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by

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ABSTRACT

This report presents the results from the NWPC (Nordic Wood Preservation Council) marine trials started in 1972 and 1976. The trials are carried out according to the NWPC Standard No. 1.4.2.2./73 "Marine test - a test against marine wood boring organisms in sea water". The test site is Kristineberg Marine Biology Station on the west coast of Sweden. The wood blocks used in the trials were made from sapwood of European redwood (**Pinus sylvestris** L.). European beech (**Fagus sylvatica** L.), European birch (**Betula** spp.) and Norway spruce (**Picea abies** (L.) Karst) were also used to a minor extent. In all, 19 water-borne wood preservatives were tested. The preservatives consisting of copper-chrome, copper-chrome-arsenic, copper-chrome-boron, copper-chrome-phosphorus and tributyltin oxide gave best performance. The ammoniacal copper preservatives failed to protect the wood against marine borers.

Key words: Marine wood borers, wood preservatives, copper-chrome, copper-chrome arsenic, copper-chrome-boron, copper-chrome-fluorine, copper-chrome-phosphorus, tributyltin oxide, ammoniacal copper preservatives, softwood, hardwood.

INTRODUCTION

In 1972 an extensive test was started to evaluate the effectiveness of various water-borne preservatives against marine borers. The Kristineberg Marine Biology Station on the Swedish west coast (Figure 1) was chosen as test site. Results after the first 2.5 years were reported by Norman and Henningsson (1975), and after 6.5 years by Henningsson and Norman (1979, 1980). Further tests with water-borne preservatives were installed in 1976. Results from the two tests were reported by Bergman **et al.** (1981). This report deals with the same tests which have now been exposed for 13 and 16 years respectively.

Biological data

At Kristineberg at the depth (1 - 6 m) where the samples are exposed, there are normally two species of molluscan borer of the family Teredinidae, (i.e. **Teredo navalis** and **Psiloteredo megotara**) and one species of crustacean borers, (i.e. **Limnoria lignorum**) (Henningsson and Norman 1979, 1980).

Footnote

This report was originally prepared (Document IRG/WP/4162) for and presented at the 21 st Annual Meeting of the International Research Group on Wood Preservation in Rotorua, New Zealand, in May 1990.

Figure 1. Map showing the location of Kristineberg Marine Biology Station and the southern limits - Mölle and Klagshamn - for the two Teredinid borers. (Henningsson and Norman 1979, 1980).

In 1972 - 1976 the population density of the molluscan borers was registered at Kristineberg. With the exception of 1974, there was a high population density of **T. navalis** during that period. The density of the population of **P. megotara** has always been considerably lower than **T. navalis**. The highest population density of **P. megotara** was registered in 1974 (Henningsson and Norman 1979, 1980).

T. navalis settles between June and September and **P. megotara** between June and August. In the coldest months of the year, when the water temperature drops below +5.0°C, the growth of **T. navalis** ceases while **P. megotara** continues to grow. After 18 months **T. navalis** can reach a length of 270 mm. **P. megotara** can reach a length of 224 mm already at the age of about 6 months (Norman 1976).

Along the west coast of Sweden **T. navalis** is common as far as Mölle in the south (Figure 1). Further south it decreases rapidly in number and Klagshamn, south of Malmö is the southernmost site at which an observation has been made. **P. megotara** also decreases in a similar manner along the west coast. The southernmost site at which this species has been observed is Mölle. **T. navalis** and **P. megotara** are also known to decrease in number with increasing water depth (Norman 1977).

Hydrographical data of the test site

Normally the salinity of the water at Kristineberg varies between 20 and 30 °/oo. The surface water temperature is at its lowest from January to March (-3 to -1°C) and at its highest in July and August (+16 to 20°C) (Norman and Henningsson 1975).

