Performance of Internal Remedial Treatments on Douglas-Fir Poles: A Large-Scale Field Trial

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Abstract

Internal decay is a common problem in poles or timbers of thin sapwood species. Several internal treatments have been developed to arrest this attack, and these systems are widely used in North America. Although these treatments have been evaluated in numerous independent field trials, there is no single test of all treatments. The objective of this study was to assess the chemical distribution and fungal colonization in Douglas-fir poles treated with each of 13 different internal remedial treatments over a 10-year period. Metam sodium treatments provided the shortest protective period, with little evidence of residual chemical 3 years after treatment. Methylisothiocyanate (MITC) in pure form provided a very high initial flush of active ingredient and a longer protective period extending from 5 to 8 years after treatment. Dazomet, which must decompose to produce MITC, took slightly longer to reach effective levels, but was still present at effective levels 10 years after treatment. Chloropicrin, which has strong interactions with wood, was associated with the highest chemical levels after 10 years. Borates took longer to reach effective levels in the poles and their protective zone was narrower than the fumigants, but boron was still present at effective levels 10 years after application. The results illustrate the different properties provided by each treatment, but also show that all tested remedial treatments were effective within certain limitations.

Pressure treatment of large timbers and poles of thin sapwood species generally produces a shallow shell of protection surrounding the untreated heartwood core (Graham 1983). The treatment remains protective if the barrier remains intact, but most large timbers or poles are treated while their internal moisture contents are still high. These materials can develop deep checks that penetrate beyond the depth of treatment as the wood seasons in service. These checks provide entry pathways for decay fungi and insects that eventually lead to internal decay development. This damage can progress to the point where the pole consists of a well-treated outer shell surrounding a hollow core, necessitating replacement.

Arresting internal decay poses a challenge because the wood that must be protected is highly resistant to preservative treatment. Thus, any supplemental treatment must be capable of moving through this refractory wood at levels capable of killing or at least inhibiting decay organisms and it must remain for an appropriate protective period. The typical inspection/remedial treatment cycle in North America is 7 to 12 years (Mankowski et al. 2002).

The two most common systems for internal remedial treatment are fumigants or water-diffusible compounds. Fumigants are compounds applied as liquids or solids but then volatilize to move as gases through wood. Fumigants are widely used in agriculture for sterilizing soils before planting and were first used in wood for killing fungi present in logs destined for export (Partridge 1961, Jones 1963). However, the first fumigant used, methyl bromide, was unsuitable as an internal treatment because of its difficult handling properties, high toxicity, and short protective period (Ricard et al. 1968). Other treatments were soon identified, including metam sodium, methylisothiocyanate (MITC), dazomet, and chloropicrin (CP). All of these chemicals move well through heartwood and have been found to be highly effective, but have slightly different properties (Hand et al. 1970; Cooper et al. 1974; Graham et al. 1976; Graham 1977; Goodell et al. 1980; Highley and

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Eslyn 1982, 1986; Zabel et al. 1982; Ruddick 1983; Helsing et al. 1984; Morrell and Corden 1986; Wang et al. 1989; Forsyth and Morrell 1993, 1995; Forsyth et al. 1998).

Water-diffusible compounds, typically boron and fluoride, diffuse through wood with moisture and are active against both fungi and insects (Becker 1976; van der Drift et al. 1987; Beauford et al. 1988; Dickinson et al. 1988; Henningsson et al. 1988; Militz 1991; McCarthy et al. 1993; Highley et al. 1994, 1996; Morrell and Schneider 1995b; Powell et al. 1998; Rhatigan et al. 2002; Morrell et al. 2011). Moisture contents above 27 percent are typically required for effective diffusion (Smith and Williams 1969). Fluoride tends to be more biologically active. Although both chemicals can be applied as pastes or liquids, they are most often used in rod form for internal treatment. Boron can be formed into glasslike rods that contain a high level of active boron, whereas fluoride powders are compressed into chalklike rods. These chemicals have been more widely used in Europe, but field trials have shown them to be effective in several North American wood species.

Although all these internal treatments have been evaluated in field tests and many are widely used, there is little comparative performance data using the same timber species with all chemicals applied at the same time. The purpose of this study was to establish a single test of all internal remedial treatments commercially available in North America at the time the test was initiated.

Materials and Methods

Pentachlorophenol-treated Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco) pole stubs (280 to 300 mm in diameter by 2.1 m long) were set to a depth of 0.6 m at a test site near Corvallis, Oregon. The site has a Mediterranean climate characterized by warm, dry summers and cool, wet winters. Three (poles treated with diffusible rods) or four (poles treated with fumigants) steeply sloping treatment holes (19 by 350 mm long) were drilled into the poles beginning at the ground line and moving upward 150 mm and around the pole 120°. The various remedial treatments (Table 1) were added to the holes at the recommended dosage for the pole diameter. The treatment holes were then plugged with removable plastic plugs. Copper naphthenate (2% Cu in diesel oil) was added to all dazomet treatments as an accelerant since liquid Cu is known to accelerate dazomet decomposition (Forsyth and Morrell 1993, 1995; Love et al. 2010). Accelerant was poured onto the top of the dazomet in the treatment holes until the visible fumigant appeared to be saturated, but not so far that the plug could not be safely inserted. No attempt was made to quantify the amount of copper naphthenate added to each treatment hole. Each treatment was replicated on five pole sections. Poles without treatment were installed for both fumigant and water-diffusible treatments.

Chemical movement was assessed 18, 30, 42, 54, 89, and 125 months after treatment by removing increment cores from three equidistant sites beginning 150 mm below ground, at ground line, and 300, 450, and 600 mm above ground line. An additional height of 900 mm above ground line was sampled for fumigant-treated poles in recognition that these chemicals have a greater ability to diffuse upward. The outer, preservative-treated shell of each core was removed (which was usually around 40 mm deep). The next 25 mm and the innermost 25 mm of the core near the pith were retained for chemical analysis using a treatment-appropriate methodology. The remainder of the core was used to assess fungal colonization. The holes were plugged with chromated copper arsenate-treated wood dowels.

Inner and outer core segments from poles treated with chemicals for which MITC is the primary active ingredient were placed into 5 mL of ethyl acetate, extracted for 48 hours at room temperature, and the resulting extract was analyzed by gas chromatography by methods described elsewhere (Zahora and Morrell 1988, 1989). Wood from CP-treated poles was analyzed by placing core segments in 5 mL of hexane, extracting for 48 hours, and analyzing the extract by gas chromatography using an electron capture detector. The extracted core segments were oven-dried at 104°C, weighed, and fumigant content was expressed on a microgram of fumigant per ovendried gram of wood basis.

Borate cores were ground to pass a 20-mesh screen and hot water extracted. The resulting extract was analyzed using the azomethine-H method (American Wood Protection Association [AWPA] 2017a). Fluoride cores were initially hot water extracted and the resulting extract was analyzed using a specific ion electrode and quantified by comparison with known standards (Collins and Kennedy 1998). However, this method proved infeasible because fluoride levels were too low to quantify. Instead, a limited number of samples was ground and analyzed using neutron activation analysis (AWPA 2017b). These results are not presented because the levels were inconsistent over the sampling points.

Table 1.—Internal remedial treatment chemicals evaluated in Douglas-fir poles.

Product[a]	Dose (g/pole)	Common name	Active ingredient	Supplier
DuraFume	280	Dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione	Osmose Utilities Services
SuperFume				Copper Care Wood Preservatives
Ultra-Fume				Viance, Inc., Charlotte, North Carolina
Basamid				BASF, Charlotte, North Carolina
Basamid Rods				
PoleFume	475	Metam Sodium	32.1% sodium *n*-methyldithiocarbamate	AMVAC Chemical Corporation
WoodFume				Osmose Utilities Services
SMDC-Fume				Copper Care Wood Preservatives
MITC-FUME	120	MITC	97% methylisothiocyanate	Osmose Utilities Services
Chloropicrin	475	Chloropicrin	98% trichloronitromethane	Great Lakes Chemicals
Impel Rods	238	Impel	Anhydrous disodium octaborate	Intec, Fort Collins, Colorado
Pole Saver Rods	134	Pole Saver	Disodium octaborate tetrahydrate/sodium fluoride	Preschem Ltd., Melbourne, Australia

[a] MITC = methylisothiocyanate.

Resulting chemical analyses were averaged for the inner and outer 25-mm core segments by distance above or below ground line for the five replicates. Previous tests have shown that variations in chemical levels within a pole are extremely high, making it difficult to assess treatment differences statistically. However, previous studies in our laboratory have shown that decay fungi are generally not cultured from wood where MITC or CP is present at levels above 20 μg/g of dry wood. This level was therefore used as a target level for effective wood protection. Threshold levels for boron were based upon previous studies (Freitag and Morrell 2005).

The data were averaged for each height for a given treatment. ''Heat-mapping'' software was used to represent increasing levels of chemical in a given pole. These heat maps were selected so that dark colors represented levels below threshold for a given chemical and increasingly lighter colors were above threshold. These maps helped illustrate the differences in chemical distribution over time.

