifiers from page 33 of Beard *et al.* (1996).
[b] Each replicate was monitored during activities on a sub-plot approximately 4 acres (1.6 hectares) in size. As noted below, the same individual was monitored for more than one replicate.
[c] The concentration is the mean of two sampling tubes attached to a single worker. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] The same driver was used for both replicates (the same individual was monitored for the bedded non-tarped driver replicates as well). This driver was also monitored during a 16-minute repair task, via a second pair of sampling tubes attached to a second pump. However, this task-specific monitoring resulted in chloropicrin below the limit of quantification of 0.07 µg/tube.
[e] The same individual was used for both replicates, and drove a tractor that followed the applicator.
[f] The same driver was used for both replicates; this same driver was also monitored for the broadcast non-tarped driver replicates.

Table 7 summarizes exposures from Phase I bedded tarped applications in Arizona. Two applications were made to the same plot, identified by Beard *et al.* (1996) as Plot 3. The same two tractor drivers were used for both applications, one to drive the application rig and one to follow in a second tractor with the mulch layer (tarp layer). The copilot followed the second tractor, making certain that the tarp material was properly aligned and helping the shovelers cover the edges of the tarp. The same two shovelers were used for both applications, cutting the ends of the tarps and covering them with soil. Six days after the application, four tarp removers walked along the furrows and used commercial propane burners to burn holes in the center of the tarp approximately every two feet (0.6 m). The holes would be used for planting, and the tarps would remain on the beds.

Table 7. Chloropicrin Exposures During Bedded Tarped Applications in Arizona [a]

Activity	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
				(μg/m^3)	ppb
Tractor Driver/Applicator [d]	1	5/2/1995	475	38.5	5.73
Tractor Driver/Applicator	2	5/2/1995	306	22.7	3.37
Tractor Driver/Tarper [e]	1	5/2/1995	394	27.2	4.05
Tractor Driver/Tarper	2	5/2/1995	311	16.9	2.51
Co-pilot [f]	1	5/2/1995	421	13.6	2.03
Co-pilot	2	5/2/1995	311	15.2	2.26
Shoveler [f]	1	5/2/1995	422	20.2	3.00
Shoveler	2	5/2/1995	422	16.2	2.40
Shoveler	3	5/2/1995	311	35.4	5.26
Shoveler	4	5/2/1995	311	41.1	6.12
Tarp Puncher [g]	1	5/8/1995	171	4.09	0.609
Tarp Puncher	2	5/8/1995	171	4.09	0.609
Tarp Puncher	3	5/8/1995	167	4.19	0.623
Tarp Puncher	4	5/8/1995	167	4.19	0.623

[a] Data from Beard *et al.* (1996), Appendix E.
[b] Each replicate was monitored during activities on a sub-plot approximately 4 acres in size. Two replicates can be the same worker on the same plot.
[c] The concentration is the mean of two sampling tubes attached to a single worker. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] The same driver was used for both replicates, and drove the application rig.
[e] The same individual was used for both replicates, and drove a tractor that followed the applicator and lay down the tarp.
[f] The same individual was used for two replicates, one for each of two applications.
[g] Four different individuals were used for the four replicates; the activity involved walking along the rows and burning holes in the tarp with a commercial propane burner. All tubes had chloropicrin below the limit of quantification of 0.07 μg/tube; ½ of this value was substituted in the concentration calculation.

Table 8 summarizes exposures from Phase I broadcast tarped applications in Arizona. Two applications were made to the same plot, identified by Beard *et al.* (1996) as Plot 4. The same tractor driver was used for both applications, driving a tractor that towed both the application rig and the tarp layer. The same co-pilot worked both applications as well, making certain that the tarp material was properly aligned and helping the shovelers cover the edges of the tarp. The same two shovelers were used for both applications, cutting the ends of the tarps and covering them with soil. Five individuals were monitored for the five tarp remover replicates. One individual (wearing two pumps) drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise; this replicate is identified in Table 8 as a “tarp splitter.” The next day, the other four individuals removed the tarp by rolling the tarp lengthwise (“roping”) and guiding it onto a trailer towed behind a tractor.

Table 8. Chloropicrin Exposures During Broadcast Tarped Applications in Arizona [a]

Activity	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
				(µg/m^3)	ppb
Tractor Driver [d]	1	5/8/1995	125	438 [e]	65.1 [e]
Tractor Driver	2	5/8/1995	147	548	81.5
Co-pilot [f]	1	5/8/1995	191	1,180	175
Co-pilot	2	5/8/1995	149	1,350	200
Shoveler [f]	1	5/8/1995	184	60.2	8.96
Shoveler	2	5/8/1995	184	288	42.9
Shoveler	3	5/8/1995	137	254	37.7
Shoveler	4	5/8/1995	137	540	80.2
Tarp Splitter [g]	1	5/14/1995	40	214	31.9
Tarp Remover [h]	1	5/15/1995	117	21.3	3.17
Tarp Remover	2	5/15/1995	118	5.93 [i]	0.882 [i]
Tarp Remover	3	5/15/1995	118	5.93 [i]	0.882 [i]
Tarp Remover	4	5/15/1995	118	26.0	3.87

[a] Data from Beard *et al.* (1996), Appendix E.
[b] Each replicate was monitored during activities on a sub-plot approximately 4 acres in size. Two replicates can be the same worker on the same plot.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] The same driver was used for both replicates. During the first application, the driver wore a backup pump with an addition two tubes.
[e] Mean of four tubes; driver wore two pumps, each with two tubes.
[f] The same individual was used for two replicates, one for each of two applications.
[g] Tarps were split 6 days post-application. One individual (wearing two pumps) drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise. Concentrations are the mean of four tubes.
[h] Tarps were removed the day after splitting. Four different individuals were used for the four replicates.
[i] Both tubes had chloropicrin below the limit of quantification of 0.07 µg/tube; ½ of this value was substituted in the concentration calculation.

Table 9 summarizes exposures monitored from Phase II broadcast tarped applications on Plot 1 in Washington. Two applications were made to the plot, each using the same tractor driver, co-pilot, and two shovelers. The two shovelers were later monitored for the six tarp remover replicates. One individual (wearing two pumps) drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise; after splitting tarps on half of the plot, the tubes on both pumps were changed and the tarp splitter completed the plot. The next day, the two workers who had been shovelers removed the tarp by rolling the tarp lengthwise ("roping") and guiding it onto a trailer towed behind a tractor.

Table 9. Chloropicrin Exposures: Broadcast Tarped Applications on Washington Plot 1 [a]

Activity	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
				(μg/m^3)	ppb
Tractor Driver [d]	1	10/17/1995	242	364 [e]	54.1 [e]
Tractor Driver	2	10/17/1995	245	210	31.3
Co-pilot [f]	1	10/17/1995	242	247	36.7
Co-pilot	2	10/17/1995	245	656	97.5
Shoveler [f]	1	10/17/1995	242	171	25.4
Shoveler	2	10/17/1995	242	73.6	10.9
Shoveler	3	10/17/1995	221	119	17.7
Shoveler	4	10/17/1995	224	152	22.6
Tarp Splitter [g]	1	10/23/1995	56	130	19.3
Tarp Splitter [g]	2	10/23/1995	50	73.6	10.9
Tarp Remover [h]	1	10/24/1995	193	791	118
Tarp Remover	2	10/24/1995	100	499	74.2
Tarp Remover	3	10/24/1995	165	1,320	196
Tarp Remover	4	10/24/1995	196	1,100	164

[a] Data from Beard *et al.* (1996), Appendix E.
[b] Each replicate was monitored during activities on a sub-plot approximately 4 acres in size. Two replicates can be the same worker on the same plot.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] The same driver was used for both replicates. During the first application, the driver wore a backup pump with an addition two tubes.
[e] Mean of four tubes; driver wore two pumps, each with two tubes.
[f] The same individual was used for two replicates, one for each of two applications.
[g] Tarps were split 6 days post-application. One individual (wearing two pumps) drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise. The same individual was monitored for both tarp splitter replicates. Concentrations for both tarp splitters are the mean of four tubes.
[h] Two individuals were used for the four replicates; these were the same individuals who had been monitored as shovelers. One of them had also been monitored for both tarp splitter replicates.

Table 10 summarizes exposures monitored from Phase II broadcast tarped applications on Plot 2 in Washington. Two applications were made to the plot, each using the same tractor driver, co-pilot, and two shovelers. All individuals monitored on Plot 2, including the tarp splitter and tarp remover replicates, had previously been monitored on Plot 1, and tasks were described exactly the same way between the two plots. However, the tractor driver on Plot 2 wore a single pump with two sample tubes for both work cycles; no backup pump was used on the driver.

Table 10. Chloropicrin Exposures: Broadcast Tarped Applications on Washington Plot 2 [a]

Activity	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
				(μg/m^3)	ppb
Tractor Driver [d]	1	10/18/1995	184	559	83.1
Tractor Driver	2	10/18/1995	150	411	61.1
Co-pilot [e]	1	10/18/1995	185	530	78.8
Co-pilot	2	10/18/1995	151	310	46.2
Shoveler [f]	1	10/18/1995	175	32.8	4.88
Shoveler	2	10/18/1995	186	138	20.5
Shoveler	3	10/18/1995	139	160	23.7
Shoveler	4	10/18/1995	144	107	15.9
Tarp Splitter [g]	1	10/24/1995	37	1,050	157
Tarp Splitter	2	10/24/1995	30	1,290	192
Tarp Remover [h]	1	10/25/1995	162	1,350	200
Tarp Remover	2	10/25/1995	73	3,220	479
Tarp Remover	3	10/25/1995	115	2,360	351
Tarp Remover	4	10/25/1995	112	2,140	318

[a] Data from Beard *et al.* (1996), Appendix E.
[b] Each replicate was monitored during activities on a sub-plot approximately 4 acres in size. Two replicates can be the same worker on the same plot.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] The same driver was used for both replicates.
[e] The same individual was used for two replicates, one for each of two applications.
[f] The same two individuals were used to give two replicates in each of two applications.
[g] Tarps were split 6 days post-application. One individual (wearing two pumps) drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise. The same individual was monitored for both tarp splitter replicates. Concentrations are the mean of four tubes.
[h] Tarps were removed the day after splitting. Two individuals were used for the four replicates; these were the same individuals who had been monitored as shovelers. One of them had also been monitored for both tarp splitter replicates.

Table 11 summarizes exposures monitored from Phase II broadcast tarped applications on Plot 3 in Washington. Two applications were made to the plot, each using the same tractor driver, co-pilot, and two shovelers. With the exception of one tarp remover (Replicate 1 in Table 11), all individuals monitored on Plot 3, had previously been monitored on Plots 1 and 2.

Table 11. Chloropicrin Exposures: Broadcast Tarped Applications on Washington Plot 3 [a]

Activity	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
				(μg/m^3)	ppb
Tractor Driver [d]	1	10/19/1995	138	1,190	177
Tractor Driver	2	10/19/1995	155	631	93.9
Co-pilot [e]	1	10/19/1995	136	1,200	179
Co-pilot	2	10/19/1995	156	543	80.7
Shoveler [f]	1	10/19/1995	126	266	39.5
Shoveler	2	10/19/1995	125	229	34.1
Shoveler	3	10/19/1995	122	235	35.0
Shoveler	4	10/19/1995	146	340	50.5
Tarp Splitter [g]	1	10/25/1995	44	4,250	632
Tarp Remover [h]	1	10/30/1995	197	80.3	11.9
Tarp Remover	2	10/30/1995	197	111	16.5

[a] Data from Beard *et al.* (1996), Appendix E.
[b] Each replicate was monitored during activities on a sub-plot approximately 4 acres in size. Two replicates can be the same worker on the same plot.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] The same driver was used for both replicates.
[e] The same individual was used for two replicates, one for each of two applications.
[f] The same two individuals were used to give two replicates in each of two applications.
[g] Tarps were split 6 days post-application. One individual (wearing two pumps) drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise. Concentrations are the mean of four tubes. This individual was previously monitored for two shoveler replicates.
[h] Tarps were removed 5 days after splitting. Two individuals were used for the four replicates; one of these was previously monitored for two shoveler replicates.

Table 12 summarizes exposures monitored from Phase II broadcast tarped applications on Plot 1 in Florida. Two applications were made to the plot, each using the same two shovelers. The driver during the first application was the co-pilot during the second application, and vice versa. One of the shovelers was later monitored for two of the six tarp remover replicates. One individual (wearing two pumps) drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise; after splitting tarps on half of the plot, the tubes on both pumps were changed and the tarp splitter completed the plot. The next day, the two workers who had been shovelers removed the tarp by rolling the tarp lengthwise ("roping") and guiding it onto a trailer towed behind a tractor. The remaining tarp remover, an individual not previously monitored, drove the tractor.

Table 12. Chloropicrin Exposures: Broadcast Tarped Applications on Plot 1 in Florida [a]

Activity	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
				(µg/m^3)	ppb
Tractor Driver [d]	1	1/16/1996	208	162	24.0
Tractor Driver	2	1/16/1996	173	108	16.1
Co-pilot [e]	1	1/16/1996	202	206	30.7
Co-pilot	2	1/16/1996	172	338	50.3
Shoveler [e]	1	1/16/1996	155	122	18.1
Shoveler	2	1/16/1996	207	105	15.6
Shoveler	3	1/16/1996	176	117	17.4
Shoveler	4	1/16/1996	165	76.4	11.4
Tarp Splitter [f]	1	1/22/1996	22	81.3 [g]	12.1 [g]
Tarp Splitter	2	1/22/1996	30	212 [g]	31.5 [g]
Tarp Remover [h]	1	1/23/1996	85	928	138
Tarp Remover	2	1/23/1996	64	355	52.7
Tarp Remover	3	1/23/1996	85	772	115
Tarp Remover	4	1/23/1996	85	304	45.1
Tarp Remover	5	1/23/1996	64	103	15.3
Tarp Remover	6	1/23/1996	64	278	41.4

[a] Data from Beard *et al.* (1996), Appendix E.
[b] Each replicate was monitored during activities on a sub-plot approximately 4 acres in size. Two replicates can be the same worker on the same plot.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] The same driver was used for both replicates.
[e] The same individual was used for two replicates, one for each of two applications.
[f] Tarps were split 6 days post-application. One individual (wearing two pumps) drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise. Concentrations are the mean of four tubes.
[g] Mean of four tubes; tarp splitter wore two pumps, each with two tubes.
[h] Tarps were removed the day after splitting. Two individuals were used for the four replicates; these were the same individuals who had been monitored as shovelers. One of them had also been monitored for both tarp splitter replicates.

Table 13 summarizes exposures monitored from Phase II broadcast tarped applications on Plot 2 in Florida. The driver during the first application was the co-pilot during the second application, and vice versa. One of those individuals (wearing two pumps) later drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise; after splitting tarps on half of the plot, the tubes on both pumps were changed twice while the tarp splitter completed the plot. Thus, all three tarp splitter replicates involved monitoring the same individual. The next day, the two workers who had been shovelers removed the tarp by rolling the tarp lengthwise ("roping") and guiding it onto a trailer towed behind a tractor.

Table 13. Chloropicrin Exposures: Broadcast Tarped Applications on Plot 2 in Florida [a]

Activity	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
				(μg/m^3)	ppb
Tractor Driver [d]	1	1/17/1996	58	348	51.8
Tractor Driver	2	1/17/1996	127	100	14.9
Tractor Driver	3	1/17/1996	137	542	80.6
Co-pilot [d]	1	1/17/1996	162	310	46.2
Co-pilot	2	1/17/1996	126	371	55.2
Co-pilot	3	1/17/1996	139	760	113
Shoveler [e]	1	1/17/1996	131	90.8	13.5
Shoveler	2	1/17/1996	140	136	20.2
Shoveler	3	1/17/1996	112	154	23.0
Shoveler	4	1/17/1996	122	59.8	8.90
Shoveler	5	1/17/1996	120	216	32.1
Shoveler	6	1/17/1996	118	175	26.0
Tarp Splitter [f]	1	1/23/1996	25	567 [g]	84.4 [g]
Tarp Splitter	2	1/23/1996	18	233 [g]	34.7 [g]
Tarp Splitter	3	1/23/1996	18	182 [g]	27.1 [g]
Tarp Remover [h]	1	1/24/1996	79	175	26.0
Tarp Remover	2	1/24/1996	80	95.7	14.2
Tarp Remover	3	1/24/1996	80	294	43.7
Tarp Remover	4	1/24/1996	52	144	21.3
Tarp Remover	5	1/24/1996	52	419	62.3
Tarp Remover	6	1/24/1996	53	258	38.4
Tarp Remover	7	1/24/1996	91	246	36.6
Tarp Remover	8	1/24/1996	82	174	25.8
Tarp Remover	9	1/24/1996	92	502	74.7

[a] Data from Beard *et al.* (1996), Appendix E.
[b] Each replicate was monitored during activities on a sub-plot approximately 4 acres in size. Two replicates can be the same worker on the same plot.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] Two individuals were used for the three replicates: the same individual was monitored for replicates 1 and 3.
[e] The same two individual were used for six replicates, each working three applications.
[f] Tarps were split 6 days post-application. One individual (wearing two pumps) drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise.
[g] Mean of four tubes; tarp splitters wore two pumps, each with two tubes.
[h] Tarps were removed the day after splitting. Two individuals were used for the four replicates; these were the same individuals who had been monitored as shovelers. One of them had also been monitored for both tarp splitter replicates.

Table 14 summarizes exposures monitored from Phase II broadcast tarped applications on Plot 2 in Florida. The driver during the first application was the co-pilot during the second application, and vice versa. One of those individuals (wearing two pumps) later drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise; after splitting tarps on half of the plot, the tubes on both pumps were changed twice while the tarp splitter completed the plot. Thus, all three tarp splitter replicates involved monitoring the same individual. Although there were two other individuals involved in removing tarps, no monitoring data are reported for them.