MATERIALS AND METHODS

The marine trials were carried out according to the NWPC (Nordic Wood Preservation Council) Standard No. 1.4.2.2./73 "Marine test - a test against marine wood boring organisms in sea water" (Anon. 1973). The wood blocks used in the trials were unplaned and had a size of 25 x 75 x 200 mm. A hole of 25 mm diameter was drilled in the middle of each block for installation of the blocks on frames. Most of the blocks in both trials were made from sapwood of European redwood (**Pinus sylvestris** L.). In the 1972 trial some blocks were made from European beech (**Fagus sylvatica** L.) and European birch (**Betula** spp.). Blocks made from water-stored sapwood of Norway spruce (**Picea abies** (L.) Karst) were also included in the 1976 trial.

The wood blocks were impregnated according to a full cell process as described in NWPC Standard 1.4.2.2./73. In the 1972 trial the European redwood samples were treated with 13 different preservatives. Their chemical formulation is listed in Table 1. Samples of European beech and birch were treated with two preservatives (Table 3). In the 1976 trial the European redwood samples were treated with 9 preservatives which are listed together with their chemical formulations in Table 4. Water-stored samples of Norway spruce were treated with one preservative (Table 6). Some of the preservatives used in 1972 were also used in 1976. In all 19 different water-borne preservatives were tested.

Five different concentrations of each preservative were used in the 1972 trial and four concentrations in the 1976 trial. However, for one preservative, Hylosan PT five concentrations were tested (Table 5). The lowest concentration in the 1972 trial corresponded to the normally recommended concentration for wood in ground contact. For every concentration, five wood blocks were treated in the 1972 trial and six wood blocks in the 1976 trial. The uptake of solution was determined by weighing each wood block before and after the treatment. The retention of the preservatives was calculated in kg/m^3 for each wood block. The tables report the average retention for each concentration level.

Untreated blocks of European redwood, beech, birch, and water-stored sapwood of Norway spruce were also included in the tests. These samples show the natural durability to marine borers and the composition and density of the marine wood borer population (Henningsson and Norman 1980). New untreated wood blocks have been installed several times since 1972.

After fixation of the preservatives and drying, the wood blocks were placed at random on ladder-like frames. The distance between the wood blocks was approximately 2.5 cm. The frames were placed in an upright position on the bottom of the sea at a depth of 6 m. These installations were made in June 1972 and in June 1976.

The samples which were installed in June 1972 were examined for the first time in November the same year. Thereafter they were examined every autumn , until 1976. Since then they have been examined every second year. The samples which were installed in June 1976 were also examined in the autumn of the same year. They were then examined annually up to 1979 and thereafter every second year.

The samples were at first examined for attack by **Limnoria.** The extent of superficial fouling organisms was also observed and registered. After removal of the fouling organisms, the samples were X-rayed by means of a Philips Macrotank K 100/Be.

According to the NWPC Standard No. 1.4.2.2./73 the attack by **Limnoria** and **Teredo** together is evaluated using the following grading system:

No attack	0
Slight attack	1/3
Moderate attack	2/3
Sample destroyed	1

Each sample is evaluated separately and for each concentration level an average index of attack is calculated. When all blocks at one concentration level have been rejected (samples destroyed) and the index of attack has reached 1, the average service life of the concentration level can be determined.

RESULTS

Average index of attack and average service life is shown for trial 1972 in Tables 2 and 3 and for trial 1976 in Tables 5 and 6. The exposure times reported are for the 1972 trial 4.5 and 16 years and for the 1976 trial 4.5 and 13 years.

The treated test blocks were exclusively attacked by the molluscan borers, mostly **T. navalis** but also to some extent by **P. megotara.** On the untreated controls, attack by **L. lignorum** occurred. The ultimate complete destruction was, however, always caused by the molluscan borers (Henningsson and Norman 1979, 1980).

Trial started in 1972

After 4.5 years of exposure four preservatives, viz. Celcure O, Kemira K64, Tanalith C and Tanalith NCA were free from attack at all concentration levels (Table 2). Six preservatives viz. Boliden APUS, Boliden K33, Celcure AP1, Celcure M, Celcure SM and Kemira C64 had slight attacks at the lowest retention levels. Boliden P50 had suffered a severe attack at the lowest retention level and slight attack at the next level. Wood blocks treated with Cuprinol Tryck and KP Cuprinol were completely destroyed at the lower concentration levels and slightly to moderately attacked at the higher levels. The untreated controls of European redwood had an average service life of 1-2 years.