The remaining section of each increment core was placed on nonamended malt extract agar and observed for the presence of fungal growth. This growth was examined under a microscope for clamp connections and other characteristics typical of basidiomycetes, which are the main decay agents of wood (Zabel and Morrell 1992). Although other fungi can degrade wood, for the purpose of this discussion, fungi with basidiomycete characteristics were called decay fungi and nonbasidiomycetes were termed nondecay fungi.

Results and Discussion

Chemical levels in most poles were elevated 18 months after treatment and gradually declined over the 125-month test (Table 2). This time interval is a typical remedial treatment cycle for inspection and treatment of poles in North America. Fumigant levels were highest toward the center of poles at any given height, reflecting the tendency for the sloping holes to direct chemical inward. Chemical levels were also highest at or below ground line and declined with distance upward.

Wood samples removed from sodium *n*-methyldithiocarbamate (NaMDC) treatments (PoleFume, SMDC-Fume, and WoodFume) contained MITC levels that were three to five times threshold 18 months after treatment. These levels declined steadily over the next 24 months but were still above threshold at most sampling locations 42 months after treatment. MITC levels continued to decline and were all uniformly below threshold 54 months after treatment (Fig. 1). MITC was virtually nondetectable after 125 months. These findings are consistent with previous NaMDC tests. These formulations contain 32.1 percent NaMDC in water, and as NaMDC decomposes in the presence of organic matter (e.g., wood) it produces a range of sulfur-containing compounds including carbon disulfide, carbonyl sulfide, and, most important, MITC (Turner and Corden 1963).

The theoretical decomposition rate of NaMDC to MITC is 40 percent of the original 32.1 percent, but numerous tests suggest that the rate in wood is actually nearer to 20 percent of the original treatment (Miller and Morrell 1990, Morrell 1994). As a result, NaMDC treatments should produce much lower levels of chemical in wood than any of the other MITC-based systems and retention should be relatively short (Morrell and Corden 1986, Morrell et al. 1998). Some NaMDC users have raised concerns about the potential for this shorter protective period to allow decay fungi to recolonize poles and cause renewed damage before the next 10-year retreatment cycle. However, there is evidence that decay fungi do not recolonize poles quickly and, in some cases, never reach the levels at which they were present before treatment (Graham and Corden 1980, Giron and Morrell 1989). For this reason, there is a substantial time lag between loss of chemical protection and recolonization that permits the use of this treatment.

MITC-FUME-treated poles contained the highest levels of MITC 18 months after treatment, with levels approaching 100 times the threshold 150 mm below ground line and 300 mm above ground. MITC levels have declined steadily since that time but were still well above threshold for protection against fungal attack 89 months after treatment (Fig. 2). MITC levels in the inner zones of cores removed 150 mm below ground line averaged 612 μg/g of wood, over 30 times threshold at 54 months. MITC levels at other locations were somewhat lower, but still three to nine times threshold. MITC levels in poles 89 months after treatment had declined sharply from those at 54 months. Although the levels were above threshold at or below ground line, MITC levels above ground were no longer protective. MITC levels after 125 months were mostly below threshold for fungal protection, indicating that retreatment would be advisable. These results illustrate the excellent properties of this treatment and are consistent with the original field trials showing that protective levels remained in Douglas-fir poles 7 years after treatment (Scheffer et al. 1982; Morrell et al. 1992, 1998; Schneider et al. 1995). These results indicate that MITC-FUME would easily provide protection against renewed fungal attack for 10 years on the basis of the time required for fungi to begin reinvading fumigant-treated poles.

Like NaMDC, dazomet decomposes to produce a range of sulfur-containing compounds, but MITC is the most important. Unlike NaMDC, dazomet is a powder, which sharply reduces the risk of worker contact or spilling. Originally, dazomet decomposition in wood was viewed as too slow to be of use as a remedial pole treatment, but extensive research indicated that the process could be improved by adding copper compounds to the powder at the time of application to accelerate decomposition to MITC (Highley and Eslyn 1986, Forsyth and Morrell 1995). At present, dazomet is commonly applied with a small dosage of oil-borne copper naphthenate.

Dazomet was applied to the test poles as a powder, in rod form, or in tubes along with copper naphthenate to accelerate decomposition (Figs. 3 and 4). MITC levels 150 mm below ground line in poles receiving dazomet powder (dazomet, DuraFume, or UltraFume) 18 months earlier ranged from 8 to 11 times threshold in UltraFume poles, and 7 to 16 times threshold in dazomet poles. In general, MITC levels were well over threshold in all dazomet treatments, although the levels 900 mm above ground line were sometimes below that level. MITC levels were all above threshold 30 and 42 months after treatment, reflecting the ability of this treatment to continue to decompose to produce MITC over time. MITC levels 54 months after treatment were still above threshold at all sampling locations, but the overall levels had declined by 30 to 50 percent over the 12-month interval (Fig. 3). MITC levels after 54 months were still 3 to 11 times threshold. As in previous trials, there was a surge in MITC in dazomet-

Table 2.—Residual methylisothiocyanate (MITC) levels 150 mm above and below ground and up to 300 mm above ground in Douglas-fir poles 18 to 125 months after application of selected remedial treatments.[a]