Table 14. Chloropicrin Exposures: Broadcast Tarped Applications on Plot 3 in Florida [a]

Activity	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
				(µg/m^3)	ppb
Tractor Driver [d]	1	1/16/1996	122	1,130	168
Tractor Driver	2	1/16/1996	112	786	117
Tractor Driver	3	1/16/1996	130	407	60.5
Co-pilot [d]	1	1/16/1996	118	519	77.1
Co-pilot	2	1/16/1996	111	918	137
Co-pilot	3	1/16/1996	127	469	69.7
Shoveler [e]	1	1/16/1996	77	979	146
Shoveler	2	1/16/1996	109	481	71.5
Shoveler	3	1/16/1996	92	232	34.4
Shoveler	4	1/16/1996	100	387	57.6
Shoveler	5	1/16/1996	128	157	23.4
Shoveler	6	1/16/1996	126	250	37.2
Tarp Splitter [f]	1	1/22/1996	24	137 [g]	20.4 [g]
Tarp Splitter	2	1/22/1996	20	102 [g]	15.1 [g]
Tarp Splitter	3	1/23/1996	21	92.9 [g]	13.8 [g]

[a] Data from Beard *et al.* (1996), Appendix E.
[b] Each replicate was monitored during activities on a sub-plot approximately 4 acres in size. Two replicates can be the same worker on the same plot.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] Two individuals were used for the three replicates: the same individual was monitored for replicates 2 and 3.
[e] The same two individual were used for six replicates, each working three applications.
[f] Tarps were split 6 days post-application. One individual (wearing two pumps) drove a quadrunner with a tarp-cutting apparatus that split the tarp lengthwise.
[g] Mean of four tubes; driver wore two pumps, each with two tubes.
[h] Two individuals were used for the four replicates; these were the same individuals who had been monitored as shovelers. One of them had also been monitored for both tarp splitter replicates.

Exposure estimates for these scenarios in the chloropicrin exposure assessment combine data in the Tables 6 – 14 with data from Rotondaro (2004). The application rates used in this study were lower than the maximum chloropicrin application rates currently allowed in California. Thus, exposure estimates for handlers involved with chloropicrin soil fumigations could be greater than exposures reported in Tables 6 – 14, and concentrations used in the exposure assessment will be adjusted for application rate.

Adjusted Concentrations from Rotondaro (2004)

This study was reviewed by Beauvais (2005), who reported mean results for each scenario. In this memo, study methods and results are discussed in greater detail.

Applications

Nine distinct application methods were each monitored at three sites (Rotondaro, 2004). Each site was considered a "replicate." Three different types of broadcast shank applications were monitored (tarped shallow, non-tarped shallow, and non-tarped deep). Table 15 summarizes

these applications. Site locations and soil characterization results are summarized in Appendix 1, and equipment used in applications is summarized in Appendix 2. Shallow shank applications at sites 1 through 6 were made at a soil depth of 12 inches (30 cm), and the deep shank injections at sites 7 through 9 were at 18 – 24 inches (46 – 53 cm).

Table 15. Chloropicrin Broadcast Shank Applications Reported by Rotondaro (2004) [a]

Site	Application Method	Tarp/Seal	Date	Application Interval (hours) [b]	Plot Size (acres) [c]	Application Rate (lbs AI/acre) [d]
1	Shallow tarped	1-mil PE [e]	February 4, 2003	06:47-09:12 (2.4)	3.5	355
2	Shallow tarped	1.5-mil PE [e]	May 14, 2003	07:35-09:45 (2.2)	3.6	315
3	Shallow tarped	1-mil PE [e]	January 23, 2004	07:01-10:48 (3.8)	5.1 [f]	342
4	Shallow non-tarped	disc, ring roller	January 2, 2004	07:33-11:12 (3.6)	5.1	191
5	Shallow non-tarped	disc, pipe	January 4, 2003	08:25-11:02 (2.6)	3.7	169
6	Shallow non-tarped	disc, ring roller	May 30, 2003	07:38-11:06 (3.5)	9.7	174
7	Deep non-tarped	packing wheel	January 24, 2003	11:30-12:22 (1.9)	2.7	200
8	Deep non-tarped	packing wheel	May 13, 2003	08:01-09:20 (1.3)	4.1	175
9	Deep non-tarped	packing wheel	January 12, 2004	11:19-14:10 (2.8)	5.1	176

[a] All applications were in California. See Appendix 1 for site location and soil characterization at each site.
[b] Time range on a 24-hour clock. Number of hours in parentheses.
[c] Multiply value by 2.471 to get area in hectares (ha).
[d] Application rate reported as verified. Multiply value by 1.123 to get rate in kilograms per hectare (kg/ha).
[e] PE: polyethylene tarp.
[f] The application was made to two different fields.

Two different types of bedded shank applications were monitored, tarped shallow and non-tarped shallow. Table 16 summarizes these applications. The depth of these applications ranged 6 to 12 inches (15 to 25 cm).

Table 16. Chloropicrin Bedded Shank Applications Reported by Rotondaro (2004) [a]

Site	Application Method	Tarp/Seal	Date	Application Interval (hours) [b]	Treated Area (acres) [c]	Application Rate (lbs AI/acre) [d]
10	Shallow tarped	1.25-mil PE [e]	February 18, 2003	07:40-11:33 (2.4)	1.11	333
11	Shallow tarped	1.25-mil PE [e]	September 3, 2003	14:19-18:42 (4.4)	1.14	592
12	Shallow tarped	1.25-mil PE [e]	June 11, 2004	07:41-15:43 (8.0)	1.93	349
13	Shallow non-tarped	bed shaper	February 28, 2003	08:24-11:26 (3.0)	1.7	187
14	Shallow non-tarped	ring roller	April 22, 2004	08:07-11:49 (3.7)	8.4 [f]	222
15	Shallow non-tarped	ring roller	March 19, 2004	07:14-10:48 (3.6)	5.6 [g]	170

[a] All applications were in California. See Appendix 1 for site location and soil characterization at each site.
[b] Time range on a 24-hour clock. Number of hours in parentheses.
[c] Beds reduced treated area to 13% to 46% of the field size. Multiply value by 2.471 to get area in hectares (ha).
[d] Application rates for bedded applications are based on treated area only. Multiply value by 1.123 to get rate in kilograms per hectare (kg/ha).
[e] PE: polyethylene tarp.
[f] The application was made to two different fields.
[g] The application was made to four different fields.

Two different types of drip irrigation applications were monitored, include surface drip tarped and buried drip non-tarped applications. In addition, handwand applications were made at three sites; these applications are made before replanting tree or vine crops. Table 17 summarizes drip and handwand applications. Rotondaro (2004) also reported on air monitoring associated with drip applications in greenhouses, but no exposure monitoring was done and those applications are not discussed in this memo.

Table 17. Chloropicrin Drip and Handwand Applications Reported by Rotondaro (2004) [a]

Site	Application Method	Tarp/Seal	Date	Application Interval (hours) [b]	Treated Area (acres) [c]	Application Rate (lbs AI/acre) [d]
16	Surface tarped	1.5-mil PE [e]	August 27, 2003	07:39-11:15 (3.6)	4.5	300
17	Surface tarped	1.25-mil PE [e]	December 18, 2002	10:30-19:04 (8.6)	6.6 [f]	300
18	Surface tarped	1.25-mil PE [e]	May 27, 2003	07:35-13:53 (6.3)	9.6	301
19	Buried non-tarped	none	January 30, 2003	08:05-19:15 (11.2)	4.64	301
20	Buried non-tarped	none	December 20, 2002	06:43-16:46 (10.0)	7.9	299
21	Buried non-tarped	none	December 8, 2003	07:24-10:29 (3.1)	0.7	315
26	Handwand	soil cover	December 13, 2002	13:08-16:05 (3.0)	0.110	472
27	Handwand	soil cover	January 3, 2003	09:51-12:59 (3.1)	0.138	507
28	Handwand	soil cover	January 22, 2004	12:28-14:29 (2.0)	0.220	546

[a] All applications were in California. See Appendix 1 for site location and soil characterization at each site.
[b] Time range on a 24-hour clock. Number of hours in parentheses.
[c] Handwand application area was estimated from reported number of locations treated (48, 60, or 96 per site), assuming each location was 100 ft^2 (9 m^2). For bedded applications, beds reduced treated area to 37% to 52% of the field size. Multiply value by 2.471 to get area in hectares (ha).
[d] Application rates for bedded applications are based on treated area only. Multiply value by 1.123 to get rate in kilograms per hectare (kg/ha).
[e] PE: polyethylene tarp.
[f] The application was made to two different fields.

Exposure Monitoring

Worker exposure monitoring data consisted of air sampling tubes containing XAD-4 connected to air pumps calibrated at 50 ml per minute. One or two air samplers were attached to each worker collar. When there were two air samplers, the second one was used to estimate exposure during specific activities occurring during a portion of the workday, including disconnecting the chloropicrin cylinder or equipment repair; reentry workers also had a second pump attached to monitor the concentration during the first hour of their activity.

In addition to the breathing zone air samplers, workers injecting chloropicrin with handwands for tree replanting had an air sampler attached to the lower leg to allow estimation of dermal exposure to chloropicrin (concentrations near the leg were anticipated to be higher during this application method).

Quality Assurance

Sorbent in the front and back sections of the air sampling tubes was extracted with ethyl acetate, and the amount of chloropicrin in each sorbent section was quantified using gas chromatography with an electron capture detector. The limit of quantification (LOQ) was 0.1 µg chloropicrin per section, or 0.2 µg/tube (Maliani, 2004). In this memo, ½ LOQ (or 0.1 µg/tube) was substituted for samples in which chloropicrin was below the LOQ.

Quality assurance samples consisted of control samples, procedural fortified tubes and field fortified (FF) tubes. Control tubes were set up at each site and air was drawn through them in the same way as the sample tubes attached to workers. Quality assurance results were acceptable, and are discussed in detail by Beauvais (2005); FF recoveries at each site are summarized by Beauvais (2005), as well. Rotondaro (2004) did not correct samples for FF recovery, instead correcting samples for procedural fortification recoveries. However, Rotondaro (2004) also reported uncorrected results, and results in this memo were adjusted for FF recovery according to DPR practice and using Table 3 in Beauvais (2005).

Results

Five days following the broadcast tarped applications to sites 1 – 3, the tarps were split (Rotondaro, 2004). Tarps were removed the following day. Ten days post-application, one or two workers at each site were monitored as they shaped soil into beds. Each replicate was monitored for the first hour of reentry, and for the full activity, which took approximately 4 hours. Results are summarized in Table 18.

Table 18. Chloropicrin Exposures: Broadcast Tarped Applications in California [a]

Activity	Site	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
					(µg/m^3)	ppb
Soil Shaper	1	1	2/14/2004	60	95.2	14.1
Soil Shaper	1	2	2/14/2004	60	76.2	11.3
Soil Shaper	2	1	5/24/2003	61	33.8 [d]	5.02 [d]
Soil Shaper	2	2	5/24/2003	59	34.6 [d]	5.15 [d]
Soil Shaper	3	1	2/2/2004	61	173	25.7
Soil Shaper	1	1	2/14/2004	241	75.5	11.2
Soil Shaper	1	2	2/14/2004	241	64.3	9.56
Soil Shaper	2	1	5/24/2003	247	9.82	1.46
Soil Shaper	2	2	5/24/2003	253	8.01 [d]	1.19 [d]
Soil Shaper	3	1	2/2/2004	243	195	29.0

[a] Data from Rotondaro (2004), Appendix D.
[b] Each replicate consists of an individual who was monitored during the indicated activity for the reported monitoring interval. For this activity, replicates were monitored both for the first hour they worked, and for the full 4-hour work period.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] Both tubes for this replicate had chloropicrin below the limit of quantification of 0.2 µg/tube; ½ of this value was substituted in the concentration calculation.

At Site 1, soil shaping consisted of driving an open-cab tractor towing a toolbar with a shovel at each end to shape the sides of the bed, and a flat piece of metal to smooth the top of the beds. At Site 2, Replicate 1 drove an open-cab tractor towing a toolbar, and Replicate 2 drove an open-cab tractor towing a culti-mulch bed shaper; the culti-mulch had a rotary tiller that pulverized the soil before smoothing it into a bed. At Site 3, the single replicate drove an open-cab tractor towing a chisel and ring-roller that shaped the bed.

Table 19 summarizes exposure monitoring associated with broadcast non-tarped applications reported by Rotondaro (2004). Drivers wore extra air sampling pumps, which were turned on while they disconnected chloropicrin cylinders. Soil shapers were monitored for the first hour of reentry, and for the full activity, which took approximately 4 hours.

Table 19. Chloropicrin Exposures: Broadcast Non-Tarped Applications in California [a]

Activity	Site	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
					(µg/m^3)	ppb
Driver	4	1	1/2/2004	275	89.1	13.3
Driver	5	1	1/14/2003	298	111	16.5
Driver	6	1	5/30/2003	272	194	28.9
Driver	6	2	5/30/2003	272	55.4	8.24
Driver - Disconnect	4	1	1/2/2004	7	362	53.8
Driver - Disconnect	5	1	1/14/2003	33	327	48.7
Driver - Disconnect	6	1	5/30/2003	14	1,080	161
Driver - Disconnect	6	2	5/30/2003	12	417	62.0
Soil Sealer	4	1	1/2/2004	260	112	16.7
Soil Sealer	5	1	1/14/2003	243	13.2	1.96
Soil Sealer	6	1	5/30/2003	245	42.7	6.35
Soil Sealer	6	2	5/30/2003	245	74.6	11.1
Soil Shaper	4	1	1/12/2004	61	33.1 [d]	4.92 [d]
Soil Shaper	5	1	1/24/2003	60	32.7 [d]	4.86 [d]
Soil Shaper	5	2	1/24/2003	63	30.8 [d]	4.59 [d]
Soil Shaper	6	1	6/9/2003	60	33.3 [d]	4.96 [d]
Soil Shaper	6	2	6/9/2003	62	45.6	6.78
Soil Shaper	4	1	1/12/2004	243	27.4	4.08
Soil Shaper	5	1	1/24/2003	245	8.01 [d]	1.19 [d]
Soil Shaper	5	2	1/24/2003	242	13.8	2.05
Soil Shaper	6	1	6/9/2003	250	12.3	1.82
Soil Shaper	6	2	6/9/2003	263	21.1	3.14

[a] Data from Rotondaro (2004), Appendix D.
[b] Each replicate consists of an individual who was monitored during the indicated activity for the reported monitoring interval. Drivers and soil shapers wore two sets of air samplers; drivers were monitored while disconnecting cylinders, and soil shapers were monitored both for the first hour they worked and for the full 4-hour work period.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] Both tubes for this replicate had chloropicrin below the limit of quantification of 0.2 µg/tube; ½ of this value was substituted in the concentration calculation.

Soil sealers drove open-cab tractors towing various implements a few rows behind the applicator tractor. The soil sealer at Site 4 towed a chisel and ring-roller. At Site 5, the soil sealer towed a disc and a pipe. At Site 6, the first soil sealer replicate towed an offset disc, and the second replicate towed a ring roller.

Ten days post-application, one or two workers at each site were monitored as they shaped soil into beds. At Site 4, the single replicate drove an open-cab tractor towing a chisel that shaped the bed. At Site 5, soil shaping consisted for both replicates of driving open-cab tractors towing toolbars with shovels at each end to shape the sides of the beds. At Site 6, Replicate 1 drove an open-cab tractor towing a toolbar, and Replicate 2 drove an open-cab tractor towing a culti-mulch bed shaper; the culti-mulch had a rotary tiller that pulverized the soil before smoothing it into a bed.

Rotondaro (2004) identified non-tarped broadcast deep applications as common for planting of perennial tree and vine crops. Ten days post-application, one or two workers at each site were monitored as they shaped soil into beds. At Site 7, both replicates drove open-cab tractors towing single row toolbars. At Site 8, Replicate 1 drove an open-cab tractor towing a two-row toolbar, and Replicate 2 drove an open-cab tractor towing a culti-mulch bed shaper. At Site 9, the single replicate drove an open-cab tractor towing a chisel and a ring roller. Each replicate was monitored for the first hour of reentry, and for the full activity, which took approximately 4 hours. Results are summarized in Table 20.

Table 20. Chloropicrin Exposures: Non-Tarped Broadcast Deep Applications [a]

Activity	Site	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
					(µg/m^3)	ppb
Soil Shaper	7	1	2/3/2003	60	32.7 [d]	4.86 [d]
Soil Shaper	7	2	2/3/2003	60	33.3 [d]	4.96 [d]
Soil Shaper	8	1	5/23/2003	61	33.8 [d]	5.02 [d]
Soil Shaper	8	2	5/23/2003	59	33.6 [d]	4.99 [d]
Soil Shaper	9	1	1/22/2004	59	34.3 [d]	5.09 [d]
Soil Shaper	7	1	2/3/2003	242	7.87 [d]	1.17 [d]
Soil Shaper	7	2	2/3/2003	242	8.99 [d]	1.34 [d]
Soil Shaper	8	1	5/23/2003	242	8.92	1.33
Soil Shaper	8	2	5/23/2003	254	14.0	2.09
Soil Shaper	9	1	1/22/2004	240	13.1	1.95

[a] Data from Rotondaro (2004), Appendix D. Applications in California.
[b] Each replicate consists of an individual who was monitored during the indicated activity for the reported monitoring interval. For this activity, replicates were monitored both for the first hour they worked, and for the full 4-hour work period.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] Both tubes for this replicate had chloropicrin below the limit of quantification of 0.2 µg/tube; ½ of this value was substituted in the concentration calculation.

Table 21 summarizes exposure monitoring associated with bedded tarped shallow applications reported by Rotondaro (2004). Drivers wore extra air sampling pumps, which were turned on

while they disconnected chloropicrin cylinders. Tarp punchers were monitored for the first hour of reentry, and for the full activity, which took approximately 4 hours.