European beech and birch samples treated with KP Cuprinol were, after 4.5 years, completely destroyed at the lowest retention level, and badly damaged at higher retentions (Table 3). Blocks treated with Boliden K33 were also completely destroyed at the lowest retention level, but at higher levels the samples were less damaged than the KP Cuprinol-treated samples. Untreated controls of European beech lasted 0.6 - 2.0 years and European birch 0.6 - 2.4 years.

After 16 years of exposure the blocks of European redwood treated with the preservatives Celcure O, Kemira C64, Kemira K64 and Tanalith C had slight to moderate attack at the lowest retention level. Higher retention levels were unattacked except for Tanalith C, which had a minor attack at the next lowest retention. The preservatives Boliden K33, Celcure AP1 and Celcure SM had an average index of attack close to 1 at the lowest retentions and slight to moderate attack at the next lowest retentions. For Boliden APUS, Celcure M and Tanalith NCA the samples were destroyed at the lowest retention levels while the samples at higher levels only suffered slight or no attack. The preservative Boliden P50 was attacked at all retention levels. At the two lowest retention levels, all the samples were destroyed. The wood blocks treated with the two ammoniacal copper

Table 1. NWPC Marine trial 1972. Preservatives tested and their chemical formulation.

Wood preservative	Chemical formulation % m/m		Active components % m/m		Manufacturer*
Boliden APUS	CuO	12.3	Cu	9.8	Boliden AB
	CrO_3	32.4	Cr	16.8	
	As_2O_5	27.4	As	17.9	
	Na_2O	3.4			
	H_2O	24.5			
Boliden K33	CuO	14.8	Cu	11.8	Boliden AB
	CrO_3	26.6	Cr	13.8	
	As_2O_5	34.0	As	22.2	
	H_2O	24.6			
Boliden P50	CuO	15.9	Cu	12.0	Boliden AB
	CrO_3	20.0	Cr	10.4	
	P_2O_5	16.6	P	7.7	
	H_2O	47.5			
Celcure O	$CuSO_4 . 5H_2O$	45	Cu	11.5	Rentokil Ltd.
	$Na_2Cr_2O_7.2H_2O$	50	Cr	18.5	
	$Cr(CH_3COO)_3.H_2O$	5			
Celcure AP1	CuO	10.2	Cu	8.1	Rentokil Ltd.
	CrO_3	26.9	Cr	13.9	
	A_2O_5	22.7	As	14.8	
	SO_3	7.4			
	Na_2O	8.3			
	H_2O	24.5			
Celcure M	$CuSO_4.5H_2O$	36.0	Cu	9.2	Rentokil Ltd.
	$Na_2Cr_2O_7.2H_2O$	40.0	Cr	14.8	
	$Cr(CH_3COO)_3.H_2O$	4.0	B	3.5	
	H_3BO_3	20.0			
Celcure SM	$CuSO_4.5H_2O$	53.0	Cu	13.5	Rentokil Ltd.
	$Na_2Cr_2O_7.2H_2O$	29.4	Cr	10.8	
	$Cr(CH_3COO)_3.H_2O$	2.9	B	2.6	
	H_3BO_3	14.7			
Cuprinol Tryck (KP-N)	CuO	12	Cu	9.5	Hager AB
	$C_7H_{15}COOH$	4.8	$C_7H_{15}COOH$	4.8	
	NH_3	~ 20			
	CO_2	~ 40			
	H_2O	~ 25			
KP Cuprinol	K-salt 91.3 %		Cu	10.9	Bönnelyche & Thuröe AB
	CuO	15	Na-PCP	6.1	
	NH_3	18			
	CO_2	44			
	H_2O	23			
	P-salt 8.7 %				
	C_6HCl_4ONa(Na-PCP)	70			
	H_2O	30			
Kemira C64	CuO	25.3	Cu	20.2	Kemira Oy
	CrO_3	40.8	Cr	21.2	
	P_2O_5	16.8	P	7.3	
	SO_3	4.4			
	H_2O	12.7			
Kemira K64	CuO	22.9	Cu	18.3	Kemira Oy
	CrO_3	33.6	Cr	17.5	
	As_2O_5	18.3	As	11.9	
	P_2O_5	10.4	P	4.5	
	SO_3	3.6			
	H_2O	11.2			
Tanalith C (Tancas C)	$CuSO_4 . 5H_2O$	35	Cu	8.9	Hickson and Welch Ltd.
	$Na_2Cr_2O_7. 2H_2O$	45	Cr	15.7	
	$As_2O_5 . 2H_2O$	20	As	11.3	
Tanalith NCA	$CuSO_4$	29.7	Cu	11.8	Hickson and Welch Ltd.
	$Na_2Cr_2O_7$	31.7	Cr	12.6	
	$As_2O_5 . 2H_2O$	26.3	As	20.0	
	$Na_4As_2O_7$	12.3			