Treatment	Cu Naph	Months after treatment	Chemical level (μg/g)											
			Height above ground line (mm)											
			−150		0		300		450		600		900	
			inner	outer	inner	outer	inner	outer	inner	outer	inner	outer	inner	outer
Control	–	18	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		30	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (4)	0 (0)
		42	11 (16)	5 (8)	8 (13)	4 (6)	5 (8)	4 (7)	8 (13)	5 (8)	5 (8)	5 (7)	7 (10)	5 (7)
		54	1 (1)	0 (1)	6 (13)	1 (2)	1 (1)	1 (1)	3 (5)	2 (4)	1 (1)	1 (1)	1 (1)	0 (1)
		89	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		125	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 0	0 0	0 0	0 0	0 0	0 0
Dazomet	+	18	**337** (266)	**158** (196)	**289** (322)	**102** (105)	**163** (112)	**151** (119)	**148** (112)	**167** (205)	**107** (99)	**123** (206)	**47** (30)	19 (12)
		30	**253** (257)	**78** (73)	**366** (278)	**78** (60)	**201** (139)	**109** (77)	**165** (102)	**93** (55)	**142** (110)	**106** (95)	**75** (38)	**48** (46)
		42	**270** (297)	**165** (146)	**299** (281)	**196** (176)	**181** (212)	**121** (69)	**128** (66)	**125** (108)	**114** (58)	**106** (103)	**99** (63)	**96** (144)
		54	**102** (86)	**63** (45)	**472** (662)	**76** (74)	**123** (116)	**57** (36)	**90** (70)	**49** (26)	**87** (67)	**51** (39)	**65** (48)	**42** (56)
		89	**139** (126)	**55** (35)	**279** (237)	**62** (57)	**100** (65)	**35** (19)	**54** (28)	**27** (15)	**34** (21)	**25** (28)	**31** (23)	10 (8)
		125	**138** (365)	**38** (41)	**61** (66)	**47** (59)	**76** (128)	**22** (27)	**32** (44)	14 (24)	18 (17)	9 (9)	12 (12)	9 (12)
Dazomet rods	+	18	**283** (260)	**181** (347)	**254** (166)	**51** (73)	**159** (66)	**95** (115)	**147** (55)	**118** (168)	**97** (53)	**53** (69)	**49** (36)	9 (21)
		30	**348** (292)	**149** (169)	**391** (394)	**115** (122)	**220** (90)	**134** (201)	**153** (55)	**84** (64)	**114** (52)	**72** (82)	**79** (37)	**29** (23)
		42	**315** (198)	**171** (145)	**691** (1128)	**176** (129)	**253** (139)	**118** (74)	**170** (53)	**118** (98)	**138** (79)	**85** (71)	**77** (32)	**35** (21)
		54	**233** (256)	**107** (104)	**413** (564)	**107** (95)	**201** (311)	**66** (50)	**105** (96)	**59** (47)	**83** (58)	**80** (82)	**49** (39)	**89** (99)
		89	**113** (62)	**66** (64)	**238** (192)	**61** (77)	**120** (67)	**46** (39)	**77** (51)	**42** (58)	**51** (31)	**24** (24)	**34** (11)	7 (9)
		125	**27** (28)	6 (11)	**40** (43)	15 (27)	**24** (30)	12 (18)	10 (9)	7 (10)	7 (10)	**21** (37)	8 (18)	11 (23)
DuraFume	+	18	**255** (164)	**126** (118)	**160** (87)	**83** (95)	**131** (81)	**82** (79)	**132** (59)	**105** (109)	**99** (86)	**90** (134)	**45** (22)	**27** (37)
		30	**297** (232)	**106** (88)	**333** (359)	**79** (55)	**212** (201)	**72** (44)	**120** (73)	**57** (37)	**92** (51)	**49** (23)	**58** (34)	**32** (18)
		42	**256** (199)	**152** (171)	**243** (150)	**143** (117)	**329** (536)	**87** (43)	**111** (52)	**88** (73)	**76** (38)	**56** (44)	**46** (26)	**36** (29)
		54	**116** (122)	**60** (59)	**134** (131)	**55** (32)	**158** (209)	**54** (44)	**60** (32)	**67** (64)	**68** (54)	**64** (88)	**60** (53)	**68** (97)
		89	**185** (198)	**48** (36)	**146** (104)	**47** (33)	**98** (61)	**41** (39)	**46** (33)	**26** (31)	**21** (20)	17 (18)	16 (12)	3 (5)
		125	**145** (136)	**23** (33)	**130** (108)	**40** (70)	**60** (74)	12 (11)	**36** (29)	13 (12)	13 (16)	8 (12)	10 (14)	3 (6)
Super-Fume tubes	+	18	**173** (152)	**50** (77)	**121** (85)	**46** (46)	**91** (72)	**54** (47)	**60** (22)	**60** (44)	**39** (17)	**38** (30)	**35** (72)	16 (19)
		30	**138** (160)	**42** (42)	**135** (104)	**58** (73)	**83** (40)	**38** (26)	**54** (21)	**31** (15)	**37** (19)	**24** (22)	**25** (10)	12 (11)
		42	**132** (150)	**72** (60)	**157** (244)	**50** (38)	**68** (23)	**39** (26)	**53** (33)	**40** (32)	**44** (21)	**23** (10)	**24** (13)	11 (8)
		54	**120** (211)	**63** (84)	**61** (44)	**36** (18)	**43** (20)	**42** (32)	**30** (12)	**26** (21)	**37** (29)	**40** (67)	**27** (31)	**33** (54)
		89	**87** (100)	**33** (33)	**57** (46)	**25** (40)	**53** (59)	18 (25)	**28** (26)	13 (18)	16 (19)	9 (14)	13 (19)	4 (7)
		125	**27** (28)	**21** (27)	**62** (65)	**25** (29)	**39** (49)	**21** (24)	**26** (18)	19 (19)	17 (11)	14 (26)	14 (23)	9 (16)
UltraFume	+	18	**174** (92)	**239** (324)	**175** (115)	**136** (183)	**168** (83)	**151** (208)	**112** (51)	**113** (134)	**98** (72)	**77** (65)	**59** (69)	**26** (20)
		30	**229** (188)	**318** (821)	**300** (198)	**136** (162)	**195** (85)	**170** (204)	**156** (79)	**103** (112)	**127** (74)	**87** (64)	**76** (47)	**39** (24)
		42	**246** (267)	**206** (163)	**283** (236)	**194** (187)	**246** (152)	**166** (105)	**150** (63)	**125** (81)	**143** (57)	**175** (187)	**78** (47)	**82** (80)
		54	**158** (116)	**131** (126)	**179** (81)	**97** (59)	**119** (89)	**113** (150)	**69** (36)	**211** (530)	**55** (24)	**52** (31)	**39** (19)	**30** (29)
		89	**91** (62)	**59** (57)	**163** (131)	**50** (38)	**102** (102)	**47** (42)	**44** (23)	**42** (37)	**37** (20)	**30** (40)	**20** (15)	10 (10)
		125	**54** (44)	**21** (25)	**111** (112)	**34** (42)	**41** (33)	19 (22)	**20** (14)	13 (12)	11 (9)	8 (8)	2 (4)	0 (1)
MITC-FUME	–	18	**1868** (1682)	**207** (219)	**24710** (88693)	**560** (1335)	**2085** (1906)	**372** (430)	**1574** (2239)	**360** (332)	**840** (673)	**283** (214)	**848** (764)	**235** (208)
		30	**1773** (1871)	**565** (435)	**2328** (1945)	**535** (461)	**1318** (1176)	**412** (323)	**882** (932)	**292** (236)	**904** (1066)	**330** (279)	**662** (589)	**261** (250)
		42	**1210** (1243)	**712** (1569)	**794** (617)	**334** (187)	**491** (311)	**246** (136)	**389** (281)	**184** (107)	**350** (284)	**189** (106)	**369** (250)	**165** (117)
		54	**612** (1472)	**155** (115)	**180** (123)	**150** (155)	**115** (83)	**78** (61)	**107** (70)	**77** (50)	**85** (41)	**68** (51)	**73** (50)	**98** (104)
		89	**66** (75)	**20** (18)	**37** (35)	20 (23)	18 (21)	9 (10)	13 (13)	7 (7)	14 (13)	5 (7)	15 (14)	9 (11)
		125	13 (19)	4 (10)	7 (8)	3 (7)	4 (7)	1 (4)	1 (4)	1 (3)	1 (2)	1 (2)	1 (3)	1 (3)

Table 2.—Continued.

Treatment	Cu Naph	Months after treatment	Chemical level (µg/g) Height above ground line (mm) −150 inner	−150 outer	0 inner	0 outer	300 inner	300 outer	450 inner	450 outer	600 inner	600 outer	900 inner	900 outer
Pol Fume	–	18	**132** (74)	**63** (56)	**661** (1539)	**69** (36)	**149** (104)	**120** (168)	**136** (76)	**123** (111)	**118** (61)	**78** (58)	**65** (29)	**35** (26)
		30	**53** (30)	**47** (49)	**52** (36)	**40** (37)	**50** (23)	**47** (24)	**51** (26)	**39** (20)	**53** (26)	**45** (23)	**41** (22)	**23** (19)
		42	**38** (28)	**21** (14)	**27** (17)	**24** (21)	**34** (24)	16 (7)	**25** (18)	15 (7)	**24** (17)	16 (8)	**20** (9)	14 (7)
		54	14 (20)	8 (12)	18 (22)	11 (18)	8 (15)	3 (1)	3 (2)	3 (2)	3 (1)	4 (2)	8 (13)	4 (2)
		89	1 (2)	0 (0)	1 (2)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	1 (3)	0 (0)	0 (0)	0 (0)
		125	1 (2)	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
SMDC-Fume	–	18	**152** (75)	**74** (55)	**168** (132)	**50** (22)	**135** (75)	**90** (77)	**144** (112)	**71** (52)	**114** (89)	**61** (47)	**72** (51)	**24** (23)
		30	**76** (50)	**48** (27)	**75** (41)	**40** (19)	**64** (28)	**45** (24)	**56** (26)	**37** (19)	**49** (20)	**31** (16)	**52** (37)	**25** (15)
		42	**39** (28)	20 (9)	**36** (21)	**20** (10)	**25** (8)	14 (3)	**26** (12)	13 (4)	**24** (10)	13 (5)	**27** (15)	13 (13)
		54	11 (8)	6 (6)	11 (13)	4 (3)	10 (18)	5 (4)	4 (2)	4 (2)	5 (3)	3 (2)	9 (19)	3 (3)
		89	0 (1)	0 (1)	0 (1)	0 (0)	0 (0)	0 (0)	1 (2)	0 (1)	1 (3)	0 (0)	0 (0)	0 (0)
		125	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Wood Fume	–	18	**187** (125)	**91** (120)	**157** (106)	**74** (54)	**156** (107)	**103** (99)	**127** (79)	**85** (112)	**129** (62)	**100** (112)	**95** (48)	**46** (60)
		30	**68** (52)	**38** (32)	**75** (61)	**45** (45)	**57** (40)	**37** (24)	**53** (34)	**35** (21)	**48** (25)	**33** (26)	**55** (28)	**32** (30)
		42	**53** (24)	20 (22)	**33** (21)	17 (19)	**24** (21)	15 (16)	20 (15)	14 (16)	**25** (24)	13 (13)	**26** (17)	12 (12)
		54	16 (13)	6 (5)	15 (11)	5 (5)	9 (8)	8 (9)	6 (5)	8 (13)	5 (5)	4 (3)	6 (4)	4 (4)
		89	2 (7)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		125	0 0	0 0	1 (2)	0 0	0 0	0 0	1 (5)	0 0	0 0	0 0	0 0	0 0
Chloropicrin	–	18	**37096** (134096)	**6052** (11848)	**16347** (24851)	**18001** (25506)	**22498** (27167)	**12951** (16512)	**9263** (14788)	**6772** (13209)	**3429** (6239)	**606** (853)	**795** (780)	**86** (181)
		30	**12749** (22396)	**4900** (8571)	**1149** (2837)	**1071** (1895)	**6516** (6511)	**1585** (1853)	**424** (1009)	**2307** (5072)	**3582** (4241)	**1129** (1819)	**3691** (11390)	**278** (339)
		42	**6488** (6654)	**2904** (3671)	**4606** (3245)	**1257** (2437)	**3438** (2753)	**4059** (5007)	**1546** (1472)	**1363** (1131)	**1720** (1489)	**678** (837)	**1639** (1990)	**310** (560)
		54	**2317** (1768)	**267** (413)	**1808** (1503)	**331** (375)	**1023** (1088)	**226** (295)	**867** (931)	**276** (376)	**984** (1040)	**381** (621)	**387** (509)	**604** (1219)
		89												
		125	**3492** (3965)	**3243** (6665)	**1335** (1210)	**889** (2074)	**723** (749)	**337** (507)	**1324** (2516)	**369** (619)	**613** (780)	**345** (393)	**202** (219)	**451** (411)

[a] Numbers in parentheses represent 1 standard deviation around the mean of 15 replicates. Numbers in bold type are above the toxic threshold, 20 µg MITC/g dry wood, 20 µg chloropicrin/g dry wood.