Table 21. Chloropicrin Exposures: Bedded Tarped Shallow Applications in California [a]

Activity	Site	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
					(µg/m^3)	ppb
Driver	10	1	2/18/2003	308	168	25.0
Driver	11	1	9/3/2004	339	66.0	9.81
Driver	12	1	6/11/2004	258	60.5	8.99
Driver	12	2	6/11/2004	257	113	16.8
Driver - Disconnect	10	1	2/18/2003	14	969	144
Driver - Disconnect	11	1	9/3/2004	41	228	33.8
Driver - Disconnect	12	1	6/11/2004	8	1,340	199
Driver - Disconnect	12	2	6/11/2004	14	384	57.2
Copilot	10	1	2/18/2003	308	213	31.7
Copilot	11	1	9/3/2004	333	180	26.7
Copilot	12	1	6/11/2004	255	27.7	4.11
Shoveler	10	1	2/18/2003	308	97.8	14.5
Shoveler	11	1	9/3/2004	333	130	19.4
Shoveler	12	1	6/11/2004	255	23.2	3.45
Tarp Puncher	10	1	2/25/2003	60	33.3 [d]	4.96 [d]
Tarp Puncher	11	1	9/10/2004	61	32.8 [d]	4.88 [d]
Tarp Puncher	12	1	6/18/2004	62	32.9 [d]	4.89 [d]
Tarp Puncher	12	2	6/18/2004	62	32.3 [d]	4.80 [d]
Tarp Puncher	10	1	2/25/2003	252	8.13 [d]	1.21 [d]
Tarp Puncher	11	1	9/10/2004	241	8.07 [d]	1.20 [d]
Tarp Puncher	12	1	6/18/2004	263	7.61 [d]	1.13 [d]
Tarp Puncher	12	2	6/18/2004	263	12.7	1.89

[a] Data from Rotondaro (2004), Appendix D.
[b] Each replicate consists of an individual who was monitored during the indicated activity for the reported monitoring interval. Drivers and tarp punchers wore two sets of air samplers; drivers were monitored while disconnecting cylinders, and tarp punchers were monitored both for the first hour they worked and for the full 4-hour work period.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] Both tubes for this replicate had chloropicrin below the limit of quantification of 0.2 µg/tube; ½ of this value was substituted in the concentration calculation.

Drivers making the bedded tarped shallow applications were in open-cab application rigs with attached bed shapers (Rotondaro, 2004). Co-pilots rode on the rigs and made sure drip irrigation tape and tarp material was correctly placed onto the beds. Shovelers stood at the ends of rows to cut the tarp material and cover the end of the tarp. The Site 11 application was made at a rate (592 lbs AI/acre) that was substantially above the target rate of 350 lbs AI/acre. Attempts were made during the application to adjust the rate, but the attempts were not successful.

Seven days post-application, tarps were punched either by driving a tractor that towed a spiked wheel (sites 10 and 11) or by hand, which consisted of marking locations to be punched with a

stick (Site 12, Replicate 1) followed by a hand-held propane burner which created the holes (Site 12, Replicate 2).

Table 22 summarizes exposure monitoring associated with bedded non-tarped shallow applications reported by Rotondaro (2004). Drivers wore extra air sampling pumps, which were turned on while they disconnected chloropicrin cylinders. Pipe layers were monitored for the first hour of reentry, and for the full activity, which took approximately 4 hours.

Table 22. Chloropicrin Exposures: Bedded Non-Tarped Shallow Applications [a]

Activity	Site	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
					(µg/m^3)	ppb
Driver	13	1	2/28/2003	301	159	23.7
Driver	14	1	4/22/2004	295	357	53.1
Driver	15	1	3/19/2004	277	191	28.3
Driver - Disconnect	13	1	2/28/2003	9	3,320	493
Driver - Disconnect	14	1	4/22/2004	27	1,260	187
Driver - Disconnect	15	1	3/19/2004	14	790	117
Driver – Outside Cab	14	1	4/22/2004	295	933	139
Driver – Outside Cab	15	1	3/19/2004	277	193	28.6
Pipe Layer	13	1	3/6/2003	60	34.9 [d]	5.18 [d]
Pipe Layer	13	2	3/6/2003	60	34.0 [d]	5.06 [d]
Pipe Layer	14	1	4/28/2004	59	34.3 [d]	5.09 [d]
Pipe Layer	14	2	4/28/2004	59	33.9 [d]	5.04 [d]
Pipe Layer	15	1	3/26/2004	63	31.7 [d]	4.72 [d]
Pipe Layer	15	2	3/26/2004	63	30.8 [d]	4.58 [d]
Pipe Layer	13	1	3/6/2003	244	8.27 [d]	1.23 [d]
Pipe Layer	13	2	3/6/2003	244	8.61	1.28
Pipe Layer	14	1	4/28/2004	202	9.71 [d]	1.44 [d]
Pipe Layer	14	2	4/28/2004	202	9.71 [d]	1.44 [d]
Pipe Layer	15	1	3/26/2004	256	7.81 [d]	1.16 [d]
Pipe Layer	15	2	3/26/2004	256	7.88 [d]	1.17 [d]

[a] Data from Rotondaro (2004), Appendix D. Applications in California.
[b] Each replicate consists of an individual who was monitored during the indicated activity for the reported monitoring interval. Drivers and pipe layers wore two sets of air samplers; drivers were monitored while disconnecting cylinders, and pipe layers were monitored both for the first hour they worked and for the full 4-hour work period.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] Both tubes for this replicate had chloropicrin below the limit of quantification of 0.2 µg/tube; ½ of this value was substituted in the concentration calculation.

Drivers making the bedded non-tarped shallow applications were in open-cab (Site 13) or closed-cab with dust filter (sites 14 and 15) application rigs having attached bed shapers. An additional sampler was mounted outside of the cab on the two closed-cab rigs; at Site 12, the outside sampler collected nearly three times the chloropicrin as the driver's sampler, but at Site 13, the two samplers yielded nearly identical concentrations. The highest concentrations, however, were from the driver "disconnect" samplers (Table 22). At Site 14, the pump for this sampler was also

turned on during a 16-minute interval while the driver stopped to repair a broken air line on the application rig; thus, the disconnect sample also includes the repair. Similarly, at Site 15, the disconnect sampler pump was turned on twice while the driver stopped to repair drips (small leaks) in one of the nozzles; the repairs totaled 7 minutes.

Reentry activities, which consisting of setting up irrigation lines (pipe laying), were monitored 6 (Site 14) or 7 (sites 13 and 15) days post-application. First, workers placed lengths of pipe on the ground, then they backtracked, connecting the pipes as they went.

Table 23 summarizes exposure monitoring associated with drip irrigation tarped surface applications reported by Rotondaro (2004). Applicators connected chloropicrin injection units into irrigation systems, attached chloropicrin cylinders, tested the system for leaks, and then began the application. Applicators stayed at the field throughout the application interval, checking on the system and making sure the application proceeded as scheduled.

Table 23. Chloropicrin Exposures: Drip Irrigation Tarped Surface Applications [a]

Activity	Site	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
					(µg/m^3)	ppb
Applicator	16	1	8/27/2003	295	26.2	3.89
Applicator	16	2	8/27/2003	295	28.9	4.29
Applicator	17	1	12/18/2002	779	85.0	12.6
Applicator	17	2	12/18/2002	777	106	15.8
Applicator	18	1	5/27/2003	487	73.3	10.9
Applicator	18	2	5/27/2003	487	76.0	11.3
Applicator - Disconnect	16	1	8/27/2003	25	80.0 [d]	11.9 [d]
Applicator - Disconnect	18	2	5/27/2003	13	157 [d]	23.4 [d]
Tarp Puncher	16	1	9/6/2003	61	33.4 [d]	4.97 [d]
Tarp Puncher	16	2	9/6/2003	59	32.9 [d]	4.89 [d]
Tarp Puncher	17	1	12/23/2002	61	56.6	8.42
Tarp Puncher	18	1	6/3/2003	62	32.6 [d]	4.84 [d]
Tarp Puncher	18	2	6/3/2003	63	32.4 [d]	4.81 [d]
Tarp Puncher	16	1	9/6/2003	268	7.55 [d]	1.12 [d]
Tarp Puncher	16	2	9/6/2003	252	8.37	1.25
Tarp Puncher	17	1	12/23/2002	254	65.6	9.75
Tarp Puncher	18	1	6/3/2003	240	8.59 [d]	1.28 [d]
Tarp Puncher	18	2	6/3/2003	246	8.37 [d]	1.24 [d]

[a] Data from Rotondaro (2004), Appendix D. Applications in California.
[b] Each replicate consists of an individual who was monitored during the indicated activity for the reported monitoring interval. Two applicators and all tarp punchers wore two sets of air samplers; applicators were monitored while disconnecting cylinders, and tarp punchers were monitored both for the first hour they worked and for the full 4-hour work period.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] Both tubes for this replicate had chloropicrin below the limit of quantification of 0.2 µg/tube; ½ of this value was substituted in the concentration calculation.

Two of the three applicators wore extra air sampling pumps, which were turned on while they disconnected chloropicrin cylinders. Tarp punchers were monitored for the first hour of reentry, and for the full activity, which took approximately 4 hours.

Drip irrigation applications at sites 16-18 were made using custom injectors that are used in commercial applications; the units were reported to be similar to one another. In each case, the irrigation water is passed through the injector, which meters chloropicrin and mixes it with the water before distributing it through the irrigation lines. At Site 16, all chloropicrin was inadvertently applied during the first hour, rather than during the intended 4.5 hours; water was run for an additional 2.75 hours to properly disperse chloropicrin in the soil.

Following the drip applications, reentry occurred 5 days (Site 17) or 10 days (sites 16 and 18) post-application; chloropicrin was below the LOQ in all samples at sites 16 and 18 (except one 4-hour sample at Site 16), but not at Site 17. Each tarp puncher drove a tractor towing a spiked wheel.

Table 24 summarizes exposure monitoring associated with drip irrigation non-tarped buried applications reported by Rotondaro (2004). Applicators connected chloropicrin injection units into irrigation systems, attached chloropicrin cylinders, tested the system for leaks, and then began the application. Applicators stayed at the field throughout the application interval.

Table 24. Chloropicrin Exposures: Drip Irrigation Non-Tarped Buried Applications [a]

Activity	Site	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
					(µg/m^3)	ppb
Applicator	19	1	1/30/2003	810 [d]	31.3	4.65
Applicator	19	2	1/30/2003	810 [d]	15.5	2.31
Applicator	20	1	12/20/2002	678	198	29.4
Applicator	20	2	12/20/2002	676	239	35.6
Applicator	21	1	12/8/2003	273	31.9	4.74
Applicator	21	2	12/8/2003	273	13.3	1.98
Applicator - Disconnect	19	1	1/30/2003	17	967	144
Applicator - Disconnect	21	1	12/8/2003	7	275 [e]	40.9 [e]

[a] Data from Rotondaro (2004), Appendix D. Applications in California.
[b] Each replicate consists of an individual who was monitored during the indicated activity for the reported monitoring interval. Two replicates wore two sets of air samplers, and were monitored while they disconnected chloropicrin cylinders.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] The application was interrupted for 154 minutes to repair a leak in the irrigation line.
[e] Both tubes for this replicate had chloropicrin below the limit of quantification of 0.2 µg/tube; ½ of this value was substituted in the concentration calculation.

Two of the three applicators wore extra air sampling pumps, which were turned on while they disconnected chloropicrin cylinders. Drip irrigation applications were made using custom injectors that are used in commercial applications; the units were reported to be similar to one another. In each case, the irrigation water is passed through the injector, which meters

chloropicrin and mixes it with the water before distributing it through the irrigation lines. At Site 19, the application was interrupted for 154 minutes to repair a leak in the irrigation system.

Table 25 summarizes exposure monitoring associated with handwand replant applications reported by Rotondaro (2004). One of the applicators at Site 28 (Replicate 1) was monitored while disconnecting a single chloropicrin cylinder; chloropicrin was below the LOQ in the duplicate sampling tubes (constituting repeated measures rather than individual replicates because they were on the same worker).

Chloropicrin was injected into the soil, with the rate calculated assuming that each injection treats a 10 ft x 10 ft area (9 m^2). Injection consisted of inserting the wand tip about 18 inches (46 cm) into the soil, injecting the desired amount of chloropicrin, removing the probe from the soil and placing it on the trailer, then covering the treated hole with soil. At sites 26 and 27, the replicates trade places frequently, with one applicator performing these tasks while the second applicator stayed on the trailer with the chloropicrin cylinders, operating the equipment that metered chloropicrin into the handwand. At Site 28, before the application could begin the unit had to be modified to work with a single cylinder. During the application at Site 28, Replicate 1 did all the injections, and Replicate 2 stayed on the tractor.

Table 25. Chloropicrin Exposures: Replant Handwand Applications [a]

Activity	Site	Replicate [b]	Date	Monitoring Interval (minutes)	Chloropicrin Concentration [c]	
					(µg/m^3)	ppb
Applicator	26	1	12/13/2002	194	104	15.4
Applicator	26	2	12/13/2002	194	73.6	11.0
Applicator	27	1	1/7/2003	257	628	93.3
Applicator	27	2	1/7/2003	257	201	29.9
Applicator	28	1	1/22/2004	309	14.1	2.10
Applicator	28	2	1/22/2004	309	13.7	2.04
Applicator - Disconnect	28	1	1/22/2004	12	167 [d]	24.8 [d]
Applicator - Leg [e]	26	1	12/13/2002	194	91.8	13.6
Applicator - Leg	26	2	12/13/2002	194	364	54.1
Applicator - Leg	27	1	1/7/2003	257	685	102
Applicator - Leg	27	2	1/7/2003	257	134	19.9
Applicator - Leg	28	1	1/22/2004	309	18.8	2.80
Applicator - Leg	28	2	1/22/2004	309	17.2	2.56

[a] Data from Rotondaro (2004), Appendix D. Applications in California.
[b] Each replicate consists of an individual who was monitored during the indicated activity for the reported monitoring interval. Applicators wore two sets of air samplers, one to sample the breathing zone and one to sample the lower leg. One applicator also wore an extra sampler and was monitored while disconnecting the chloropicrin cylinder.
[c] The concentration is the mean of two sampling tubes attached to a single worker, unless otherwise indicated. Concentrations were corrected for field fortification recovery and rounded to 3 significant figures.
[d] Both tubes for this replicate had chloropicrin below the limit of quantification of 0.2 µg/tube; ½ of this value was substituted in the concentration calculation.
[e] In addition to the breathing zone air sampler, a second sampler was attached to the leg of each applicator.

Factors Potentially Affecting Exposure Within Scenarios

Occupational exposure scenarios associated with chloropicrin soil fumigations are broadly defined, and within each are several factors that could potentially confound exposure estimates. Dawson and Smith (2008) provided an overview of factors investigated as potential mitigation measures to minimize volatilization of soil fumigants, using field flux and tarp permeability data. Factors reviewed included tarps, soil texture, and higher levels of soil moisture and organic matter. Some of these factors could potentially act to decrease handler exposures, and those that both decrease emission and can be controlled by applicators could be effective mitigation measures. Dawson and Smith noted that field characteristics such as soil texture and organic matter content are not easily altered; they are considered in this section as potential confounders for equipment types and soil moisture, which can be controlled.

Scenarios Associated with Non-Tarped Shank Applications

Table A2-1 in Appendix 2 summarizes descriptions of equipment used in non-tarped shank applications. Shallow broadcast applications were monitored by Beard *et al.* (1996) at one site in Arizona (Plot 1) and by Rotondaro (2004) at three sites in California (Sites 4 – 6). After adjusting to the maximum application rate, chloropicrin concentrations did not differ substantially between studies. The mean of the two Arizona soil sealer replicates monitored by Beard *et al.* (1996) was 124 $\mu g/m^3$, and the mean of the four California replicates monitored by Rotondaro (2004) was 167 $\mu g/m^3$. Drivers monitored by Beard *et al.* (1996) had a mean exposure of 404 $\mu g/m^3$, and the four California replicates monitored by Rotondaro (2004) had a mean of 319 $\mu g/m^3$. Different equipment was used in the Arizona and California applications (four chisel and two wing-shaped shanks in Arizona versus Noble plow in California). Soil texture also differed (loam in Arizona versus sandy loam in California). Soil moisture (expressed as percent field capacity; see Table A1-14 and A1-15) and organic matter content were higher at the California sites than at the Arizona site. Yet the differences noted in application conditions were not reflected in monitoring results.

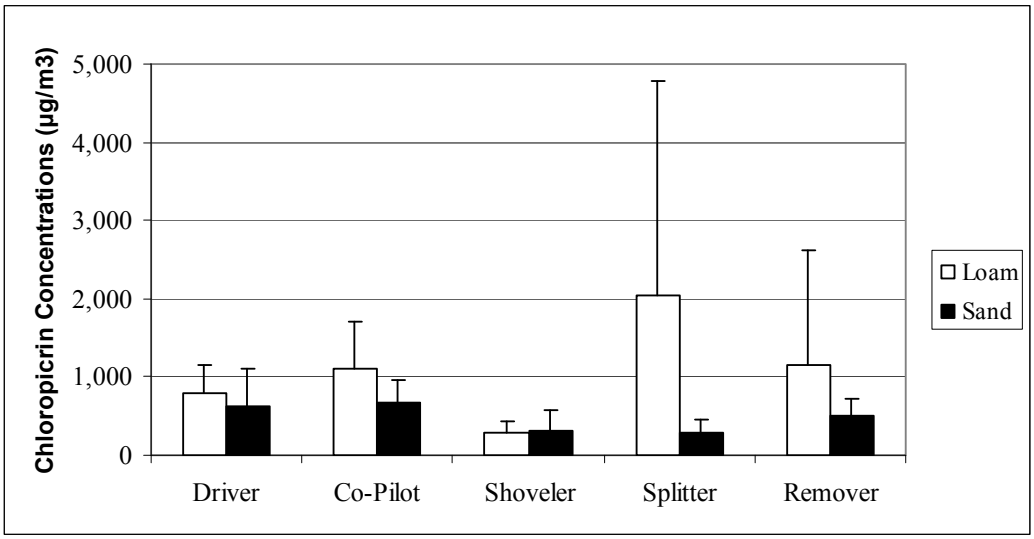
Exposure monitoring was conducted during non-tarped bedded shank applications at one site in Arizona (Plot 2) and three sites in California (Sites 13 – 15). After adjusting to the maximum application rate, concentrations measured by Rotondaro (2004) were higher than those measured by Beard *et al.* (1996): the mean of the two Arizona driver replicates was 104 $\mu g/m^3$, and the three California driver replicates monitored by Rotondaro (2004) had a mean of 299 $\mu g/m^3$. There were no consistent differences between the Arizona and California sites in type of equipment used or soil characteristics, and it is possible that different results between the studies may reflect typical variability.