* Manufacturer that originally ordered the test or at the time when the test was started produced the preservative.

Table 2. NWPC Marine trial 1972. Results after 4.5 and 16 years' testing. Wood species: European redwood (sapwood).

Preservative	Concentration % m/m	Retention kg/m^3	Average index of attack exposure period		Average service life
			4.5 years	16 years	years
Boliden APUS	2.0	14	0.39	1	8.5
	3.0	22	0	0	
	4.0	26	0	0	
	5.0	35	0	0	
	6.0	42	0	0	
Boliden K33	2.0	14	0.33	0.95	
	3.0	22	0	0.17	
	4.0	28	0	0	
	5.0	36	0	0	
	6.0	42	0	0	
Boliden P50	2.0	14	0.83	1	5.1
	3.0	21	0.33	1	8.0
	4.0	27	0	0.83	
	5.0	34	0.06	0.39	
	6.0	42	0	0.22	
Celcure O	3.0	20	0	0.45	
	4.5	33	0	0	
	6.0	43	0	0	
	7.5	54	0	0	
	9.0	68	0	0	
Celcure API	2.5	17	0.22	0.83	
	3.8	26	0	0.50	
	5.0	36	0	0	
	6.3	45	0	0	
	7.5	54	0	0	
Celcure M	3.0	22	0.28	1	9.7
	4.5	32	0.06	0.39	
	6.0	43	0	0	
	7.5	54	0	0.11	
	9.0	64	0	0	
Celcure SM	3.0	21	0.11	0.78	
	4.5	32	0	0.22	
	6.0	43	0	0	
	7.5	52	0	0	
	9.0	63	0	0	
Cuprinol Tryck	3.5	24	1	1	2.7
	5.3	35	1	1	3.5
	7.0	48	1	1	3.9
	8.8	61	0.78	1	6.3
	10.5	71	0.83	1	5.4
KP Cuprinol	3.5	24	1	1	3.7
	5.3	35	1	1	4.4
	7.0	48	0.89	1	5.0
	8.8	58	0.50	1	6.7
	10.5	71	0.11	0.95	
Kemira C64	2.0	14	0.06	0.45	
	3.0	21	0	0	
	4.0	29	0	0	
	5.0	36	0	0	
	6.0	43	0	0	
Kemira K64	2.0	14	0	0.22	
	3.0	21	0	0	
	4.0	27	0	0	
	5.0	36	0	0	
	6.0	43	0	0	
Tanalith C	2.5	18	0	0.45	
	3.8	25	0	0.11	
	5.0	36	0	0	
	6.3	45	0	0	
	7.5	53	0	0	
Tanalith NCA	2.5	19	0	1	12
	3.8	26	0	0.28	
	5.0	36	0	0.17	
	6.3	45	0	0	
	7.5	51	0	0	
Untreated controls					1-2

Table 3. NWPC Marine trial 1972. Results after 4.5 and 16 years' testing. Wood species: European beech and European birch.