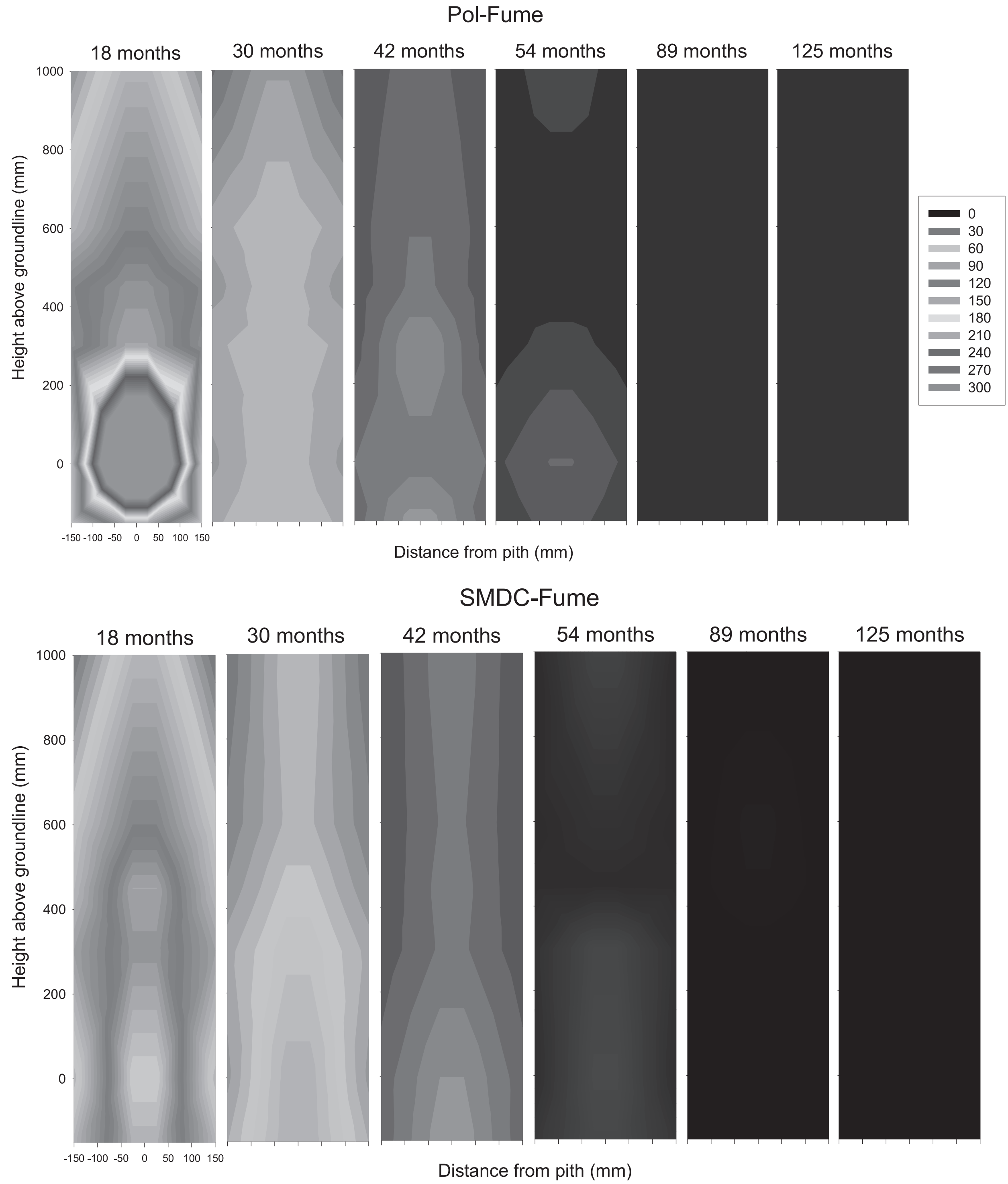

Figure 1.—Methylisothiocyanate (MITC) levels in Douglas-fir poles 18 to 125 months after application of sodium n-*methyldithiocarbamate. Values are presented in a gray scale where black represents levels below the threshold for fungal attack and increasingly lighter shades represent higher levels. See Table 1 for source of chemicals.*

treated poles that was attributed to periods of elevated rainfall and increased wood moisture content, thereby enhancing decomposition of residual dazomet in the treatment holes. It is impossible to predict when this occurs during testing, but MITC levels remained more than sufficient to provide protection against fungal attack in all dazomet treatments. MITC levels 89 months after application of all three dazomet systems were above threshold from below ground line to 600 mm above ground line. Overall levels were continuing to decline, but MITC concentrations remained three to six times threshold at many locations. MITC levels in poles 125 months after treatment remained above threshold 300 mm below ground to 300 mm above ground. MITC levels were more variable above 300 mm,

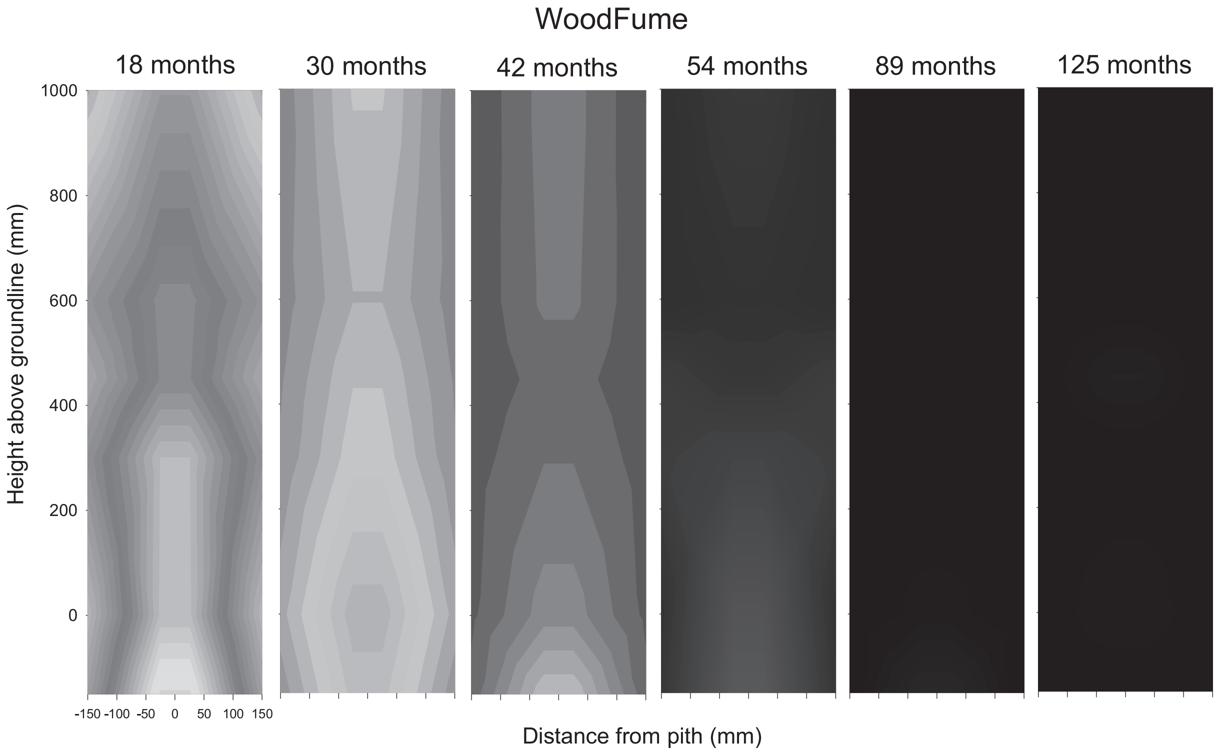

Figure 1.—Continued.