Various soil sealing equipment was used in non-tarped applications. All chloropicrin product labels require soil sealing immediately following application, including ring rollers, drag sleds, etc., for non-tarped applications (some labels require use of tarps). Thus, the use of cultipackers and other equipment in non-tarped applications was appropriate. No information is available on relative effectiveness of various equipment, and equipment types were not replicated in either broadcast or bedded applications, precluding conclusions about potential effects on exposures.

Scenarios Associated with Tarped Shank Applications

Table A2-2 summarizes descriptions of tarped shank applications given in the study reports. Exposure monitoring during broadcast tarped applications was conducted solely by Beard *et al.* (1996) in Arizona, Washington, and Florida. Figure 1 compares exposures (adjusted to maximum application rates) at sites with loam (Arizona and Washington) and sand (Florida). Soil textures were classified using an online calculator provided by the U.S. Department of Agriculture (USDA, 2009); Dawson and Smith (2008) described texture classifications in detail. In addition to differing soil textures, applications in Arizona and Washington were made with four chisel and two wing-shaped shanks, while applications in Florida used a rig that had two straight shanks and six Noble plows. Although Noble plows were associated with lower driver exposure than chisel and wing shank combinations in tarped broadcast applications, no differences occurred in non-tarped applications. Noble plow equipment was used only in broadcast applications; no data beyond the tarped and non-tarped broadcast are available for comparison. Both comparisons are confounded with site and other differences, precluding a conclusion about effects of shank type on handler exposure.

Figure 1. Chloropicrin Exposures During Broadcast Tarped Applications at Sites with Loam and Sand Soils [a]



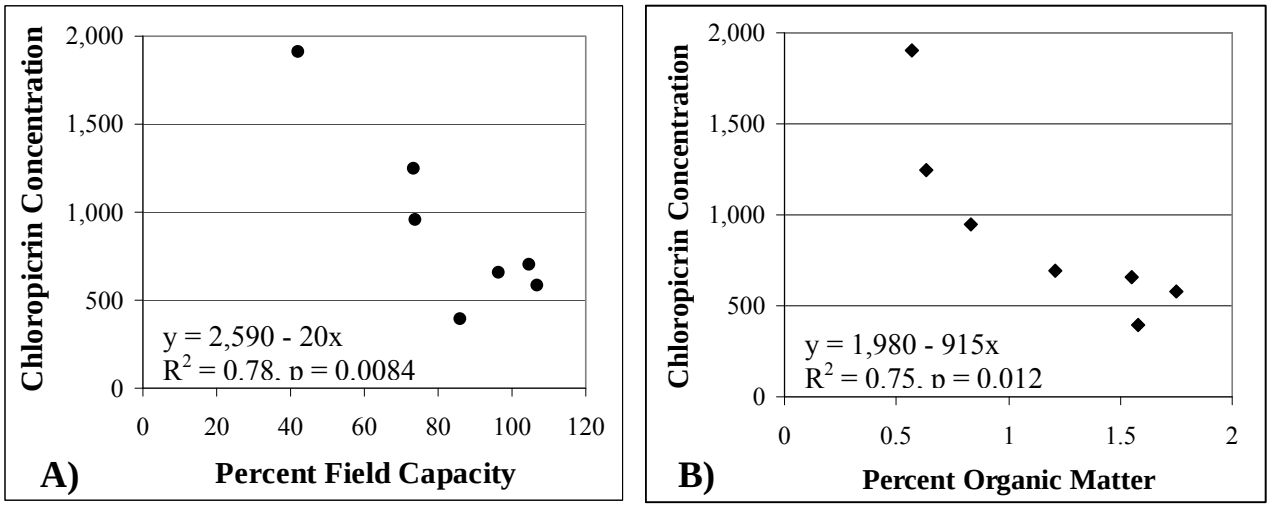
[a] Data from Beard *et al.* (1996). Each bar represents between five and sixteen individuals. Error bars on means are standard deviations.

In an analysis of variance (ANOVA; SAS, 2003) comparing the handler exposures summarized in Figure 1, there were no significant differences in exposures for any scenario: drivers, co-pilots, shovelers, tarp splitters, and tarp removers ($p = 0.62$, 0.33, 0.82, 0.33, and 0.58, respectively). Although the mean exposure of tarp splitters was 7.2-fold higher in applications to loam soils than to sand (2,040 µg/m^3 versus 284 µg/m^3), the range of exposures in the former group (107 – 6,050 µg/m^3) overlapped exposures in the latter group (117 – 822 µg/m^3).

Soil moisture (as percent field capacity, or %FC) and organic matter content (%OM) varied among the sites monitored during broadcast tarped applications. Analysis with SAS General

Linear Models procedure (SAS, 2003) suggested that co-pilot exposures varied inversely with %FC (p = 0.0084), and that exposures of co-pilots and shovelers also varied inversely with %OM (p = 0.012 and 0.027, respectively). Figure 2 shows co-pilot exposure plotted against both %FC and %OM, along with linear regression equations; examination of Figure 2B suggests that the regression on %OM might be better fit with a non-linear equation. Driver, tarp splitter and tarp remover exposures did not vary significantly with either %FC (p = 0.36, 0.86, and 0.18, respectively) or %OM (p = 0.066, 0.42, and 0.078, respectively). Appendix 3 contains figures relating broadcast handler exposures (other than co-pilot) to soil moisture and organic matter.

Figure 2. Chloropicrin Co-Pilot Exposures During Broadcast Tarped Applications Versus (A) Soil Moisture as Percent Field Capacity and (B) Percent Organic Matter in Soil [a]



[a] Data from Beard *et al.* (1996). Each point represents two or three individuals during one application. Concentration in μg/m^3. Linear regression from Proc GLM (SAS, 2003).

Tarped bedded shank exposure monitoring was conducted by Beard *et al.* (1996) at one site in Arizona (Plot 3) and by Rotondaro (2004) at three sites in California (Sites 10 – 12). Although measured concentrations were higher at the California sites than at the Arizona site when adjusted for maximum application rate, because only one site was monitored by Beard *et al.* (1996) statistical comparisons between the two studies could not be made. The mean exposure of the four Arizona driver replicates was 35.0 μg/m^3, lower than the mean of the four California replicates, 139 μg/m^3. The two co-pilots monitored during Arizona applications had a mean exposure of 19.2 μg/m^3, and the mean of the three California replicates was 186 μg/m^3. The four shovelers monitored during Arizona applications had a mean exposure of 37.5 μg/m^3, and the three shovelers monitored during California applications had a mean exposure of 96.4 μg/m^3. There were no consistent differences between the Arizona and California sites in type of equipment used or soil characteristics. Handler exposures did not vary significantly with either %FC or %OM.

Table A2-3 summarizes descriptions of tarps by Beard *et al*. (1996) and Rotondaro (2004). With the exception of the "plastic mulch" tarped bedded shank application reported by Beard *et al*. (1996), all of the tarps in monitored applications were polyethylene of thickness ranging from 1.0 to 1.5 mil. No statistical comparisons can be made among exposures associated with tarps of different thickness, however. With the exception of Site 2 in California, which was covered by a

1.5-mil tarp, all broadcast tarped applications were covered with 1.0-mil tarps; without replication of an application covered by a 1.5-mil tarp, no statistical comparison is possible.

Scenarios Associated with Drip Applications

Applicator exposures were monitored by Rotondaro (2004) during surface tarped and buried non-tarped drip applications; tarp punchers associated with surface tarped applications were also monitored. No statistical comparisons of exposure variability with soil textures were possible, as each of the three sites for both types of applications had a different soil texture; i.e., soil texture was not replicated. Applicator exposures did not vary by %FC or %OM.

Surface tarped drip applications were monitored at Sites 16 – 18. A green polyethylene 1.5-mil tarp was used at Site 16, and black polyethylene 1.25-mil tarps were used at Sites 17 and 18. As the 1.5-mil tarp was not replicated, no statistical tarp comparison was done.

Scenario-Specific Exposure Estimates

This memo has summarized results of two exposure monitoring studies (Beard *et al*., 1996; Rotondaro, 2004). Data from these studies are combined to provide chloropicrin concentration estimates to which handlers and reentry workers are exposed. Appendix 4 summarizes numbers of replicates taken from each table in this memo, for each scenario.

In many cases, the applications monitored in these studies did not use chloropicrin at the maximum rate allowed for the various methods. Estimates reported in this section have been adjusted to the maximum application rate for each method, as given on product labels currently registered in California. For each exposure scenario, reported chloropicrin concentrations were adjusted both for site-specific FF recoveries and application rates. The adjustments for shank applications are summarized in Table 26. Both studies reported monitoring data for four of the five methods listed in Table 26; the exception is broadcast non-tarped deep, which was investigated only by Rotondaro (2004).

Table 26. Application Rate Adjustment Factors for Shank Applications

Application Method	Site [a]	Actual Application Rate [b]	Maximum Application Rate [c]	Rate Adjustment Factor [d]
Broadcast Tarped Shallow	A-4	332	500	1.51
	W-1	343	500	1.46
	W-2	360	500	1.39
	W-3	351	500	1.42
	F-1	346	500	1.45
	F-2	345	500	1.45
	F-3	334	500	1.50
	1	355	500	1.41
	2	315	500	1.59
	3	342	500	1.46
Broadcast Non-Tarped Shallow	A-1	171	500	2.92
	4	191	500	2.62
	5	169	500	2.96
	6	174	500	2.87
Broadcast Non-Tarped Deep	7	200	500	2.50
	8	175	500	2.86
	9	176	500	2.84
Bedded Tarped Shallow	A-3	377	500	1.33
	10	333	500	1.50
	11	592	500	0.845
	12	349	500	1.43
Bedded Non-Tarped Shallow	A-2	149	500	3.36
	13	187	500	2.67
	14	222	500	2.25
	15	170	500	2.94

[a] Identifiers containing both letters and numbers represent sites from Beard *et al.* (1996). Sites identified with numbers only are from Rotondaro (2004).
[b] Rate reported as verified by Beard *et al.* (1996) or Rotondaro (2004).
[c] Maximum allowed in California.
[d] Ratio of maximum to actual rate. Results from this site were adjusted by multiplying them by this value.

Application rate adjustment factors for drip and handwand applications are summarized in Table 27. All exposure monitoring data associated with these methods comes from Rotondaro (2004).

Table 27. Application Rate Adjustment Factors for Drip and Handwand Applications

Application Method	Site	Actual Application Rate [a]	Maximum Application Rate [b]	Rate Adjustment Factor [c]
Surface Drip Tarped	16	300	300	1.00
	17	300	300	1.00
	18	301	300	1.00
Buried Non-Tarped	19	301	300	1.00
	20	299	300	1.00
	21	315	300	0.952
Handwand	26	472	500	1.06
	27	507	500	0.986
	28	546	500	0.916

[a] Rate reported as verified by Rotondaro (2004).
[b] Maximum allowed in California.
[c] Ratio of maximum to actual rate. Results from this site were adjusted by multiplying them by this value.

Exposure estimates are needed for short-term (defined in this memo as acute and up to one week), seasonal (intermediate-term intervals, lasting from one week to one year), and annual exposures.

For short-term exposures, DPR estimates the highest exposure an individual may realistically experience during or following legal chloropicrin uses. In order to estimate this "upper bound" of short-term exposure, DPR generally uses the estimated population 95th percentile of daily exposure, assuming daily exposures have a lognormal distribution:

$$95^{\text{th}} \text{ percentile} = \exp\left\{\hat{\mu} + 1.645 \cdot \hat{\sigma}_P\right\}$$

where $\hat{\mu}$ and $\hat{\sigma}_P$ stand for the arithmetic mean and arithmetic standard deviation of the natural (base *e*) logarithms of measured daily exposure, and 1.645 is the value corresponding to the 95th percentile of the standard normal distribution (often called a *Z* value). The arithmetic standard deviation used in this formula is the "population" standard deviation, calculated by dividing the sum of squared deviations by N. The population standard deviation is calculated as:

$$\hat{\sigma}_P = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}{n}}$$

where Y_i is the natural logarithm of an exposure value. This is obtained in Excel by applying the STDEVP function to the natural logarithms of exposure.

The 95th percentile concentration estimates were calculated in Excel. First the natural logarithm (ln) was calculated for each concentration value using the LN function; the arithmetic mean and population standard deviation were then calculated for the natural logarithms. The NORMSINV function, with a probability of 0.95, was used to get the inverse of the standard normal cumulative distribution, which was multiplied by the population standard deviation of lns. This result was added to the arithmetic mean of lns, and the sum taken as the power of e with the EXP function. The entire Excel formula is:

= EXP(AVERAGE(lns) + NORMSINV(0.95)*STDEVP(lns)).

A sample calculation is shown in Table 28.

Table 28. Sample Calculation of Arithmetic Mean and 95th Percentile Concentrations [a]

Table in Memo [b]	Rate Adjustment Factor [c]	Minutes	Concentration (µg/m^3)	Adjusted (µg/m^3) [d]	ln (µg/m^3) [e]	Concentration (ppb)	Adjusted (ppb) [d]	ln (ppb) [e]
Table 6	2.92	215	41.6	122	4.801	6.19	18.1	2.896
Table 6	2.92	137	42.9	125	4.832	6.38	18.7	2.923
Table 19	2.62	260	112	293	5.681	16.7	43.7	3.775
Table 19	2.96	243	13.2	39.0	3.665	1.96	5.80	1.759
Table 19	2.87	245	42.7	123	4.810	6.35	18.2	2.904
Table 19	2.87	245	74.6	214	5.368	11.1	31.9	3.462
Mean		224		153	4.86		22.7	2.95
Standard Deviation		41		80.7	0.628		12.0	0.628
95th Percentile:				**362**			**53.9**	

Assuming lognormal distribution, 95th percentile is calculated in Excel as follows [f]:

EXP(AVERAGE(lns)+NORMSINV(0.95)*STDEVP(lns))

Stepwise calculations (shown to clarify the above equation):

(1)	NORMSINV(0.95) = 1.645	NORMSINV(0.95) = 1.645
(2)	(4.859 + (1.645)(0.6280)) = 5.892	(2.954 + (1.645)(0.6280)) = 3.987
(3)	$e^{5.892}$ = 362	$e^{3.987}$ = 53.9

[a] Calculations shown for soil sealer involved in shallow broadcast non-tarped chloropicrin applications. Data from Beard *et al.* (1996) and Rotondaro (2004).
[b] Data for individual replicates are summarized in the indicated tables.
[c] Ratio of the maximum allowed application rate to rate used in the monitored application.
[d] Concentrations were adjusted by multiplying them by the rate adjustment factor.
[e] This column lists the natural logarithm of the adjusted concentrations, which are used to calculated the 95th percentile concentration.
[f] In this equation, the abbreviation "lns" means the natural logarithms of adjusted concentrations. Four Excel functions are used. EXP gives the constant e raised to the power of the specified number (e equals 2.71828182845904; it is the base of the natural logarithm). AVERAGE gives the arithmetic mean. STDEVP gives the population arithmetic standard deviation. NORMSINV gives the inverse of the cumulative standard normal distribution (which has a mean of zero and a standard deviation of one). Given a value for probability, here 0.95, NORMSINV finds that value z such that NORMSDIST(z) = probability (Microsoft, 2003).

To estimate seasonal and annual exposures, the average daily exposure is of interest because over these periods of time, a worker is expected to encounter a range of daily exposures (i.e., DPR assumes that with increased exposure duration, repeated daily exposure at the upper-bound level is unlikely). To estimate the average, DPR uses the arithmetic mean of daily exposure (Powell, 2003).

Table 29 summarizes concentration estimates for activities associated with broadcast tarped shank applications. Estimates for handlers (driver, co-pilot, shoveler, tarp splitter, and tarp remover) in Table 29 are based on data from Beard *et al*. (1996); estimates for soil shapers are based on data from both Beard *et al*. (1996) and Rotondaro (2004). Unlike Rotondaro (2004), Beard *et al*. (1996) did not separately monitor concentrations while chloropicrin cylinders were being disconnected, and no concentrations during cylinder disconnect are available for broadcast tarped shank applications.

Table 29. Chloropicrin Concentrations Associated with Broadcast Tarped Applications [a]

Scenario	N [b]	Minutes (mean)	Chloropicrin (µg/m^3) [c]			Chloropicrin (ppb) [c]		
			Mean	SD	95th	Mean	SD	95th
Driver	16	153	724 [d]	457	1,880 [d]	108 [d]	67.9	280 [d]
Co-pilot	16	163	906 [d]	528	1,970 [d]	135 [d]	78.4	293 [d]
Shoveler	32	150	317	270	778 [d]	47.1	40.2	116 [d]
Tarp Splitter	14	31.1	876 [d]	1,520	2,480 [d]	130 [d]	226	369 [d]
Tarp Remover	29	107	885 [d]	1,080	4,930 [d]	132 [d]	160	734 [d]
Soil Shaper (1-hour)	5	60.2	121	73.3	264	17.9	10.9	39.3
Soil Shaper (4-hour)	5	245	102	99.1	398	15.2	14.7	59.2

[a] Data from Beard *et al.* (1996) and Rotondaro (2004).
[b] Number of replicates with data in scenario.
[c] Concentration arithmetic means (Mean), standard deviations (SD), and 95th percentile (95th). The 95th percentile was calculated assuming a lognormal distribution. Concentrations were adjusted for field spike recoveries and for an allowed maximum application rate of 500 lbs AI/acre.
[d] Chloropicrin product labels specify that anytime the air concentration of chloropicrin exceeds 0.1 ppm (100 ppb or 672 µg/m^3), handlers are required to wear a respirator equipped with a fresh organic vapor removing cartridge with a prefilter approved for pesticides or a respirator with a fresh canister approved for pesticides.

Mean and 95th percentile concentrations summarized in Table 29 exceed 100 ppb for several scenarios, including driver, co-pilot, shoveler (95th percentile only), tarp splitter and tarp remover. Chloropicrin-only product labels all require that handlers wear an air purifying respirator when concentrations exceed 100 ppb, and specify that to protect the eyes, a full-face respirator must be worn. Methyl bromide/chloropicrin product labels require handlers to wear either a supplied-air respirator or a self-contained breathing apparatus whenever chloropicrin concentrations exceed 100 ppb. And 1,3-dichloropropene/chloropicrin product labels require handlers to wear either a half-face or a full-face respirator at concentrations above 100 ppb. The concentrations reported in Table 29 suggest that monitoring is needed during broadcast tarped applications to ensure that handlers know when concentrations exceed 100 ppb.