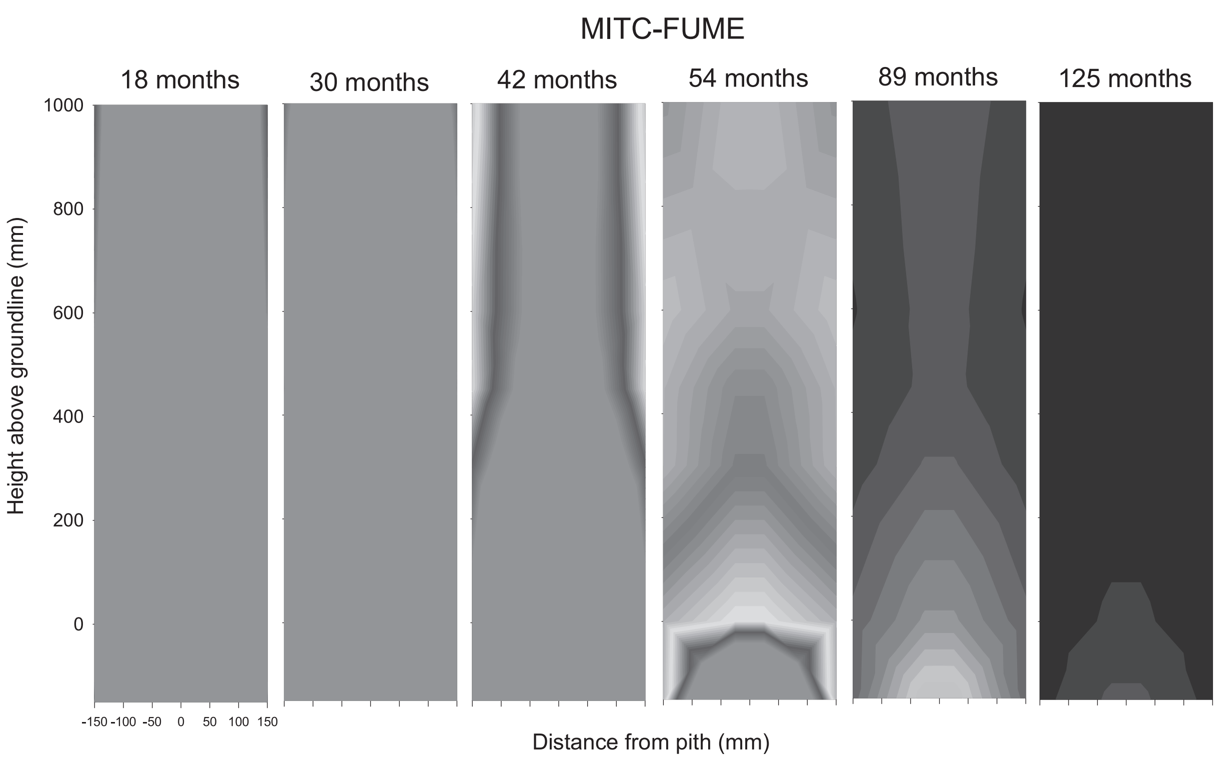

Figure 2.—Methylisothiocyanate (MITC) levels in Douglas-fir poles 18 to 125 months after application of MITC-FUME. Values are presented in a gray scale where black represents levels below the threshold for fungal attack and increasingly lighter shades represent higher levels. See Table 1 for source of chemicals.

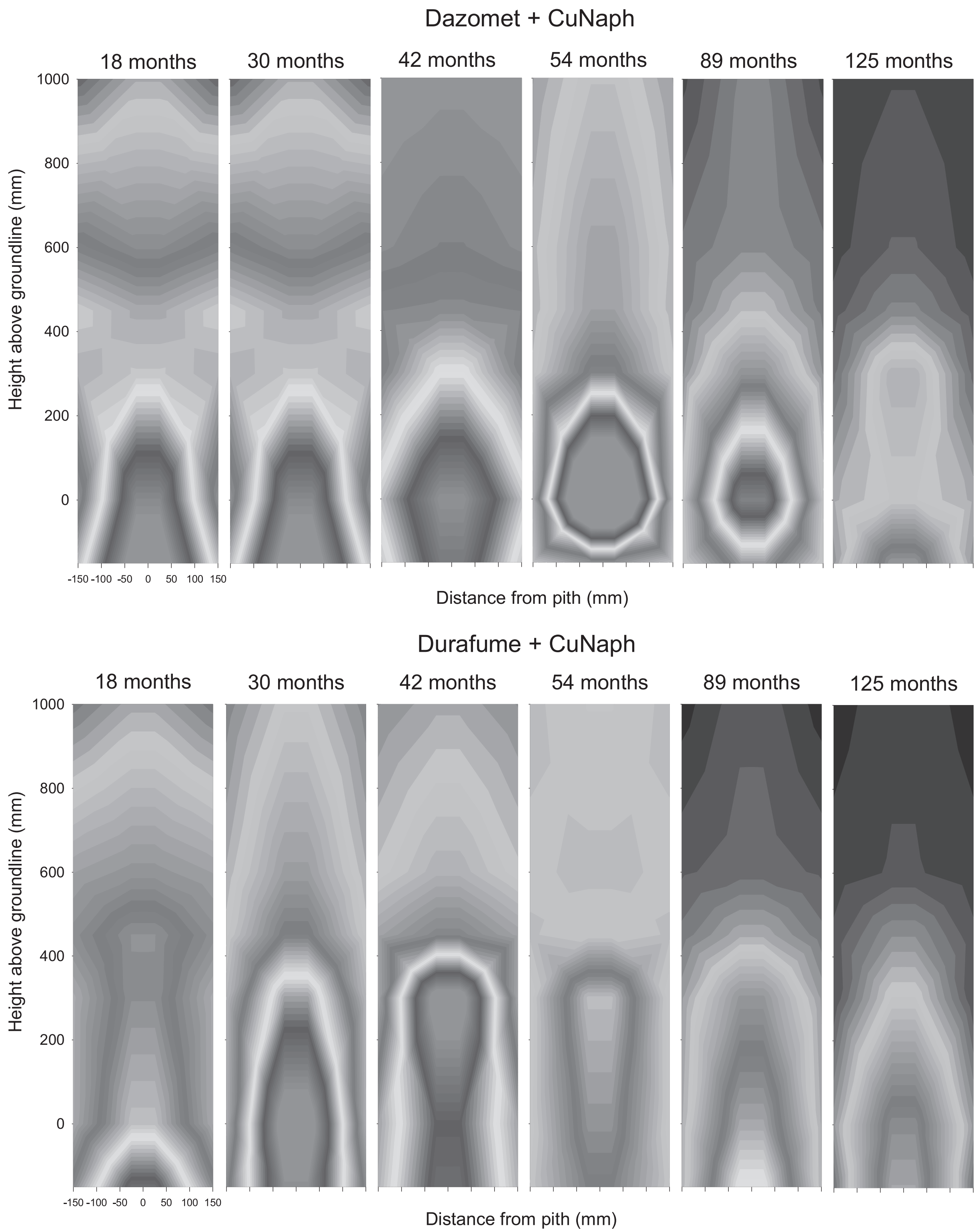

Figure 3.—Methylisothiocyanate (MITC) levels in Douglas-fir poles 18 to 125 months after application of dazomet powder. Values are presented in a gray scale where black represents levels below the threshold for fungal attack and increasingly lighter shades represent higher levels. See Table 1 for source of chemicals.

but many areas still contained protective levels of chemical. These results are also consistent with previous field trials and indicate that this system will provide at least 10 years of protection. There also appeared to be little difference in performance between the three dazomet treatments.

MITC levels in poles receiving dazomet in either rod or tube form (Super-Fume tubes) tended to be lower than powdered treatments but were still above threshold at all sampling points below ground line and up to 900 mm above ground line. Chemical levels near the surface at 900 mm

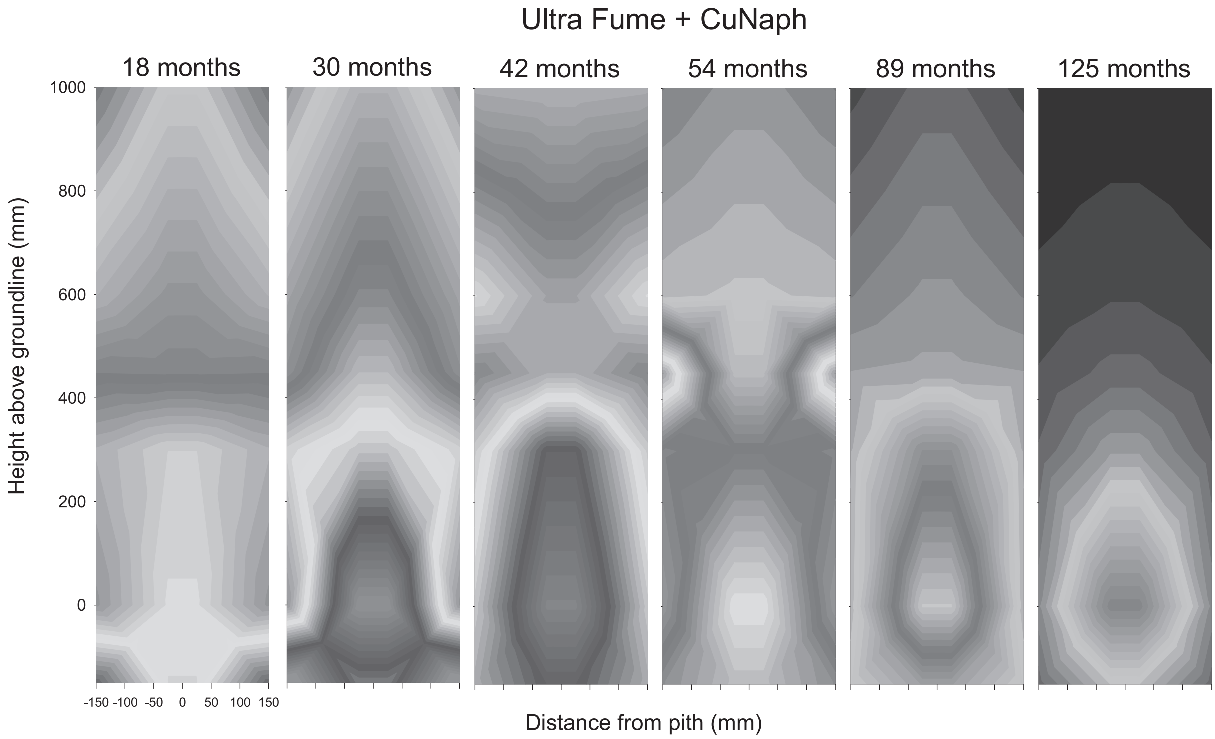

Figure 3.—Continued.

were more variable than in the powdered treatments (Fig. 4). The rods and tubes may restrict contact between wood and chemical, creating the potential for reduced decomposition. There were negligible differences in MITC levels between poles receiving powdered or rod dazomet for most of the test. Tubes appeared to have a greater effect on MITC release, with consistently lower MITC levels than the other dazomet-based systems; however, levels remained 1.5 to 6 times threshold at 54 months at all sampling locations. It is possible that copper naphthenate interactions with the dazomet were more limited by the tubes. These results indicate that although tubes slow MITC release, this did not result in chemical levels below threshold at 54 months. The results at 89 months indicated that MITC levels continued to decline in poles treated with either a rod or tube system but were still above threshold up to 300 mm above ground line, then declined below threshold higher up the pole. As in previous inspections, MITC levels tended to be slightly lower in poles receiving tubes than rods. Dazomet rods appeared to produce MITC levels that were like those found with powder for the first 54 months. MITC levels after that time tended to be slightly lower in poles receiving either rods or tubes and were approaching threshold at 125 months. Results indicate that dazomet rod or tube systems would provide protection using a typical 10-year inspection cycle.

These results with MITC-based fumigants have supported previous tests done on individual systems as they were developed. In general, results show that metam sodium provided the shortest protective period, whereas MITC-FUME and dazomet provided longer-term protection consistent with a typical pole retreatment cycle.

CP levels in poles were more than 2,000 times the 20 μg per ovendried gram of wood threshold in the inner zone of poles below ground 18 months after treatment. Levels declined slightly 30 months after treatment but remained extremely high. CP levels declined 42 months after treatment, but remained 17 to 350 times threshold, and were still 13 to 100 times threshold 54 months after treatment (Fig. 5). CP was not analyzed 89 months after treatment but was analyzed again after 125 months. CP levels were 10 to 150 times threshold above ground line. Unlike MITC, CP has strong chemical interactions with wood, which result in much longer residence times (Goodell et al. 1980, Peralta and Morrell 1992). We have found detectable CP in poles 20 years after treatment, and the results in this study are consistent with a long residual protective period for this fumigant (Morrell and Corden 1986, Morrell and Scheffer 1995, Schneider et al. 1995).

Boron-based internal remedial treatments have been available in Europe since the late 1970s but were not introduced into the United States until much later (Becker 1976, Henningsson et al. 1988, Peylo and Bechgaard 2001). Unlike fumigants, which diffuse as gases, boron moves with moisture. Generally, wood moisture levels must be above the fiber saturation point for diffusion to occur. Elevated moisture levels should be present at ground line in most poles, except under drier conditions where moisture tends to be deeper in the soil. The threshold for boron for protection against internal decay has been calculated at 0.5 kg/m^3 boric acid equivalents (Freitag and Morrell 2005).

Boron levels in poles receiving either Impel Rods or Pole Saver Rods tended to be below threshold 300 mm above ground line, regardless of sampling time or core position (inner/outer; Table 3). Although boron is water diffusible, it has a limited ability to diffuse upward. Boron levels 150 mm below ground line and at ground line were above threshold in the inner zone for both Impel Rod- and Pole Saver Rod-treated poles 18 months after treatment, but below threshold in the outer zone (Fig. 6). The difference

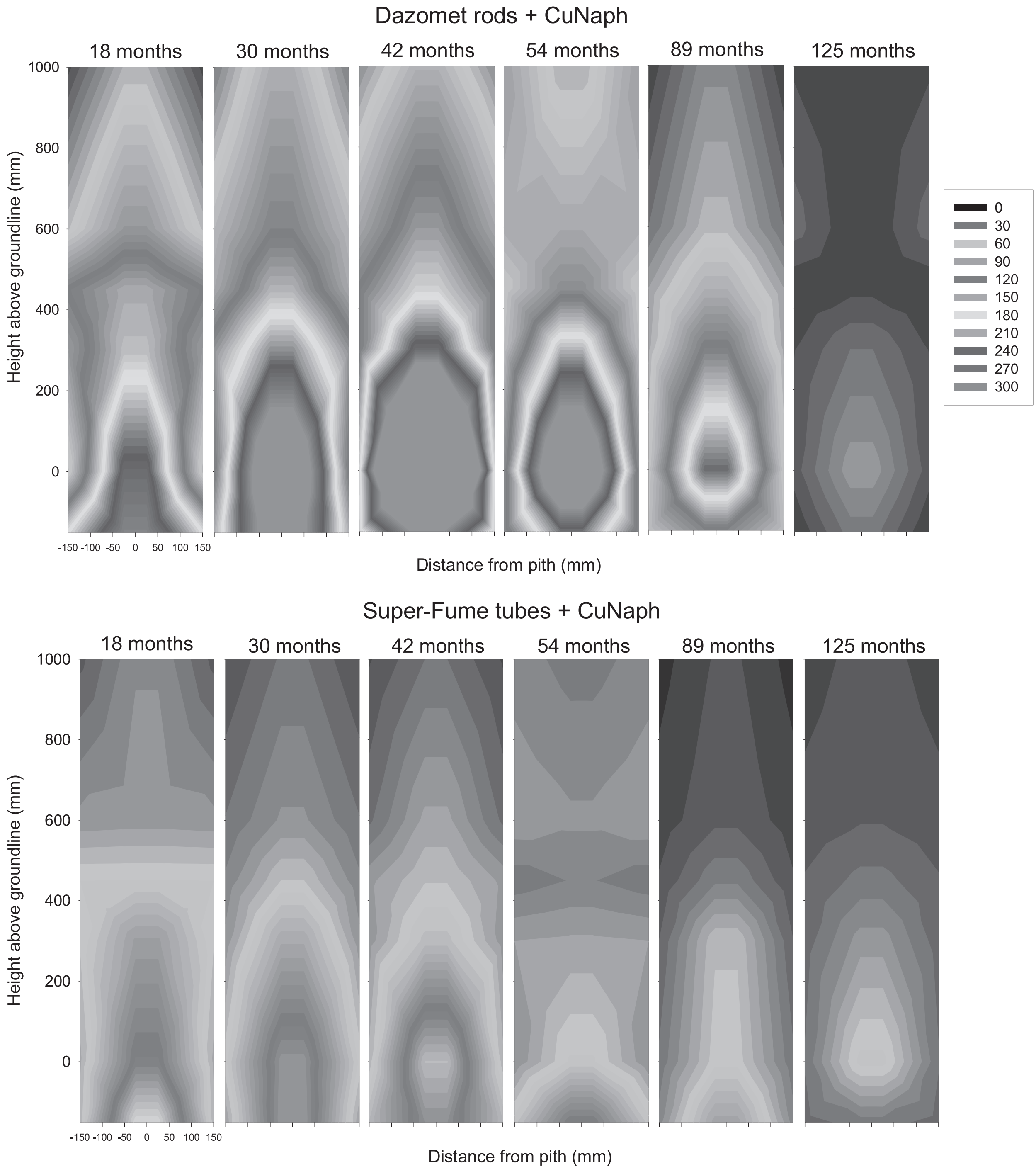

Figure 4.—Methylisothiocyanate (MITC) levels in Douglas-fir poles 18 to 125 months after application of dazomet in rods or encapsulated in tubes. Values are presented in a gray scale where black represents levels below the threshold for fungal attack and increasingly lighter shades represent higher levels. See Table 1 for source of chemicals.

again reflects the tendency of the sloping treatment holes to direct chemical downward toward the center of the pole. Boron levels were above threshold for both inner and outer zones 30 months after treatment with either rod system, but still below threshold in the outer zone 150 mm below ground line. Boron levels were all well above threshold both below and at ground line 42 and 54 months after treatment (Fig. 6). Boron levels in pole sections treated with either rod system were still well above threshold in the inner zones at or below ground line 89 and 125 months after treatment, but declined below threshold in the outer zones of poles receiving Pole Saver Rods. Boron was at threshold 300 mm above ground line at only 18 or 42 months in the inner zone of poles receiving Impel Rods.