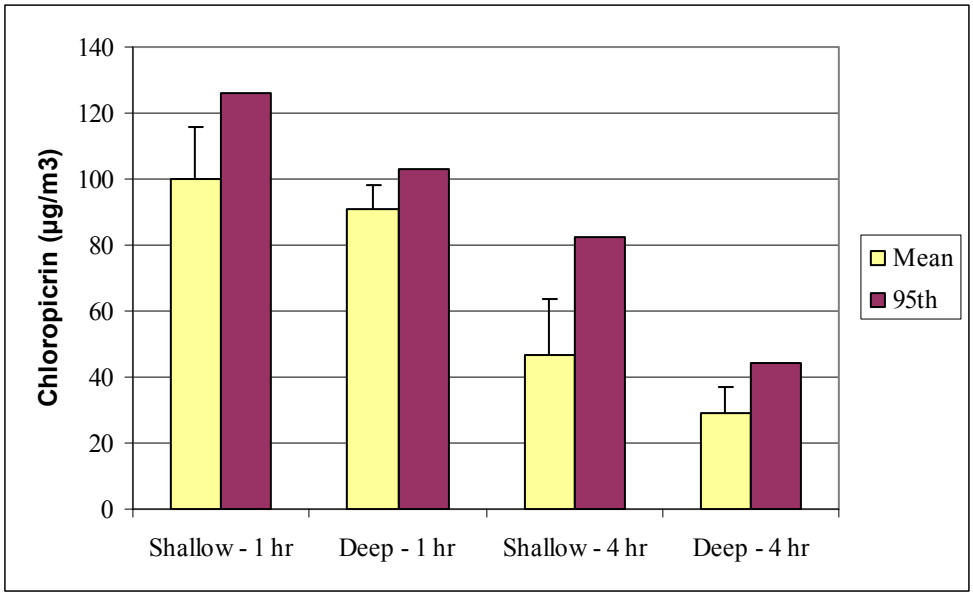
Table 30 summarizes concentration estimates for activities associated with broadcast non-tarped shank applications, both shallow (4-13" deep) and deep (18-24"). Only reentry workers shaping soil were monitored following deep shank applications; no handler activities were monitored during deep shank applications. Statistics reported in Table 30 suggest that concentrations were somewhat lower following deep than they were following shallow applications. Comparisons are shown in Figure 3, which also shows 1-hour estimates (these were greater than 4-hour estimates). Reentry activities occurred at the same post-application interval (10 days post-application) following both shallow and deep applications, which tends to increase confidence in these comparisons.

Table 30. Chloropicrin Concentrations Associated with Broadcast Shank Non-Tarped Applications [a]

Scenario	N [b]	Minutes (mean)	Chloropicrin (µg/m³) [c]			Chloropicrin (ppb) [c]		
			Mean	SD	95th	Mean	SD	95th
Shallow								
Driver	6	248	348	134	637	51.8	19.9	94.7
Driver Disconnect [d]	4	16.5	1,550 [e]	900	3,020 [e]	231 [e]	134	449 [e]
Soil Sealer	6	224	153	80.7	362	22.7	12.0	53.9
Soil Shaper (1-hour)	5	61.2	100	15.8	126	14.9	2.35	18.7
Soil Shaper (4-hour)	5	249	46.4	17.4	82.4	6.91	2.59	12.3
Deep								
Soil Shaper (1-hour)	5	59.8	91.0	6.97	103	13.5	1.04	15.3
Soil Shaper (4-hour)	5	244	29.0	8.13	44.1	4.31	1.21	6.56

[a] Data from Beard *et al.* (1996) and Rotondaro (2004).
[b] Number of replicates with data in scenario.
[c] Concentration arithmetic means (Mean), standard deviations (SD), and 95th percentile (95th). The 95th percentile was calculated assuming a lognormal distribution. Concentrations were adjusted for field spike recoveries and for an allowed maximum application rate of 500 lbs AI/acre.
[d] A second sampling pump was used to monitor drivers while they disconnected cylinders. This operation is part of the overall activity for a driver, and it was not considered as a separate scenario in the exposure assessment.
[e] Chloropicrin product labels specify that anytime the air concentration of chloropicrin exceeds 0.1 ppm (100 ppb or 672 µg/m³), handlers are required to wear a respirator equipped with a fresh organic vapor removing cartridge with a prefilter approved for pesticides or a respirator with a fresh canister approved for pesticides.

Figure 3. Mean and 95th Percentile Chloropicrin Concentrations During Monitoring of Soil Shapers Ten Days Following Shallow and Deep Non-Tarped Shank Applications [a]



[a] Data from Rotondaro (2004). Each bar represents five individuals, monitored at a total of three sites (one or two per site). Error bars on means are standard deviations. See Table 30 and surrounding text for details.

One scenario in Table 30, drivers involved in shallow broadcast non-tarped shank applications disconnecting the cylinder, has an estimated chloropicrin exposure to a mean concentration of 231 ppb and a 95th percentile concentration of 449 ppb. These concentrations exceed 100 ppb, the concentration at which handlers are required to wear respiratory protection. A second sampling pump was used to monitor drivers while they disconnected cylinders. This operation is part of the overall activity for a driver, lasting on average 16.5 minutes of the 248 minutes drivers were monitored, and although reported separately in Table 30 for completeness it was not considered as a separate scenario for exposure assessment purposes.

Minutes reported in Table 29 and subsequent tables refer to intervals when workers were monitored; i.e., when sample pumps were running. Exposures were calculated based on monitoring intervals. However, application start and stop times were also reported by Beard *et al.* (1996) and by Rotondaro (2004). Comparison of application times with monitoring intervals for shank applications suggests that on average workers were monitored about 25% longer than the application intervals. Conversely, in one broadcast tarped and one bedded tarped application, reported application times were longer (as much as twice as long) than monitoring times. To the extent that volumes sampled by sampling pumps included "clean" air, exposures could potentially be underestimated if monitoring was initiated before the application began. However, individuals onsite can be exposed to volatilized chloropicrin once the application is completed; thus, the implication of differences in monitoring intervals and application intervals is unclear. For consistency, all exposure estimates reported in this memo are based on monitoring intervals.

Application times can be divided by numbers of acres treated to get a sense of the pace at which applications proceeded. In applications reported by Beard *et al.* (1996) and by Rotondaro (2004), broadcast tarped and broadcast non-tarped applications took approximately the same time per acre. Mean $\pm$ SD for the seven broadcast tarped applications were 34 $\pm$ 7 minutes per acre, and for the four broadcast non-tarped applications they were 36 $\pm$ 10 minutes per acre. At these rates, a 10-acre application would take slightly more than 5 hours. The four non-tarped bedded applications took longer, 48 $\pm$ 40 minutes per acre. The four tarped bedded applications took considerably longer, 183 $\pm$ 67 minutes per acre, an average of three hours per acre. These times are probably longer than commercial applications not involving exposure monitoring, but exact differences are not known.

Table 31 summarizes concentration estimates for activities associated with bedded tarped shank applications. Mean and 95th percentile concentrations for drivers disconnecting chloropicrin cylinders exceed 100 ppb; all other concentrations are below 100 ppb.

Table 31. Chloropicrin Concentrations Associated with Shallow Tarped Shank Bedded Soil Fumigation [a]

Scenario	N [b]	Minutes (mean)	Chloropicrin (µg/m^3) [c]			Chloropicrin (ppb) [c]		
			Mean	SD	95th	Mean	SD	95th
Driver	8	331	87.0	75.2	228	12.9	11.2	33.9
Driver Disconnect [d]	4	19.2	1,030 [e]	690	3,260 [e]	153 [e]	103	485 [e]
Co-pilot	5	326	110	116	382	16.3	17.2	56.8
Shoveler	7	337	62.8	43.9	149	9.34	6.52	22.1
Tarp Puncher (1-hour)	4	61.2	42.8	8.81	61.6	6.36	1.31	9.17
Tarp Puncher (4-hour)	8	212	8.76	4.36	16.2	1.30	0.648	2.41

[a] Data from Beard *et al.* (1996) and Rotondaro (2004).
[b] Number of replicates with data in scenario.
[c] Concentration arithmetic means (Mean), standard deviations (SD), and 95th percentile (95th). The 95th percentile was calculated assuming a lognormal distribution. Concentrations were adjusted for field spike recoveries and for an allowed maximum application rate of 500 lbs AI/acre.
[d] A second sampling pump was used to monitor drivers while they disconnected cylinders. This operation is part of the overall activity for a driver, and it was not considered as a separate scenario in the exposure assessment.
[e] Chloropicrin product labels specify that anytime the air concentration of chloropicrin exceeds 0.1 ppm (100 ppb or 672 µg/m^3), handlers are required to wear a respirator equipped with a fresh organic vapor removing cartridge with a prefilter approved for pesticides or a respirator with a fresh canister approved for pesticides.

Table 32 summarizes concentration estimates for activities associated with non-tarped shallow shank applications. Mean and 95th percentile concentrations for drivers disconnecting chloropicrin cylinders exceed 100 ppb; all other concentrations are below 100 ppb.

Table 32. Chloropicrin Concentrations Associated with Shallow Non-Tarped Shank Bedded Soil Fumigation [a]

Scenario	N [b]	Minutes (mean)	Chloropicrin (µg/m^3) [c]			Chloropicrin (ppb) [c]		
			Mean	SD	95th	Mean	SD	95th
Driver	5	229	221	117	542	32.8	17.3	80.6
Driver Disconnect [d]	3	16.7	2,340 [e]	1,490	5,130 [e]	348 [e]	221	762 [e]
Pipe Layer (1-hour)	6	60.7	43.5	3.62	49.9	6.46	0.539	7.42
Pipe Layer (4-hour)	6	234	11.3	0.281	11.7	1.67	0.0418	1.74

[a] Data from Beard *et al.* (1996) and Rotondaro (2004).
[b] Number of replicates with data in scenario.
[c] Concentration arithmetic means (Mean), standard deviations (SD), and 95th percentile (95th). The 95th percentile was calculated assuming a lognormal distribution. Concentrations were adjusted for field spike recoveries and for an allowed maximum application rate of 250 lbs AI/acre.
[d] A second sampling pump was used to monitor drivers while they disconnected cylinders. This operation is part of the overall activity for a driver, and it was not considered as a separate scenario in the exposure assessment.
[e] Chloropicrin product labels specify that anytime the air concentration of chloropicrin exceeds 0.1 ppm (100 ppb or 672 µg/m^3), handlers are required to wear a respirator equipped with a fresh organic vapor removing cartridge with a prefilter approved for pesticides or a respirator with a fresh canister approved for pesticides.

Table 33 summarizes concentration estimates for activities associated with tarped surface or non-tarped buried drip irrigation applications. With the exception of the 95th percentile for applicators disconnecting chloropicrin cylinders following non-tarped buried drip applications, all concentrations in Table 33 are less than 100 ppb.

Table 33. Chloropicrin Concentrations Associated with Drip Irrigation [a]

Scenario	N [b]	Minutes (mean)	Chloropicrin (µg/m^3) [c]			Chloropicrin (ppb) [c]		
			Mean	SD	95th	Mean	SD	95th
Tarped Surface								
Applicator	6	520	65.8	29.1	141	9.79	4.32	20.9
Applicator Disconnect [d]	2	19.0	118	38.2	194	17.6	5.69	28.9
Tarp Puncher (1-hour)	5	61.2	37.5	9.54	52.4	5.58	1.42	7.79
Tarp Puncher (4-hour)	5	252	19.7	23.0	48.9	2.93	3.41	7.27
Non-Tarped Buried								
Applicator	6	587	88.0	93.8	305	13.1	13.9	45.4
Applicator Disconnect [d]	2	12.0	613	351	1,470 [e]	91.1	52.2	218 [e]

[a] Data from Rotondaro (2004).
[b] Number of replicates with data in scenario.
[c] Concentration arithmetic means (Mean), standard deviations (SD), and 95th percentile (95th). The 95th percentile was calculated assuming a lognormal distribution. Concentrations were adjusted for field spike recoveries and for an allowed maximum application rate of 300 lbs AI/acre.
[d] A second sampling pump was used to monitor applicators while they disconnected cylinders. This operation is part of the overall activity for an applicator, and it was not considered as a separate scenario in the exposure assessment.
[e] Chloropicrin product labels specify that anytime the air concentration of chloropicrin exceeds 0.1 ppm (100 ppb or 672 µg/m^3), handlers are required to wear a respirator equipped with a fresh organic vapor removing cartridge with a prefilter approved for pesticides or a respirator with a fresh canister approved for pesticides.

Table 34 summarizes concentration estimates for activities associated with replant handwand applications. The 95th percentile for concentrations measured by samplers in both the breathing zone and attached to the applicator's leg exceeded 100 ppb.

Table 34. Chloropicrin Concentrations Associated with Replant Handwand Applications [a]

Scenario	N [b]	Minutes (mean)	Chloropicrin (µg/m^3) [c]			Chloropicrin (ppb) [c]		
			Mean	SD	95th	Mean	SD	95th
Applicator	6	253	172	210	751 [e]	25.6	31.2	112 [e]
Applicator Disconnect [d]	1	12	167	NA	NA	24.8	NA	NA
Applicator - Leg	6	253	221	238	1,010 [e]	32.8	35.4	151 [e]

[a] Data from Rotondaro (2004).
[b] Number of replicates with data in scenario.
[c] Concentration arithmetic means (Mean), standard deviations (SD), and 95th percentile (95th). The 95th percentile was calculated assuming a lognormal distribution. Concentrations were adjusted for field spike recoveries and for an allowed maximum application rate of 500 lbs AI/acre. NA: not applicable (single value).
[d] A second sampling pump was used to monitor applicators while they disconnected cylinders. This operation is part of the overall activity for an applicator, and it was not considered as a separate scenario in the exposure assessment.
[e] Chloropicrin product labels specify that anytime the air concentration of chloropicrin exceeds 0.1 ppm (100 ppb or 672 µg/m^3), handlers are required to wear a respirator equipped with a fresh organic vapor removing cartridge with a prefilter approved for pesticides or a respirator with a fresh canister approved for pesticides.

Adjustment to Short-Term Exposure Estimates for Aeration and Reentry Scenarios

As previously mentioned, short-term exposure estimates were adjusted by the ratio of the maximum application rate to the rate used at each site. Additionally, in many cases product labels and California regulation allow aeration and reentry earlier than when monitoring was conducted. As chloropicrin dissipates with time, exposures could be underestimated for workers entering on days earlier than when monitoring was conducted. Scenario-specific adjustments are needed to avoid potential underestimates. Table 35 summarizes post-application days when monitoring occurred, and the earliest post-application day when each activity can legally occur based on product labels or California regulation.

Table 35. Post-Application Days When Aeration and Reentry Scenarios Were Monitored and Earliest Allowed Reentry [a]

Scenario	Monitored [b]	Chloropicrin 100% [c]	Chloropicrin 55% [d]	Chloropicrin 10.5% [d]	Chloropicrin 2% [d]
Broadcast Tarp					
• Tarp Splitter	5 – 6 [e]	**not given on label**	**5**	**5**	**5**
• Tarp Remover	7	**1 – 2** [f]	**6**	**6**	**6**
• Soil Shaper	10 – 11	10 – 14	12	12	12
Broadcast NT					
• Soil Shaper	10	10 – 14	**4**	**4**	**4**
Bedded Tarped					
• Tarp Puncher	6 – 7	**1 – 2** [f]	**5**	**5**	**5**
Bedded NT					
• Pipe Layer	6 – 7	10 – 14	**3**	**3**	**3**
Chemigation					
• Tarp Puncher	5 – 10 [g]	**1 – 2** [f]	**5**	**5**	**5**

[a] Bold: activity can occur earlier than when monitoring by Beard *et al.* (1996) and Rotondaro (2004) was done.
[b] Number of days post-application when activity was monitored.
[c] Number of days post-application when activity can legally occur, based on current chloropicrin-containing product labels approved in California.
[d] Number of days post-application when activity can legally occur, according to California regulation of soil fumigation with methyl bromide (California Code of Regulation Title 3, Section 6447.3). Chloropicrin percentages in the three categories of formulations are the highest for chloropicrin use as an active ingredient (55%), in the product Methyl Bromide 89.5%, containing an elevated chloropicrin concentration for a warning agent (10.5%), and for chloropicrin as a warning agent (2%).
[e] All tarp splitters monitored at 5 days post-application, except one replicate in Washington who was monitored at 6 days.
[f] One product, Chlor-O-Pic, allows tarp removal after 24 hours. All other chloropicrin-only products allow tarp removal after 48 hours.
[g] One tarp puncher was monitored at 5 days post-application, and two were monitored at 10 days.

Appendix 5 summarizes data used to calculate the adjustment made to aeration and reentry exposures using ratios of flux (reported as percent loss of applied mass) on the days of interest. Adjustments assume that the flux (expressed as percent chloropicrin lost during equivalent intervals on days being compared) is proportional to the amount of chloropicrin available.

Table 36 summarizes concentrations used for short-term aerator and reentry exposure estimates, before and after adjusting with the flux ratio. Pre-adjustment short-term exposures are taken from the 95th percentile concentrations in tables 29 through 33.

Table 36. Short-Term Exposure Estimates for Aeration and Reentry Scenarios, Before and After Adjustment for Earliest Allowed Reentry [a]

Scenario	Pre-Adjustment (ppb)		Adjustment [b]	Post-Adjustment (ppb)	
	1-Hour	8-Hour		1-Hour	8-Hour
Broadcast Tarped Shank					
• Tarp Splitter	369 [f]	369 [f]	20 [d] (2, 6)	7,490 [f]	7,490 [f]
• Tarp Remover	734 [f]	734 [f]	4 [d] (2, 7)	3,140 [f]	3,140 [f]
• Soil Shaper	59.2	59.2	1.4 (10, 11)	84.2	84.2
Broadcast Non-Tarped Shank					
• Soil Shaper	18.7	12.3	1 (10, 10)	18.7	12.3
Bedded Tarped Shank					
• Tarp Puncher	9.17	2.41	19 [d] (2, 7)	174 [f]	45.6
Bedded Non-Tarped Shank					
• Pipe Layer	7.42	1.74	1 [e] (10, 7)	7.42	1.74
Tarped Drip					
• Tarp Puncher	7.79	7.79	2.1 (2, 10)	16.6	16.6

[a] Short-term exposures are upper-bound concentrations estimates that cover intervals from 1 hour to 1 week. For occupational exposures, 1-hour and 8-hour intervals represent the shortest duration for which toxicity endpoints and concentrations can reasonably be estimated, and a typical workday, respectively. The two intervals have identical estimates unless 1-hour monitoring was done and yielded higher concentrations than full-shift monitoring.

[b] Adjustments are ratios of flux (reported as percent loss of applied mass) on earliest post-application day when activity is allowed to post-application day when activity was monitored (days are in parentheses after each value).

[d] One product, Chlor-O-Pic, allows tarp removal at 24 hours. Flux ratios are 28 and 6, respectively, for tarp splitters and tarp removers associated with broadcast tarped applications. The flux ratio is 49 for tarp punchers associated with bedded tarped applications (flux on post-application day 1 divided by flux on post-application day 7).

[e] The daytime 12-hour mass loss on Day 7 was zero, and was adjusted to 0.01% (lowest reported percent loss in study) for ratio calculation.

[f] Chloropicrin product labels specify that anytime the air concentration of chloropicrin exceeds 0.1 ppm (100 ppb or 672 $\mu g/m^3$), handlers are required to wear a respirator equipped with a fresh organic vapor removing cartridge with a prefilter approved for pesticides or a respirator with a fresh canister approved for pesticides. When concentrations exceed 4 ppm (4,000 ppb or 26,900 $\mu g/m^3$), product labels state that a positive-pressure self-contained breathing apparatus or a supplied air respirator must be worn by handlers.

For two scenarios in Table 36, tarp splitters and tarp removers associated with broadcast tarped applications, pre-adjustment concentrations exceed 100 ppb, the concentration above which chloropicrin product labels specify that handlers must wear respiratory protection. For both scenarios, post-adjustment concentrations exceed 4,000 ppb, the concentration above which product labels specify that a positive-pressure self-contained breathing apparatus or a supplied air respirator must be worn by handlers. For one scenario in Table 36, post-adjustment concentrations exceed 100 ppb. These concentrations suggest that monitoring is needed in association with tarped soil fumigations to ensure that handlers know when concentrations exceed 100 ppb.

Comments for Exposure Appraisal

To decrease the likelihood of underestimating exposures, results in this memo were corrected for FF recoveries. This practice is recommended by U.S. EPA for data used to estimate exposure (U.S. EPA, 1992); DPR is in accordance with U.S. EPA policy to correct only for FF recoveries below 90% (U.S. EPA, 1998). Corrections for FF recoveries are intended to compensate for loss of analyte during the sampling period and subsequent transportation and storage, as well as incomplete recovery in the analysis; the correction assumes that both sample and spiked tubes are subjected to the same factors at similar intensities. Rather than correct for FF recoveries, Rotondaro (2004) corrected results for laboratory spike recoveries, which focuses on differences between analytical batches in the laboratory rather than between conditions in the field during sample collection and processing. As sampling intervals were quite long in some cases (as long as 13 hours), and as conditions differed substantially between some sites, DPR believes that correction for FF recoveries is appropriate for these samples. In this memo, results reported by Beard *et al.* (1996) and Rotondaro (2004) were corrected for FF recoveries according to DPR policy. Uncorrected results were reported in both study reports, along with corrected results; as needed, DPR used the uncorrected results and corrected for FF recoveries.

Results in this memo were also adjusted to reflect the maximum application rate allowed in California. Concentration adjustments for various application rates assume that the concentration that individuals involved in an application or reentering an area post-application is proportional to the application rate.

Although acknowledging that environmental concentration and exposure monitoring data are likely to be lognormally distributed (Ott, 1990), DPR believes that the arithmetic mean is the appropriate statistic to use in exposure estimates (Powell, 2003). DPR uses the arithmetic mean exposure for intermediate- or long-term exposures because the parameter of interest for exposure assessment is the overall exposure that a person is expected to have during the averaging period. For environmental samples, the arithmetic mean concentration is the best estimate of the average mass of residue per unit of environmental medium; it is equivalent to compositing all of the samples and measuring the concentration of the mixture (Parkhurst, 1998). This is true regardless of the shape of the underlying distribution.

DPR generally uses the 95th percentile of daily exposure to estimate short-term exposure. The 95th percentile upper bound is the value such that 95% of anticipated exposures would be lower, and 5% would exceed it. DPR believes upper-bound estimates are appropriate for short-term exposures because high-end exposures are possible, and DPR has an obligation to protect all individuals exposed to pesticides as a result of legal uses. Protecting at the level of "average or typical" exposure would, by definition, suggest that many individuals (anyone with above-average exposure) could be exposed to acutely toxic concentrations.

DPR generally uses the 95th percentile of daily exposure rather than the maximum, because DPR assumes a lognormal distribution, which in theory has an indefinitely large maximum. In practice of course, exposures must have a finite maximum value because a finite amount of AI is applied. The 95th percentile is used by DPR rather than a higher percentile (e.g., 99th percentile), because the higher a percentile, the less reliably it can be estimated. Also, DPR recognizes that the assumed lognormal distribution may not exactly match the actual distribution of exposure

values, and that any discrepancy from the lognormal distribution will be greatest at the upper extremes (Ott, 1990). DPR believes that the 95th percentile upper bound is a realistic exposure estimate for short durations.

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Sally Powell in DPR's Worker Health and Safety Branch provided the approach for estimating 95th percentile concentrations, along with the explanation of the calculations that is in the Scenario-Specific Exposure Estimates section. Eric Miguelino, Roger Cochran, and Sue Edmiston in Worker Health and Safety reviewed earlier drafts of this memo and provided valuable corrections.

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Appendix 1. Soil Characterization.

Table A1-1. Arizona Plots, Phase 1 (Beard *et al*., 1996).

Plot	Sample depth (inches)	Soil Texture [a]	Bulk Density (g/cm^3) [b]	Organic Matter (%) [c]	Sand (%) [c]	Clay (%) [c]	Silt (%) [c]	Soil Moisture (%) [d]
1	1 – 6	Loam	1.47	0.61	43.5	21.2	35.3	8.46
	9 – 15	Loam	1.89	0.52	44.1	21.2	34.7	11.5
2	1 – 6	Sandy Loam	1.65	0.23	60.8	11.2	28.0	7.03
	9 – 15	Sandy Loam	1.47	0.29	58.8	11.2	30.0	9.17
3	1 – 6	Sandy Loam	1.47	0.29	53.5	13.6	32.9	7.15
	9 – 15	Loam	1.47	0.41	50.8	15.6	33.6	11.1
4	1 – 6	Loam	1.43	0.38	49.5	17.6	32.9	5.71
	9 – 15	Loam	1.38	0.38	51.5	17.6	30.9	10.7

[a] Soil texture from USDA (2009).
[b] Pooled sample.
[c] Mean of three samples.
[d] Mean of six samples, three collected pre-application and three collected post-application. Soil moisture determined by weighing soil samples before and after drying.

Table A1-2. Washington Plots, Phase 2 (Beard *et al*., 1996).

Plot	Sample depth (inches)	Soil Texture [a]	Bulk Density (g/cm^3) [b]	Organic Matter (%) [c]	Sand (%) [c]	Clay (%) [c]	Silt (%) [c]	Soil Moisture (%) [d]
1	1 – 6	Loam	1.41	1.59	40.4	22.3	37.7	17.8
	9 – 15	Loam	1.36	1.51	44.4	21.6	34.0	19.9
2	1 – 6	Loam	1.35	1.89	48.4	22.3	29.3	19.7
	9 – 15	Loam	1.04	1.60	49.1	21.6	29.3	22.2
3	1 – 6	Loam	1.37	0.59	48.4	21.6	30.0	14.3
	9 – 15	Loam	0.88	0.67	48.4	23.6	28.0	14.4

[a] Soil texture from USDA (2009).
[b] Pooled sample.
[c] Mean of three samples.
[d] Mean of six samples, three collected pre-application and three collected post-application. Soil moisture determined by weighing soil samples before and after drying.

Appendix 1 continued...

Table A1-3. Florida Plots, Phase 2 (Beard *et al*., 1996).

Plot	Sample depth (inches)	Soil Texture [a]	Bulk Density (g/cm^3) [b]	Organic Matter (%) [c]	Sand (%) [c]	Clay (%) [c]	Silt (%) [c]	Soil Moisture (%) [d]
1	1 – 6	Sand	1.42	1.88	93.2	0.8	6.0	7.17
	9 – 15	Sand	1.38	1.28	93.2	0.8	6.0	13.2
2	1 – 6	Sand	1.00	1.84	93.2	2.8	4.0	8.95
	9 – 15	Sand	0.95	0.57	93.9	0.8	5.3	15.8
3	1 – 6	Sand	1.40	1.16	93.2	0.8	6.0	7.58
	9 – 15	Sand	1.16	0.51	93.2	0.8	6.0	9.90

[a] Soil texture from USDA (2009).
[b] Pooled sample.
[c] Mean of three samples.
[d] Mean of six samples. Soil moisture determined by weighing soil samples before and after drying.

Table A1-4. Shank Broadcast Tarped Shallow Applications (Rotondaro, 2004).

Site [a]	Sample depth (inches)	Soil Texture [b]	Bulk Density (g/cm^3) [c]	Organic Matter (%) [d]	Sand (%) [d]	Silt (%) [d]	Clay (%) [d]	Soil Moisture (%) [e]
1	0 – 3	Sandy Loam	1.35	0.70	65	28	7	5.8
	9 – 15	Sandy Loam	1.47	0.63	68	25	7	6.5
2	0 – 3	Sandy Loam	1.27	0.57	69	24	7	7.0
	9 – 15	Sandy Loam	1.29	0.57	69	24	7	7.9
3	0 – 3	Sandy Loam	1.21	1.07	59	22	19	10.8
	9 – 15	Sandy Loam	1.27	0.90	61	22	17	12.6

[a] All sites were in California, in or near the following communities: Site 1, Thermal; Site 2, Parlier; Site 3, Irvine.
[b] Soil texture from USDA (2009).
[c] Mean of two samples.
[d] Mean of three samples.
[e] Mean of two samples. Soil moisture determined by weighing soil samples before and after drying.

Table A1-5. Shank Broadcast Non-Tarped Shallow Applications (Rotondaro, 2004).

Site [a]	Sample depth (inches)	Soil Texture [b]	Bulk Density (g/cm^3) [c]	Organic Matter (%) [d]	Sand (%) [d]	Silt (%) [d]	Clay (%) [d]	Soil Moisture (%) [e]
4	0 – 3	Sandy Loam	1.17	0.70	76	15	10	14.4
	9 – 15	Sandy Loam	1.24	0.70	78	13	9	13.6
5	0 – 3	Sandy Loam	1.39	0.70	67	26	7	9.5
	7 – 13	Sandy Loam	1.51	0.73	62	31	7	8.3
6	0 – 3	Sandy Loam	1.27	0.90	53	37	10	7.3
	9 – 15	Sandy Loam	1.38	0.70	53	37	10	9.1

[a] All sites were in California, in or near the following communities: Site 4, Irvine; Site 5, Thermal; Site 6, Parlier.
[b] Soil texture from USDA (2009).
[c] Mean of two samples.
[d] Mean of three samples.
[e] Mean of two samples. Soil moisture determined by weighing soil samples before and after drying.

Appendix 1 continued...

Table A1-6. Shank Broadcast Non-Tarped Deep Applications (Rotondaro, 2004).

Site [a]	Sample depth (inches)	Soil Texture [b]	Bulk Density (g/cm^3) [c]	Organic Matter (%) [d]	Sand (%) [d]	Silt (%) [d]	Clay (%) [d]	Soil Moisture (%) [e]
7	0 – 3	Sandy Loam	1.38	0.70	63	30	7	8.7
	9 – 15	Sandy Loam	1.47	0.27	66	28	6	8.2
8	0 – 3	Sandy Loam	1.22	1.0	55	35	10	10.5
	7 – 13	Sandy Loam	1.50	0.40	56	35	9	7.9
9	0 – 3	Sandy Loam	1.18	0.87	60	22	19	13.4
	9 – 15	Sandy Loam	1.28	0.77	64	19	16	14.4

[a] All sites were in California, in or near the following communities: Site 7, Thermal; Site 8, Parlier; Site 9, Irvine.
[b] Soil texture from USDA (2009).
[c] Mean of two samples.
[d] Mean of three samples.
[e] Mean of two samples. Soil moisture determined by weighing soil samples before and after drying.

Table A1-7. Shank Bedded Tarped Shallow Applications (Rotondaro, 2004).

Site [a]	Sample depth (inches)	Soil Texture [b]	Bulk Density (g/cm^3) [c]	Organic Matter (%) [d]	Sand (%) [d]	Silt (%) [d]	Clay (%) [d]	Soil Moisture (%) [e]
10	0 – 3	Sandy Loam	1.20	0.70	62	30	8	8.8
	3 – 9	Sandy Loam	1.41	0.70	64	29	7	7.8
11	0 – 3	Sandy Loam	1.35	1.6	66	16	17	7.1
	6 – 12	Sandy Loam	1.42	1.7	69	15	15	7.0
12	0 – 3	Loamy Sand	1.35	0.43	83	9	8	0.7
	5 – 11	Loamy Sand	0.85	0.43	83	9	8	5.6

[a] All sites were in California, in or near the following communities: Site 10, Thermal; Site 11, Salinas; Site 9, Del Mar.
[b] Soil texture from USDA (2009).
[c] Mean of two samples.
[d] Mean of three samples.
[e] Mean of two samples. Soil moisture determined by weighing soil samples before and after drying.

Appendix 1 continued...

Table A1-8. Shank Bedded Non-Tarped Shallow Applications (Rotondaro, 2004).

Site [a]	Sample depth (inches)	Soil Texture [b]	Bulk Density (g/cm^3) [c]	Organic Matter (%) [d]	Sand (%) [d]	Silt (%) [d]	Clay (%) [d]	Soil Moisture (%) [e]
13	0 – 3	Sandy Loam	1.22	0.77	58	35	7	13.2
	6 – 12	Sandy Loam	1.34	0.73	58	35	7	7.5
14	0 – 3	Clay Loam	1.22	2.3	34	29	37	14.5
	9 – 15	Clay Loam	1.35	2.6	34	29	37	16.7
15	0 – 3	Sandy Loam	1.25	0.83	56	28	16	6.6
	9 – 15	Sandy Loam	1.30	0.77	59	28	13	2.7

[a] All sites were in California, in or near the following communities: Site 13, Thermal; Site 14, Watsonville; Site 15, Parlier.
[b] Soil texture from USDA (2009).
[c] Mean of two samples.
[d] Mean of three samples.
[e] Mean of two samples. Soil moisture determined by weighing soil samples before and after drying.

Table A1-9. Drip Tarped Surface Applications (Rotondaro, 2004).

Site [a]	Sample depth (inches)	Soil Texture [b]	Quad [c]	Bulk Density (g/cm^3) [d]	Organic Matter (%) [e]	Sand (%) [e]	Silt (%) [e]	Clay (%) [e]	Soil Moisture (%) [d]
16	0 – 3	Sandy Loam	1	1.22	1.3	73	16	10	5.18
	0 – 6	Sandy Loam	1	1.33	1.5	78	13	9	5.53
	0 – 3	Sandy Loam	2		1.8	67	17	15	
	0 – 6	Sandy Loam	2		1.5	67	19	15	
	0 – 3	Loamy Sand	3		1.2	83	10	7	
	0 – 6	Loamy Sand	3		1.1	79	13	8	
	0 – 3	Loamy Sand	4		1.3	80	12	8	
	0 – 6	Loamy Sand	4		1.1	79	13	8	
17	0 – 3	Loamy Sand		1.29	0.49	76	21	3	10.7
	0 – 6	Loamy Sand		1.27	0.53	75	22	3	11.3
18	0 – 3	Sandy Clay Loam		1.06	1.3	44	25	31	25.3
	0 – 6	Sandy Clay Loam		1.20	1.3	46	24	30	24.3

[a] All sites were in California: Site 16, Salinas; Site 17, Thermal; Site 18, Irvine.
[b] Soil texture from USDA (2009).
[c] Quadrant sampled. Site 16 was divided into quadrants before sampling; the other sites were not. Bulk density and soil moisture at Site 16 were analyzed on pooled samples.
[d] Mean of two samples. Soil moisture determined by weighing soil samples before and after drying.
[e] Mean of three samples.

Appendix 1 continued...

Table A1-10. Drip Non-Tarped Buried Applications (Rotondaro, 2004).

Site [a]	Sample depth (inches)	Soil Texture [b]	Bulk Density (g/cm^3) [c]	Organic Matter (%) [d]	Sand (%) [d]	Silt (%) [d]	Clay (%) [d]	Soil Moisture (%) [e]
19	0 – 3	Sandy Clay Loam	1.28	1.1	52	25	23	16.6
	7 – 13	Sandy Clay Loam	1.44	1.0	51	26	23	15.4
20	0 – 3	Sand	1.36	0.20	91	7	3	4.6
	7 – 13	Sand	1.55	0.20	89	6	5	7.8
21	0 – 3	Sandy Loam	1.24	0.33	74	20	7	4.4
	5 – 11	Sandy Loam	1.39	0.33	75	19	6	6.0

[a] All sites were in California, in or near the following communities: Site 19, Mettler; Site 20, Felicity; Site 21, Parlier.
[b] Soil texture from USDA (2009).
[c] Mean of two samples.
[d] Mean of three samples.
[e] Mean of two samples. Soil moisture determined by weighing soil samples before and after drying.

Table A1-11. Greenhouse Drip Tarped Surface Applications (Rotondaro, 2004).