Boron levels in poles treated with Impel Rods and Pole Saver Rods were similar near ground line, whereas boron levels were higher in Impel Rod-treated poles in the inner zone below ground. An alternative approach to examining

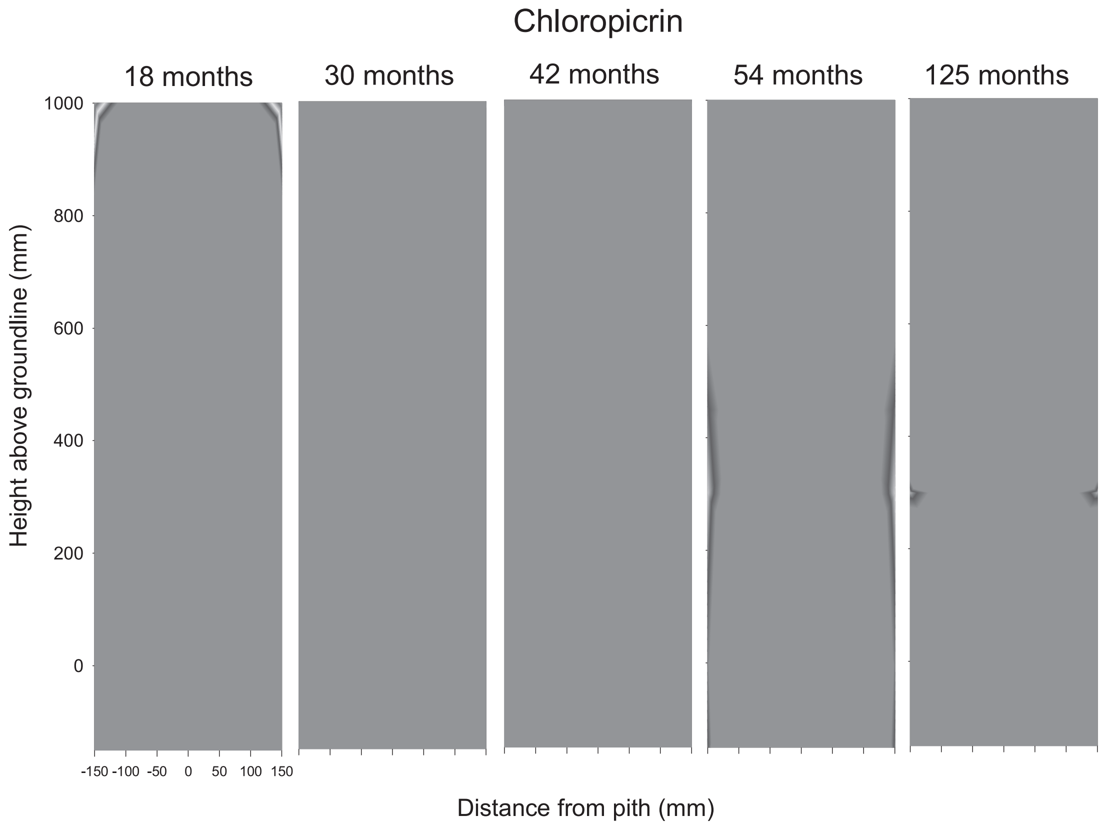

Figure 5.—Chloropicrin (CP) levels in Douglas-fir poles 18 to 125 months after application of CP. Values are presented in a gray scale where black represents levels below the threshold for fungal attack and increasingly lighter shades represent higher levels. See Table 1 for source of chemicals.

boron distribution would be to look at the inner zones at ground line or below ground over the test period (Fig. 6). The inner zone is likely to present a more stable environment for moisture that would facilitate boron movement over time. Boron levels below ground in the inner zones of poles treated with Pole Saver Rods remained low for the entire exposure period, whereas they were at very high levels at ground line early in the exposure period and then declined over time. Soil moisture levels at this test site are high during winter, which should facilitate boron loss from poles over time, especially below ground. Boron levels in poles treated with Impel Rods rose between 18 and 30 months 150 mm below ground line, then steadily declined over time. However, boron levels were more than

Table 3.—Boron levels at various distances above and below the ground line in Douglas-fir poles 18 to 125 months after application of Impel or Pole Saver Rods.

		Residual boron content (kg/m^3 B_2O_3)[a]									
		150 mm below ground line		Ground line		+300 mm		+450 mm		+600 mm	
Treatment	Time (mo)	Inner	Outer	Inner	Outer	Inner	Outer	Inner	uter	Inner	Outer
Impel	18	**2.59**	0.37	**7.68**	0.16	0.02	**0.97**	0.02	0.02	0.02	0.00
	30	**6.67**	0.39	**1.30**	**2.14**	0.16	0.15	0.07	0.10	0.07	0.05
	42	**5.49**	**0.98**	**6.30**	**3.09**	**0.53**	**0.72**	0.09	0.17	0.07	0.08
	54	**3.34**	**1.12**	**3.57**	**0.84**	0.47	0.13	0.12	0.09	0.06	0.04
	89	**1.91**	**3.95**	**3.16**	**2.25**	**0.76**	0.00	0.06	0.00	0.00	0.00
	125	**4.00**	**3.13**	**2.99**	**3.50**	**0.07**	0.24	0.00	0.23	0.00	0.25
Pole Saver	18	**0.84**	0.14	**7.50**	**0.61**	0.00	0.04	0.02	0.06	0.02	0.03
	30	**1.54**	0.31	**4.44**	**1.28**	0.18	0.18	0.12	0.09	0.09	0.07
	42	**1.24**	**1.02**	**1.73**	**1.03**	0.13	0.16	0.11	0.11	0.13	0.11
	54	**0.74**	**0.53**	**3.56**	**1.17**	0.15	0.05	0.06	0.00	0.05	0.00
	89	**0.72**	0.18	**1.34**	0.44	0.01	0.00	0.08	0.00	0.00	0.07
	125	0.23	0.14	**1.72**	0.41	0.27	0.00	0.00	0.22	0.05	0.10

[a] Values represent means of three samples per height from each of five poles per treatment. Figures in bold are above the threshold for protection against internal fungal attack (0.6 kg/m^2). Inner represents the innermost 25 mm of the core, whereas outer represents the 25 mm inside the preservative-treated zone.

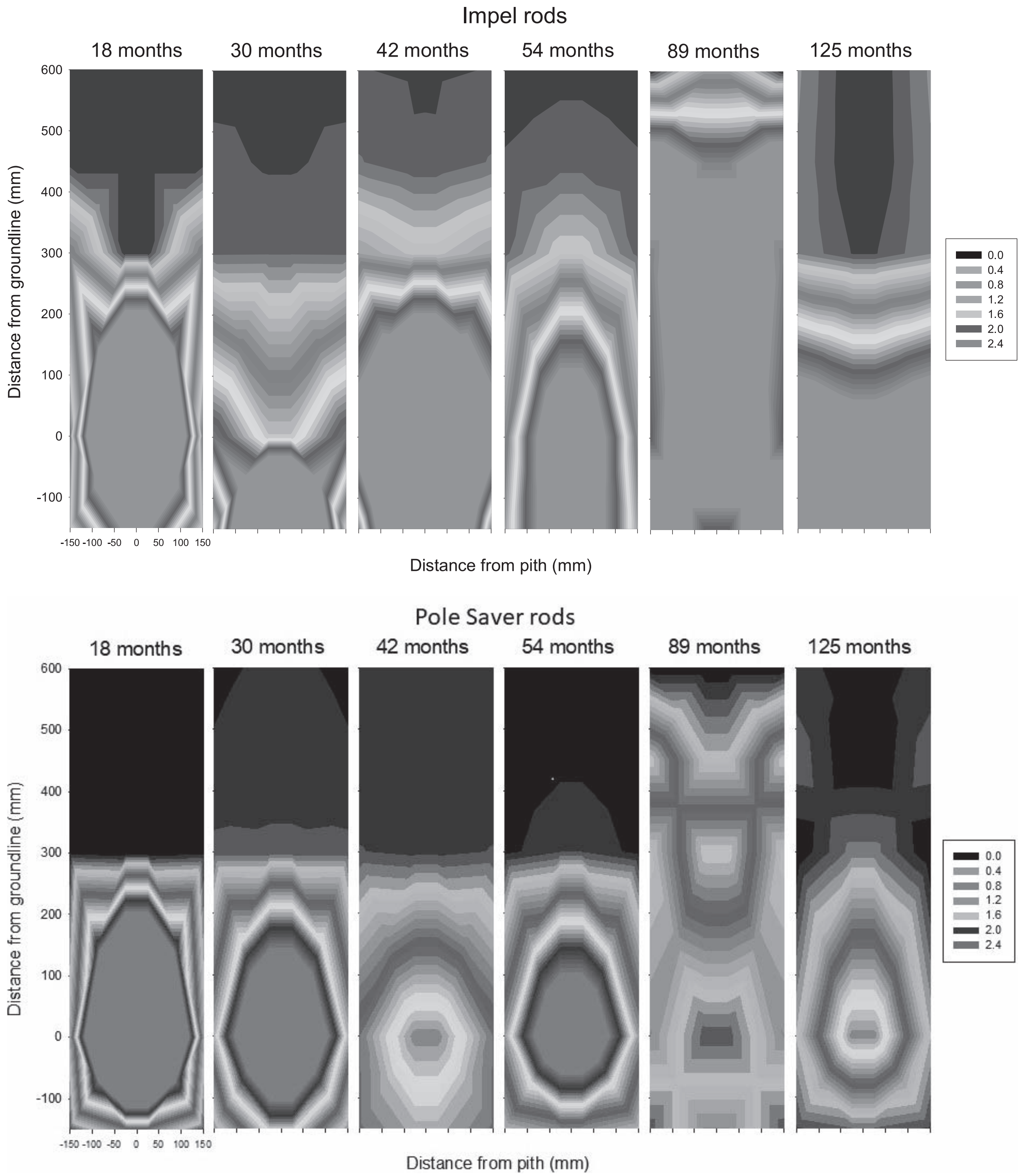

Figure 6.—Boron levels in Douglas-fir poles 18 to 125 months after application of fused boron rods or a boron/fluoride rod. Values are presented in a gray scale where black represents levels below the boron threshold for fungal attack and increasingly lighter shades represent higher levels.

two times higher than those found in Pole Saver Rod poles. Boron levels at ground line in Impel Rod-treated poles tended to vary more widely throughout the test but were more than twice those found in Pole Saver poles at the same locations. Impel Rods represent a highly densified boron delivery system, whereas Pole Saver Rods are less dense and therefore have less chemical to deliver. Our results reflect those differences, although it is important to note that boron levels in poles treated with both systems were well over the protective level 89 months after treatment. The overall trends indicated that boron-based systems were producing protective levels within the ground-line zone, but diffusion above this zone was very limited.

The incidence of decay fungi was high in nonremedially treated control poles, especially at or below ground line (Table 4). Isolation levels were also higher in poles treated

Table 4. —Degree of fungal colonization (%) above and below ground in Douglas-fir poles 18 to 125 months after internal remedial treatment with water-diffusible rods or fumigants.[a]

			Height above ground line (mm)													
			−150		0		300		450		600		1,000		Pole	
Treatment	Cu naph	Months after treatment	DF	NF	DF	NF	DF	NF	DF	NF	DF	NF	DF	NF	DF	NF
Fumigant control	−	18	33	17	17	0	0	0	0	0	0	0	0	0	8	3
		30	33	50	33	50	17	17	0	17	0	17	0	0	14	25
		42	50	50	50	50	50	50	33	50	33	17	0	50	36	44
		54	22	11	33	0	11	0	33	0	33	0	22	0	26	2
		89	33	56	56	56	56	33	56	11	44	22	22	44	44	37
		125	67	100	67	89	56	22	44	56	44	78	0	56	46	67
Dazomet	+	18	0	7	0	0	7	13	0	7	0	7	0	7	1	7
		30	0	0	0	0	0	0	0	7	0	0	0	0	0	1
		42	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		54	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		89	0	0	0	7	0	0	0	0	0	0	0	7	0	2
		125	0	20	7	20	7	0	0	0	0	13	0	13	2	11
Dazomet rods	+	18	0	0	0	7	0	0	0	0	0	0	0	7	0	2
		30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		42	0	0	0	7	0	0	0	0	0	0	0	0	0	1
		54	0	0	0	0	0	0	0	0	0	7	0	0	0	1
		89	0	7	0	0	0	0	0	0	0	0	0	0	0	1
		125	0	33	0	13	0	0	0	0	0	7	0	7	0	10
DuraFume	+	18	0	7	0	7	0	0	0	0	0	7	0	7	0	4
		30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		42	0	0	0	7	0	0	0	7	0	0	0	0	0	2
		54	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		89	0	0	0	7	0	7	7	7	0	0	0	0	1	3
		125	13	33	0	7	0	20	0	0	0	13	0	0	2	12
MITC-FUME	−	18	0	0	0	13	0	0	0	0	0	0	0	0	0	2
		30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		42	0	0	0	7	0	0	0	0	0	0	0	0	0	1
		54	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		89	0	7	0	0	0	0	0	0	0	0	0	0	0	1
		125	7	40	0	33	0	33	7	40	7	33	0	7	3	31
Pol Fume	−	18	0	0	0	7	0	7	0	13	0	0	0	20	0	8
		30	0	0	0	13	0	0	0	0	0	0	0	7	0	3
		42	7	7	0	0	7	7	0	7	7	7	0	0	3	4
		54	0	7	0	0	0	0	0	0	0	0	0	0	0	1
		89	0	60	0	87	27	27	40	27	27	7	0	40	16	41
		125	33	47	40	47	33	33	33	53	33	40	33	60	34	47
SMDS-Fume	−	18	0	0	0	13	0	7	0	7	0	13	0	7	0	8
		30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		42	0	0	0	0	0	7	0	0	0	0	0	0	0	1
		54	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		89	0	67	7	73	0	13	0	27	0	40	0	20	1	40
		125	0	87	7	73	20	53	7	47	0	40	0	73	6	62
Super-Fume tubes	+	18	0	0	0	0	0	13	0	7	0	0	0	7	0	4
		30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		42	0	7	0	0	0	7	0	7	0	7	0	0	0	4
		54	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		89	7	0	0	0	0	20	0	13	0	0	0	0	1	6
		125	0	20	0	20	0	13	0	0	7	0	0	7	1	10
UltraFume	+	18	0	0	0	0	0	20	0	7	0	7	0	0	0	6
		30	0	0	0	0	0	0	0	7	0	0	0	7	0	2
		42	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		54	0	0	0	0	0	0	0	7	0	0	0	0	0	1
		89	0	13	0	0	0	0	0	0	0	0	0	0	0	2
		125	0	7	0	7	0	13	0	7	0	7	0	20	0	10
WoodFume	−	18	0	0	0	0	0	0	0	0	0	20	0	7	0	4
		30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		42	0	0	0	0	0	0	0	20	0	7	0	0	0	4
		54	0	0	0	7	0	0	0	0	0	0	0	0	0	1
		89	0	47	0	33	7	27	13	13	0	27	7	7	4	26
		125	13	67	7	67	13	73	33	60	7	60	7	47	13	62

Table 4. —Continued.

			Height above ground line (mm)													
			−150		0		300		450		600		1,000		Pole	
Treatment	Cu naph	Months after treatment	DF	NF	DF	NF	DF	NF	DF	NF	DF	NF	DF	NF	DF	NF
Chloropicrin		18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		30	0	7	7	0	0	0	0	0	0	0	7	0	2	1
		42	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		54	0	27	0	7	0	7	0	0	0	0	0	0	0	7
		89	0	13	0	13	0	0	0	0	0	7	0	13	0	8
		125	0	60	0	33	7	33	0	40	0	20	0	33	1	37
Diffusible Control		18	0	0	14	0	0	0	0	0	0	0	n/a		3	0
		30	22	56	33	11	0	22	0	0	0	22			11	22
		42	33	67	33	67	33	33	22	44	0	44			24	51
		54	0	0	0	0	0	0	0	0	0	0			0	0
		89	0	67	0	56	11	22	0	56	11	56			4	51
		125	17	67	33	50	0	33	0	50	0	17			10	36
Impel rods		18	0	7	0	8	0	18	0	8	0	7	n/a		0	10
		30	7	47	0	7	0	27	7	33	0	47			3	32
		42	0	67	0	27	7	60	13	60	7	60			5	55
		54	0	0	0	0	7	0	0	0	0	0			1	0
		89	0	60	0	27	20	67	40	40	7	53			13	49
		125	0	40	0	20	33	47	27	47	13	53			15	41
Pole Saver rods		18	0	0	0	0	0	0	0	0	0	0	n/a		0	0
		30	0	67	0	0	0	33	0	44	0	44			0	38
		42	0	78	0	56	0	78	0	78	0	78			0	73
		54	0	0	0	0	0	0	0	0	0	0			0	0
		89	0	44	0	56	0	22	0	44	11	33			2	40
		125	0	22	0	22	0	56	0	67	0	56			0	44
FLUROD		18	0	0	0	0	0	20	0	40	0	13	n/a		0	15
		30	0	13	0	0	0	47	0	60	0	60			0	36
		42	0	20	0	20	0	33	0	20	0	53			0	29
		54	0	0	0	0	0	0	0	7	0	0			0	1
		89	0	47	0	20	0	27	0	13	7	20			1	25
		125	7	60	0	60	0	53	0	53	7	40			3	53

[a] DF = percentage of cores containing decay fungi; NF = percentage of cores containing nondecay fungi; MITC = methylisothiocyanate; SMDS = sodium *n*-methyldithiocarbamate.

with metam sodium systems (PoleFume, SMDS Fume, or WoodFume), reflecting the relatively short-term protection afforded by this fumigant. Isolations were highest in poles treated with PoleFume in the 300- to 900-mm zone above ground line. This zone is consistent with the area where fumigant is likely to dissipate most quickly after treatment. Decay fungi were also isolated sporadically from poles treated with Super-Fume or DuraFume, but levels were low and showed no evidence of a colonization pattern. One decay fungus was isolated from a CP-treated pole, which was interesting given the extraordinarily high levels of residual fumigant.

Decay fungi were also isolated from cores removed from Impel Rod and Pole Saver Rod poles; however, isolation levels were extremely low. Decay fungi were more frequent beginning 300 mm above ground line in Impel Rod-treated poles (Table 4). Water-diffusible systems tend to remain relatively close to the point of application and should not move upward for appreciable distances. Isolation of decay fungi above the application point is consistent with these tendencies and illustrates the need to reconsider application patterns for water-diffusible treatments because they are unlikely to diffuse upward to provide protection. Decay fungi tend to be less common above ground, but can be a problem in areas where wind-driven rain tends to create conditions suitable for aboveground decay (Morrell and Schneider 1995a).

Conclusions

All of the remedial treatments evaluated produced fungitoxic levels of chemical in wood for at least 4 years and most provided much longer protective periods. The protective zone tended to extend farther above the ground line in poles treated with fumigants, but water-diffusible treatments still provide protection around the ground line. The results provide comparative data for those contemplating the use of these treatments for protecting Douglas-fir poles from internal fungal attack.

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