Site [a]	Sample depth (inches)	Soil Texture [b]	Bulk Density (g/cm^3) [c]	Organic Matter (%) [d]	Sand (%) [d]	Silt (%) [d]	Clay (%) [d]	Soil Moisture (%) [e]
22	0 – 3	Sandy Clay Loam	1.32	2.3	62	17	21	2.3
	0 – 6	Sandy Clay Loam	1.17	1.9	61	17	22	2.8
23	0 – 3	Sandy Clay Loam	1.27	1.0	58	22	20	15.8
	0 – 6	Sandy Clay Loam	1.26	0.93	58	21	21	16.8
24	0 – 3	Sandy Loam	1.38	0.57	65	27	8	7.0
	0 – 6	Sandy Loam	1.46	0.53	61	29	10	7.0

[a] All sites were in California, in or near the following communities: Site 22, Watsonville; Site 23, Irvine; Site 24, Thermal.
[b] Soil texture from USDA (2009).
[c] Mean of two samples.
[d] Mean of three samples.
[e] Mean of two samples. Soil moisture determined by weighing soil samples before and after drying.

Appendix 1 continued...

Table A1-12. Replant Wand Applications (Rotondaro, 2004).

Site [a]	Sample depth (inches)	Soil Texture [b]	Bulk Density (g/cm^3) [c]	Organic Matter (%) [d]	Sand (%) [d]	Silt (%) [d]	Clay (%) [d]	Soil Moisture (%) [e]
26	0 – 3	Sandy Loam	1.46	0.77	73	15	11	9.1
	15 – 21	Sandy Loam	1.42	0.20	73	19	8	7.8
27	0 – 3	Sandy Loam	1.55	0.87	59	27	14	11.9
	15 – 21	Sandy Loam	1.31	0.30	63	26	11	10.4
28	0 – 3	Sandy Loam	1.26	1.1	69	17	14	10.7
	21 – 27	Sandy Loam	1.35	0.80	60	24	16	13.1

[a] All sites were in California, in or near the following communities: Site 26, Shafter; Site 27, Wasco; Site 28, Irvine.
[b] Soil texture from USDA (2009).
[c] Mean of two samples.
[d] Mean of three samples.
[e] Mean of two samples. Soil moisture determined by weighing soil samples before and after drying.

Table A1-13. Field Capacity for Hydrologic Soil Groups

Hydrologic Soil Group [a]	Soil Textures	Field Capacity [b]
A	Sand, Loamy Sand, Sandy Loam	11.8
B	Silt Loam, Loam	19.5
C	Sandy Clay Loam	22.4
D	Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay, Clay	24.1

[a] Classifications from the University of Purdue web page titled, "Hydrologic Soil Groups." http://www.ecn.purdue.edu/runoff/documentation/hsg.html Website accessed on July 29, 2009.
[b] Mean field capacity for 0 – 3 m strata from Table 2 of Carsel *et al*. (1988).

Table A1-14. Soil Moisture Content at Beard *et al.* (1996) Study Sites

Site	Soil Texture	Hydrologic Soil Group [a]	Soil Moisture (%) [b]	Percent Field Capacity [c]
Arizona Plot 1	Loam	B	9.97	51.1
Arizona Plot 2	Sandy Loam	A	8.10	68.6
Arizona Plot 3	Sandy Loam	A	9.12	77.3
Arizona Plot 4	Loam	B	8.22	42.1
Washington Plot 1	Loam	B	18.9	96.7
Washington Plot 2	Loam	B	20.9	107
Washington Plot 3	Loam	B	14.4	73.6
Florida Plot 1	Sand	A	10.2	86.2
Florida Plot 2	Sand	A	12.4	105
Florida Plot 3	Sand	A	8.74	74.1

[a] Classifications from the University of Purdue web page titled, "Hydrologic Soil Groups." http://www.ecn.purdue.edu/runoff/documentation/hsg.html Website accessed on July 29, 2009.
[b] Soil moisture determined by weighing soil samples before and after drying.
[c] Calculated by dividing measured soil moisture by field capacity for soil hydrologic group listed in Table A1-13.

Appendix 1 continued...

Table A1-15. Soil Moisture Content at Rotondaro (2004) Study Sites

Site	Soil Texture	Hydrologic Soil Group [a]	Soil Moisture (%) [b]	Percent Field Capacity [c]
1	Sandy Loam	A	6.13	51.9
2	Sandy Loam	A	7.43	62.9
3	Sandy Loam	A	11.6	98.7
4	Sandy Loam	A	14.0	118
5	Sandy Loam	A	8.88	75.2
6	Sandy Loam	A	8.15	69.1
7	Sandy Loam	A	8.45	71.6
8	Sandy Loam	A	9.20	78.0
9	Sandy Loam	A	13.9	118
10	Sandy Loam	A	8.30	70.3
11	Sandy Loam	A	7.05	59.7
12	Loamy Sand	A	3.13	26.5
13	Sandy Loam	A	10.3	87.5
14	Clay Loam	D	15.6	64.6
15	Sandy Loam	A	4.63	39.2
16	Sandy Loam	A	5.35	45.3
17	Loamy Sand	A	11.0	93.0
18	Clay Loam	D	24.8	103
19	Sandy Clay Loam	C	16.0	71.3
20	Sand	A	6.18	52.3
21	Sand	A	5.20	44.1
22	Sandy Clay Loam	C	2.53	11.3
23	Sandy Clay Loam	C	16.3	72.7
24	Sandy Loam	A	6.98	59.1
26	Sandy Loam	A	8.43	71.4
27	Sandy Loam	A	11.2	94.5
28	Sandy Loam	A	11.9	101

[a] Classifications from the University of Purdue web page titled, "Hydrologic Soil Groups." http://www.ecn.purdue.edu/runoff/documentation/hsg.html Website accessed on July 29, 2009.
[b] Soil moisture determined by weighing soil samples before and after drying.
[c] Calculated by dividing measured soil moisture by field capacity for soil hydrologic group listed in Table A1-13.

Appendix 2. Application Equipment Described in Study Reports.

Table A2-1. Non-Tarped Shank Applications in Chloropicrin Exposure Monitoring Studies

Application Method and Location	Description of Shanks [a]	Shank Spacing (inches)	Depth (inches) [b]
Shallow Broadcast Shank [c]			
Arizona (Plot 1)	Four chisel and two wing-shaped; soil sealed with a cultipacker	12	12 – 13.5
Shallow Broadcast Shank [d]			
California, Site 4	Noble plow with eight injection points; soil sealed with a chisel and ring-roller	12	12
California, Site 5	Noble plow with eight injection points; soil sealed with a disc and a pipe	12	12
California, Site 6	Noble plow with eight injection points; soil sealed with an offset disc or a ring roller	12	12
Deep Broadcast Shank [d]			
California, Site 7	Two ripper shanks; soil sealed with a small packing wheel	72	18 – 24
California, Site 8	Three ripper shanks; soil sealed with a small packing wheel	36	18 – 24
California, Site 9	Two ripper shanks; soil sealed with a small packing wheel	72	18 – 24
Bedded Shank [c]			
Arizona (Plot 2)	Four backswept shanks; soil sealed with flat weights on top of beds	40	12.5
Bedded Shank [d]			
California, Site 13	Two swept back shanks; soil sealed by bed shaper	12	9 – 10
California, Site 14	Four angled shanks, 1 to side of each bed; soil sealed by ring rollers	40	12
California, Site 15	Four angled shanks, 1 to side of each bed; soil sealed by ring rollers	40	12

[a] From descriptions given in study reports.
[b] Depth as reported in narrative application descriptions.
[c] Described in pages 23 – 31 of Beard *et al.* (1996).
[d] Described in pages 25 – 42 of Rotondaro (2004).

Appendix 2 continued...

Table A2-2. Tarped Shank Applications in Chloropicrin Exposure Monitoring Studies

Application Method and Location	Description of Shanks [a]	Shank Spacing (inches)	Depth (inches) [b]
Broadcast Shank [c]			
Arizona (Plot 4)	Four chisel and two wing-shaped	12	10.5
Washington [d]	Four chisel and two wing-shaped	12	9
Florida [d]	Two straight shanks and six Noble plows, 2 injection points each	Not given	10
Broadcast Shank [e]			
California, Site 1	Noble plow and chisel shanks	12	12
California, Site 2	Noble plow and chisel shanks	12	12
California, Site 3	Noble plow and chisel shanks	12	12
Bedded Shank [c]			
Arizona (Plot 3)	Two backswept shanks on bed shaper	40	11
Bedded Shank [e]			
California, Site 10	Two backswept shanks on bed shaper	12	6
California, Site 11	Three backswept shanks on bed shaper	8	9
California, Site 12	Two shanks on bed shaper	12	8

[a] From descriptions given in study reports.
[b] Depth as reported in narrative application descriptions.
[c] Described in pages 23 – 31 of Beard *et al.* (1996).
[d] The same application equipment was used in each plot at this location.
[e] Described in pages 25 – 42 of Rotondaro (2004).

Appendix 2 continued...

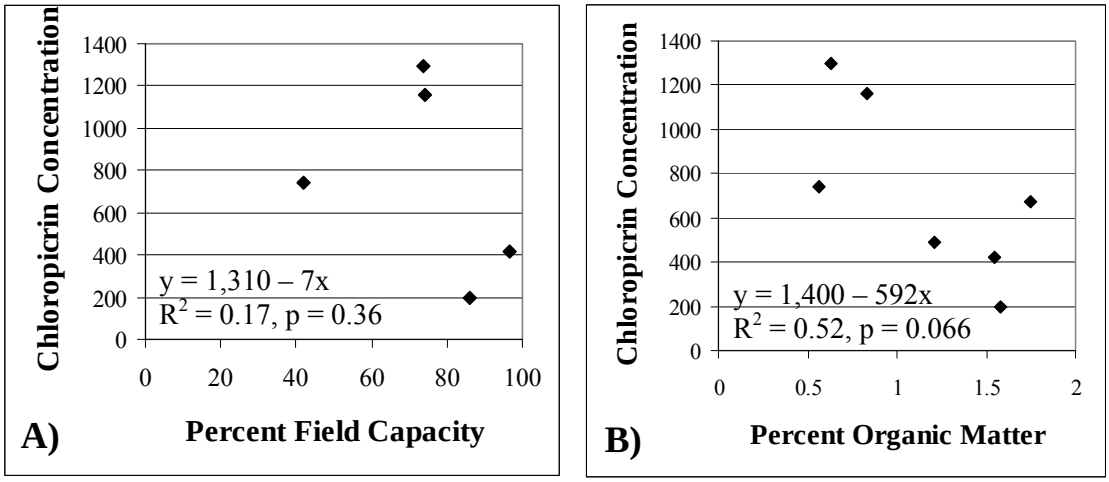
Table A2-3. Tarp Materials Used in Chloropicrin Exposure Monitoring Studies

Application Method and Location	Description of Tarp Material [a]	Manufacturer	Thickness (mil) [b]
Broadcast Shank [c]			
Arizona	Polyethylene tarp	ND [d]	1.0
Washington	Polyethylene high-barrier tarp	ND	1.0
Florida	Polyethylene tarp	ND	1.0
Broadcast Shank [e]			
California, Site 1	Polyethylene, clear	Tyco	1.0
California, Site 2	Polyethylene, clear	Tyco	1.5
California, Site 3	Polyethylene, clear	Tyco	1.0
Bedded Shank [c]			
Arizona	Plastic mulch	ND	1.5
Bedded Shank [e]			
California, Site 10	Polyethylene, black, embossed	Pliant	1.25
California, Site 11	Polyethylene, clear, embossed (Climagro)	Leco Industries	1.25
California, Site 12	Polyethylene, black, embossed, taffeta	Pliant	1.25
Surface Drip [e]			
California, Site 16	Polyethylene, green	Plassein International	1.5
California, Site 17	Polyethylene, black	ND	1.25
California, Site 18	Polyethylene, black, embossed	Pliant	1.25
Greenhouse Drip [e]			
California, Site 22	Polyethylene, clear	Tyco	1.0
California, Site 23	Polyethylene, clear	Arman Plastics	1.5
California, Site 24	Polyethylene, clear	Plassein International	1.5

[a] No indication was given regarding whether the polyethylene was high- or low-density.
[b] 1.0 mil = 0.025 mm.
[c] Described in pages 23 – 31 of Beard *et al.* (1996). The "high-barrier" tarp used in Washington applications was probably similar to tarps used in Arizona and Florida.
[d] Not described or identified in study report.
[e] Described in pages 25 – 42 of Rotondaro (2004).

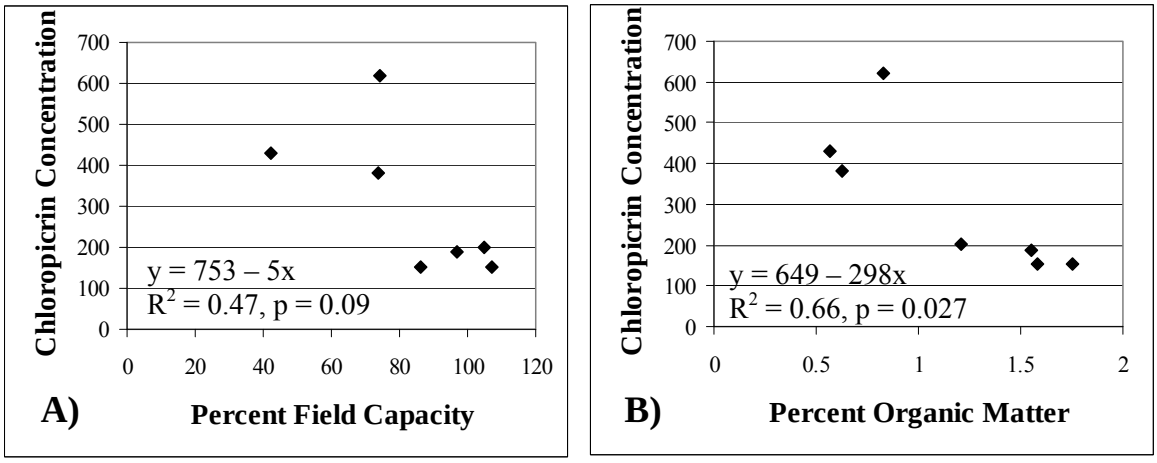
Appendix 3. Broadcast Tarped Handler Exposures to Chloropicrin as Related to Soil Characteristics at Study Sites (See Figure 2 for Co-Pilot Exposure).

Figure A3-1. Chloropicrin Driver Exposures During Broadcast Tarped Applications Versus (A) Soil Moisture as Percent Field Capacity and (B) Percent Organic Matter [a]



[a] Data from Beard *et al.* (1996). Each point represents two or three individuals during one application. Concentration in µg/m^3. Linear regression from Proc GLM (SAS, 2003).

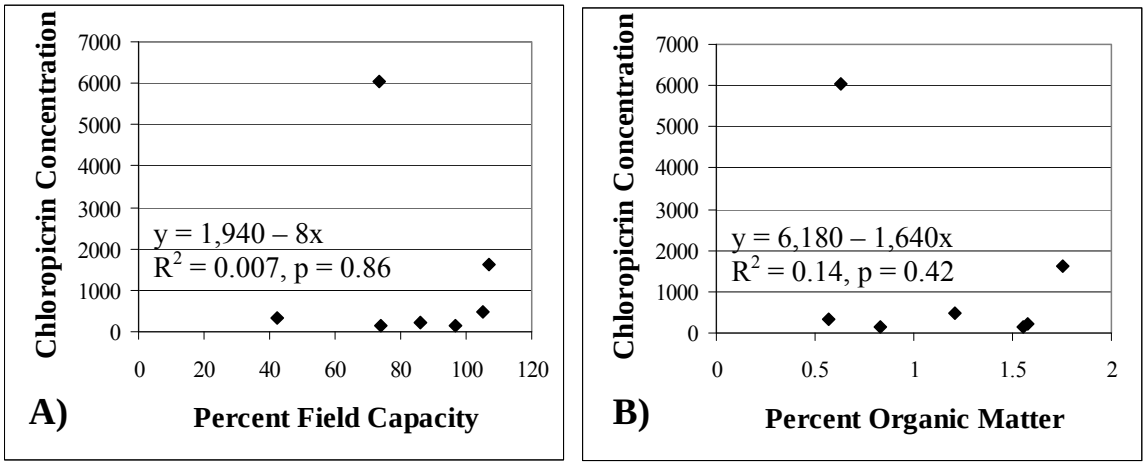
Figure A3-2. Chloropicrin Shoveler Exposures During Broadcast Tarped Applications Versus (A) Soil Moisture as Percent Field Capacity and (B) Percent Organic Matter [a]



[a] Data from Beard *et al.* (1996). Each point represents four or six individuals during one application. Concentration in µg/m^3. Linear regression from Proc GLM (SAS, 2003).

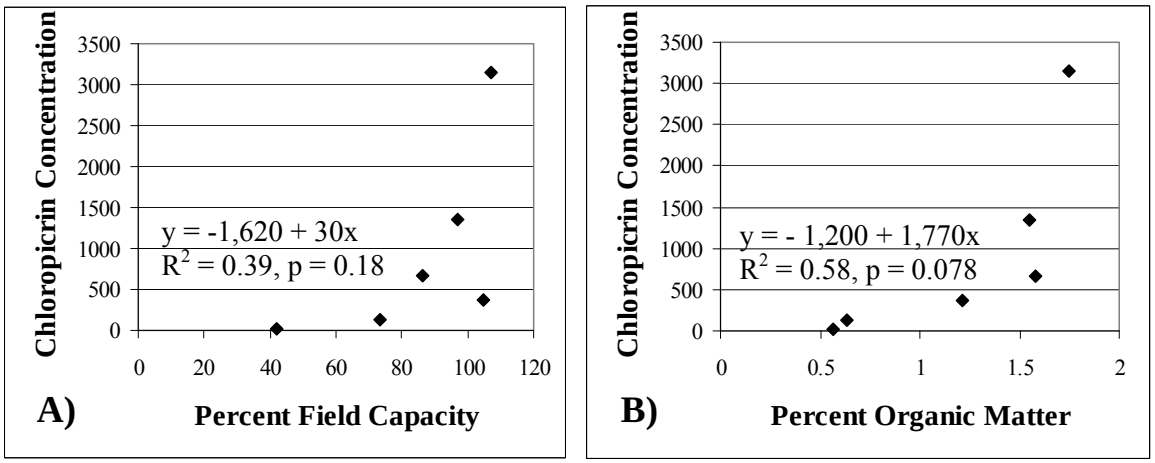
Appendix 3 continued...

Figure A3-3. Chloropicrin Exposures to Broadcast Tarp Splitters Versus (A) Soil Moisture as Percent Field Capacity and (B) Percent Organic Matter [a]



[a] Data from Beard *et al.* (1996). Each point represents one to three individuals associated with one application. Concentration in μg/m^3. Linear regression from Proc GLM (SAS, 2003).

Figure A3-4. Chloropicrin Exposures to Broadcast Tarp Removers Versus (A) Soil Moisture as Percent Field Capacity and (B) Percent Organic Matter [a]



[a] Data from Beard *et al.* (1996). Each point represents one to none individuals associated with one application. Concentration in μg/m^3. Linear regression from Proc GLM (SAS, 2003).

Appendix 4. Numbers of Replicates from Each Table Used in Each Scenario.

Table A4-1. Numbers of Replicates from Each Table for Broadcast Shank Applications

Scenario	N [a]	Minutes (mean ± SD [a])	Number of Replicates from Table										
			6	8	9	10	11	12	13	14	18	19	20
Tarped Shallow													
Driver	16	153 ± 47	0	2	2	2	2	2	3	3	0	0	0
Co-pilot	16	163 ± 39	0	2	2	2	2	2	3	3	0	0	0
Shoveler	32	150 ± 42	0	4	4	4	4	4	6	6	0	0	0
Tarp Splitter	14	31.1 ± 11.9	0	1	2	2	1	2	3	3	0	0	0
Tarp Remover	29	107 ± 45	0	4	4	4	2	6	9	0	0	0	0
Soil Shaper (1-hour)	5	60.2 ± 0.7	0	0	0	0	0	0	0	0	5	0	0
Soil Shaper (4-hour)	5	245 ± 5	0	0	0	0	0	0	0	0	5	0	0
Non-Tarped Shallow													
Driver	6	248 ± 49	2	0	0	0	0	0	0	0	0	4	0
Driver Disconnect	4	16.5 ± 9.9	0	0	0	0	0	0	0	0	0	4	0
Soil Sealer	6	224 ± 41	2	0	0	0	0	0	0	0	0	4	0
Soil Shaper (1-hour)	5	61.2 ± 1.2	0	0	0	0	0	0	0	0	0	5	0
Soil Shaper (4-hour)	5	249 ± 8	0	0	0	0	0	0	0	0	0	5	0
Non-Tarped Deep													
Soil Shaper (1-hour)	5	59.8 ± 0.7	0	0	0	0	0	0	0	0	0	0	5
Soil Shaper (4-hour)	5	244 ± 5	0	0	0	0	0	0	0	0	0	0	5

[a] Abbreviations: N = number of replicates in scenario; SD = standard deviation.

Appendix 4 continued...

Table A4-2. Numbers of Replicates from Each Table for Bedded Shank Applications

Scenario	N [a]	Minutes (mean ± SD [a])	Number of Replicates from Table			
			6	7	21	22
Tarped Shallow						
Driver	8	331 ± 68	0	4	4	0
Driver Disconnect	4	19.2 ± 12.8	0	0	4	0
Co-pilot	5	326 ± 54	0	2	3	0
Shoveler	7	337 ± 58	0	4	3	0
Tarp Puncher (1-hour)	4	61.2 ± 0.8	0	0	4	0
Tarp Puncher (4-hour)	8	212 ± 43	0	4	4	0
Non-Tarped Shallow						
Driver	5	229 ± 77	2	0	0	3
Driver Disconnect	3	16.7 ± 7.6	0	0	0	3
Pipe Layer (1-hour)	6	60.7 ± 1.7	0	0	0	6
Pipe Layer (4-hour)	6	234 ± 23	0	0	0	6

[a] Abbreviations: N = number of replicates in scenario; SD = standard deviation.

Table A4-3. Numbers of Replicates from Each Table for Drip and Handwand Applications

Scenario	N [a]	Minutes (mean ± SD)	Number of Replicates from Table		
			23	24	25
Tarped Surface Drip					
Applicator	6	520 ± 199	6	0	0
Applicator Disconnect	2	19.0 ± 6.0	2	0	0
Tarp Puncher (1-hour)	5	61.2 ± 1.3	5	0	0
Tarp Puncher (4-hour)	5	252 ± 9	5	0	0
Non-Tarped Buried Drip					
Applicator	6	587 ± 228	0	6	0
Applicator Disconnect	2	12.0 ± 5.0	0	2	0
Handwand Tree Replant					
Applicator (Breathing Zone)	6	253 ± 47	0	0	6
Applicator Disconnect	1	12.0	0	0	1
Applicator (Leg)	6	253 ± 47	0	0	6

[a] Abbreviations: N = number of replicates in scenario; SD = standard deviation.

Appendix 5. Chloropicrin Percent Loss.

Table A5-1. Chloropicrin Percent Loss from a Tarped Broadcast Shank Application [a]

Day	Interval [b]	Loss During Interval (kg) [c]	Minutes	Hours	% Loss [d]	% Loss * Hr [e]	12-hour TWA % loss [f]
	0 to 6	13.63	360	6	1.133	6.80	
	6 to 12	20.53	360	6	1.707	10.329	1.42
	12 to 18	146.99	360	6	12.219	73.312	
0	18 to 24	120.3	360	6	10.000	60.000	11.11
	24 to 30	21.00	360	6	1.746	10.474	
	30 to 36	20.12	360	6	1.672	10.035	1.71
	36 to 42	93.45	360	6	7.768	46.608	
1	42 to 48	104.74	360	6	8.707	52.239	8.24
	48 to 60	19.94	720	12	1.658	19.890	1.66
2	60 to 72	71.93	720	12	5.982	71.781	5.98
	72 to 84	11.52	720	12	0.958	11.491	0.96
3	84 to 96	32.93	720	12	2.737	32.848	2.74
	96 to 108	6.68	720	12	0.555	6.663	0.56
4	108 to 120	15.91	720	12	1.323	15.870	1.32
	120 to 132	1.36	720	12	0.113	1.357	0.11
	132 to 138	1.33	360	6	0.111	0.663	
5	138 to 144	5.45	360	126	0.453	2.718	0.28
	144 to 150	1.42	360	6	0.118	0.708	
	150 to 156	2.84	360	6	0.236	1.416	0.18
	156 to 162	2.66	360	6	0.221	1.411	
6	162 to 168	4.55	360	6	0.378	2.124	0.29
	168 to 180	3.83	720	12	0.318	3.820	0.32
7	180 to 192	16.85	720	12	1.401	16.808	1.40
	192 to 204	1.43	720	12	0.119	1.426	0.12
8	204 to 216	5.31	720	12	0.441	5.297	0.44
	216 to 228	1.89	720	12	0.157	1.885	0.16
9	228 to 240	0.94	720	12	0.078	0.938	0.08
	240 to 252	0.48	720	12	0.040	0.479	0.04
10	252 to 264	1.38	720	12	0.115	1.377	0.11
	264 to 276	0.28	720	12	0.023	0.279	0.02
11	276 to 288	0.97	720	12	0.081	0.968	0.08
	288 to 300	0.35	720	12	0.029	0.349	0.03
12	300 to 312	0.38	720	12	0.032	0.379	0.03

[a] Data from Beard *et al*. (1996), from page 58, page 133 (Table 36), and Appendix I. Application to 7.97 acres.
[b] Hours post-application at which monitoring interval began and ended. Hour 0 started at end of application.
[c] Estimated amount of chloropicrin lost through volatilization during interval, calculated from flux.
[d] Calculated by dividing chloropicrin lost during interval by total mass applied (1,203 kg).
[e] Percent chloropicrin lost in interval multiplied by number of hours in interval.
[f] Time-weighted average percent loss over 12-hour interval.

Appendix 5 continued...

Table A5-2. Chloropicrin Percent Loss from a Non-Tarped Broadcast Shank Application [a]

Day	Interval [b]	Loss During Interval (kg) [c]	Minutes	Hours	% Loss [d]	% Loss * Hr [e]	12-hour TWA % loss [f]
	0 to 6	126.26	360	6	20.319	121.91	
	6 to 12	44.22	360	6	7.116	42.697	13.72
	12 to 18	34.70	360	6	5.584	33.505	
0	18 to 24	28.02	360	6	4.509	27.055	5.05
	24 to 30	41.98	360	6	6.756	40.534	
	30 to 36	24.50	360	6	3.943	23.656	5.35
	36 to 42	13.26	360	6	2.134	12.803	
1	42 to 48	6.78	360	6	1.091	6.547	1.61
	48 to 60	17.02	720	12	2.739	32.868	2.74
2	60 to 72	9.93	720	12	1.598	19.176	1.60
	72 to 84	6.79	720	12	1.093	13.112	1.09
3	84 to 96	4.37	720	12	0.703	8.439	0.70
	96 to 108	2.31	720	12	0.372	4.461	0.37
4	108 to 120	2.71	720	12	0.436	5.233	0.44
	120 to 132	0.21	720	12	0.034	0.406	0.03
5	132 to 144	0.15	720	12	0.024	0.290	0.02
	144 to 156	0.39	720	12	0.063	0.753	0.06
6	156 to 168	0.36	720	12	0.058	0.695	0.06
	168 to 180	0.10	720	12	0.016	0.193	0.02
7	180 to 192	0.00	720	12	0.000	0.000	0.00
	192 to 204	0.10	720	12	0.016	0.193	0.02
8	204 to 216	0.03	720	12	0.005	0.058	0.00
	216 to 228	0.24	720	12	0.039	0.463	0.04
9	228 to 240	0.00	720	12	0.000	0	0.00
	240 to 252	0.05	720	12	0.008	0.0966	0.01
10	252 to 264	0.00	720	12	0.000	0	0.00
	264 to 276	0.00	720	12	0.000	0	0.00
11	276 to 288	0.00	720	12	0.000	0	0.00
	288 to 300	0.06	720	12	0.010	0.1159	0.01
12	300 to 312	0.04	720	12	0.006	0.0772	0.01

[a] Data from Beard *et al*. (1996), from page 57, page 130 (Table 33), and Appendix F. Application to 8.01 acres.
[b] Hours post-application at which monitoring interval began and ended. Hour 0 started at end of application.
[c] Estimated amount of chloropicrin lost through volatilization during interval, calculated from flux.
[d] Calculated by dividing chloropicrin lost during interval by total mass applied (621.4 kg).
[e] Percent chloropicrin lost in interval multiplied by number of hours in interval.
[f] Time-weighted average percent loss over 12-hour interval.

Appendix 5 continued...

Table A5-3. Chloropicrin Percent Loss from a Tarped Bedded Shank Application [a]

Day	Interval [b]	Loss During Interval (kg) [c]	Minutes	Hours	% Loss [d]	% Loss * Hr [e]	12-hour TWA % loss [f]
	0 to 6	12.04	295	5	2.371	11.66	
	6 to 12	25.71	360	6	5.064	30.384	3.85
	12 to 18	51.48	360	6	10.140	60.839	
0	18 to 24	68.15	360	6	13.423	80.540	11.78
	24 to 30	73.55	360	6	14.487	86.921	
	30 to 36	29.65	360	6	5.840	35.040	10.16
	36 to 42	30.43	360	6	5.994	35.962	
1	42 to 48	15.33	360	6	3.019	18.117	4.51
	48 to 60	15.12	720	12	2.978	35.738	2.98
2	60 to 72	8.9	720	12	1.753	21.036	1.75
	72 to 84	4.62	720	12	0.910	10.920	0.91
3	84 to 96	2.63	720	12	0.518	6.216	0.52
	96 to 108	-0.56	720	12	-0.110	-1.324	-0.11
4	108 to 120	2.32	720	12	0.457	5.484	0.46
	120 to 132	1.82	720	12	0.358	4.302	0.36
	132 to 138	0.72	402	7	0.142	0.950	
5	138 to 144	0.64	318	5	0.126	0.668	0.13
	144 to 150	0.3	360	6	0.059	0.355	
	150 to 156	0.4	360	6	0.079	0.473	0.07
	156 to 162	0.55	360	6	0.108	0.650	
6	162 to 168	0.41	360	6	0.081	0.485	0.09
	168 to 180	0.35	720	12	0.069	0.827	0.07
7	180 to 192	0.47	720	12	0.093	1.111	0.09
	192 to 204	0.60	720	12	0.118	1.418	0.12
8	204 to 216	1.09	720	12	0.215	2.576	0.21
	216 to 228	0.15	720	12	0.030	0.355	0.03
9	228 to 240	0.18	720	12	0.035	0.4254481	0.04
	240 to 252	0.14	720	12	0.028	0.3309	0.03
10	252 to 264	0.00	720	12	0.000	0	0.00
	264 to 276	0.36	720	12	0.071	0.8508962	0.07
11	276 to 288	0.23	720	12	0.045	0.54362813	0.05
	288 to 300	0.13	720	12	0.026	0.3073	0.03
12	300 to 312	0.41	720	12	0.081	0.9691	0.08

[a] Data from Beard *et al*. (1996), from page 58, page 132 (Table 35), and Appendix H. Application to 2.96 of 5.92 acres.
[b] Hours post-application at which monitoring interval began and ended. Hour 0 started at end of application.
[c] Estimated amount of chloropicrin lost through volatilization during interval, calculated from flux.
[d] Calculated by dividing chloropicrin lost during interval by total mass applied (507.7 kg).
[e] Percent chloropicrin lost in interval multiplied by number of hours in interval.
[f] Time-weighted average percent loss over 12-hour interval.

Appendix 5 continued...

Table A5-4. Chloropicrin Percent Loss from a Non-Tarped Bedded Shank Application [a]

Day	Interval [b]	Loss During Interval (kg) [c]	Minutes	Hours	% Loss [d]	% Loss * Hr [e]	12-hour TWA % loss [f]
	0 to 6	83.38	360	6	25.343	152.06	
	6 to 12	26.28	360	6	7.988	47.927	16.67
	12 to 18	16.23	360	6	4.933	29.599	
0	18 to 24	7.05	360	6	2.143	12.857	3.54
	24 to 30	6.23	360	6	1.894	11.362	
	30 to 36	4.70	360	6	1.429	8.571	1.66
	36 to 42	2.2	360	6	0.669	4.012	
1	42 to 48	1.4	360	6	0.426	2.553	0.55
	48 to 60	2.41	720	12	0.733	8.790	0.73
2	60 to 72	0.51	720	12	0.155	1.860	0.16
	72 to 84	0.52	720	12	0.158	1.897	0.16
3	84 to 96	0.17	720	12	0.052	0.620	0.05
	96 to 108	0.1	720	12	0.030	0.365	0.03
4	108 to 120	0	720	12	0.000	0.000	0.00
	120 to 132	0.05	720	12	0.015	0.182	0.02
5	132 to 144	0.11	720	12	0.033	0.401	0.03
	144 to 156	0	720	12	0.000	0.000	0.00
6	156 to 168	0	720	12	0.000	0.000	0.00
7	168 to 180	0.03	720	12	0.009	0.109	0.01

[a] Data from Beard *et al*. (1996), from page 57, page 131 (Table 34), and Appendix G. Application to 4.86 of 8.46 acres.
[b] Hours post-application at which monitoring interval began and ended. Hour 0 started at end of application.
[c] Estimated amount of chloropicrin lost through volatilization during interval, calculated from flux.
[d] Calculated by dividing chloropicrin lost during interval by total mass applied (329 kg).
[e] Percent chloropicrin lost in interval multiplied by number of hours in interval.
[f] Time-weighted average percent loss over 12-hour interval.

Appendix 5 continued...

Table A5-5. Chloropicrin Percent Loss From a Chemigation Application [a]

Day	Interval [b]	Loss During Interval (kg) [c]	Minutes	Hours	% Loss [d]	% Loss * Hr [e]	12-hour TWA % loss [f]
	0 to 4	13.9	240	4	8.927	35.71	
	4 to 8	35.4	240	4	22.736	90.94	
	8 to 12	11.8	240	4	7.579	30.315	0.71
	12 to 16	2.86	240	4	1.837	7.35	
	16 to 20	2.42	240	4	1.554	6.217	
0	20 to 24	1.32	240	4	0.848	3.391	1.04
	24 to 28	3.69	240	4	2.370	9.480	
	28 to 32	5.91	240	4	3.796	15.183	
	32 to 36	2.87	240	4	1.843	7.373	0.90
	36 to 40	1.09	240	4	0.700	2.800	
	40 to 44	0.444	240	4	0.285	1.141	
1	44 to 48	0.451	240	4	0.290	1.159	0.87
	48 to 60	2.64	690	11.5	1.696	19.499	1.70
2	60 to 72	0.226	720	12	0.145	1.742	0.15
	72 to 84	0.67	720	12	0.430	5.164	0.43
3	84 to 96	0.397	720	12	0.255	3.060	0.25
	96 to 108	0.547	720	12	0.351	4.216	0.35
4	108 to 120	0.288	720	12	0.185	2.220	0.18
	120 to 132	0.247	720	12	0.159	1.904	0.16
5	132 to 144	0.159	720	12	0.102	1.225	0.10
	144 to 156	0.0758	720	12	0.049	0.584	0.05
6	156 to 168	0.118	720	12	0.076	0.909	0.08
	168 to 180	0.00	720	12	0.000	0.000	0.00
7	180 to 192	0.11	720	12	0.071	0.848	0.07
	192 to 204	0.00	720	12	0.000	0.000	0.00
8	204 to 216	0.159	720	12	0.102	1.225	0.10
	216 to 228	2.67	720	12	1.715	20.578	1.71
9	228 to 240	0.258	720	12	0.166	1.98843931	0.17
	240 to 252	1.24	720	12	0.796	9.5568	0.80
10	252 to 264	0.346	720	12	0.222	2.66666667	0.22
	264 to 276	0.485	720	12	0.311	3.73795761	0.31
11	276 to 288	0.252	720	12	0.162	1.94219653	0.16

[a] Data from Rotondaro, from page 36 and page 723 (Appendix E). Application to 4.50 of 8.67 acres.
[b] Hours post-application at which monitoring interval began and ended. Hour 0 started at end of application.
[c] Estimated amount of chloropicrin lost through volatilization during interval, calculated from flux.
[d] Calculated by dividing chloropicrin lost during interval by total mass applied (155.7 kg).
[e] Percent chloropicrin lost in interval multiplied by number of hours in interval.
[f] Time-weighted average percent loss over 12-hour interval.