Wood species	Preservative	Concentration % m/m	Retention kg/m³	Average index of attack exposure period		Average service life
				4.5 years	16 years	years
European beech	KP Cuprinol	3.5	22	1	1	4.0
		5.3	36	0.78	1	5.1
		7.0	46	0.72	1	5.4
		8.8	60	0.28	1	7.6
		10.5	68	0.11	1	7.0
	Boliden K33	2.0	13	1	1	4.4
		3.0	20	0.67	1	6.1
		4.0	27	0.17	1	12
		5.0	36	0	0.72	
		6.0	42	0	0.28	
	Untreated controls					0.6-2.0
European birch	KP Cuprinol	3.5	23	1	1	4.4
		5.3	34	0.95	1	4.7
		7.0	47	0.95	1	4.7
		8.8	59	0.50	1	6.7
		10.5	70	0.17	1	7.9
	Boliden K33	2.0	13	1	1	4.4
		3.0	19	0.67	1	6.1
		4.0	28	0.22	0.83	
		5.0	33	0.06	0.33	
		6.0	38	0	0.57	
	Untreated controls					0.6-2.4

Table 4. NWPC Marine trial 1976. Preservatives tested and their chemical formulation.

Wood preservative	Chemical formulation % m/m		Active components % m/m		Manufacturer*
ACCA	CuO	7.4	Cu	5.9	-
	CrO_3	4.0	Cr	2.1	
	As_2O_5	4.0	As	2.6	
	NH_3	19.0			
	CO_2	39.0			
	H_2O	26.4			
Basilit CFK	$CuSiF_6 \cdot 4H_2O$	35.9	Cu	8.2	Farbenfabriken
	$(NH_4)_2 Cr_2O_7$	63.1	F^-	14.7	Bayer AG
	$(NH_4)_2HPO_4$	1.0	Cr	26.0	
Boliden K33	CuO	14.8	Cu	11.8	Boliden AB
	CrO_3	26.6	Cr	13.8	
	As_2O_5	34.0	As	22.2	
	H_2O	24.6			
Boliden P50B	CuO	11.2	Cu	8.9	Boliden AB
	CrO_3	15.8	Cr	8.2	
	P_2O_5	13.2	P	5.8	
	B_2O_3	14.1	B	4.4	
	H_2O	45.7			
Celcure AP5	CuO	13.1	Cu	10.5	Boliden AB
	CrO_3	34.4	Cr	17.9	
	As_2O_5	27.5	As	17.9	
	H_2O	25.0			
Cuprinol Tryck (KP-N)	CuO	12	Cu	9.5	Hager AB
	$C_7H_{15}COOH$	4.8	$C_7H_{15}COOH$	4.8	
	NH_3	~ 20			
	CO_2	~ 40			
	H_2O	~ 25			
Gufa 521	CuO	13.8	Cu	11.1	Gullviks Fabriks AB
	H_3BO_3	4.0	B	0.7	
	C_2H_5COOH	5.1			
	NH_3, CO_2, H_2O	rest**			
Hylosan PT (Permapruf T)	TBTO	10	TBTO	10	Penarth Research Centre
	Benzalkyl trimethyl ammoniumchloride (BA)	40	BA	40	
	Additives	~ 6			
	H_2O	~44			
Wolmanit CB	CuO	10.8	Cu	8.6	Dr Wolman GmbH
	CrO_3	26.4	Cr	13.3	
	H_3BO_3	25.5	B	4.5	
	$KHSO_4$	37.3			

* Manufacturer that originally ordered the test or at the time when the test was started produced the preservative.

** Not specified in detail.

Table 5. NWPC Marine trial 1976. Results after 4.5 and 13 years' testing. Wood species: European redwood (sapwood).

Preservative	Concentration % m/m	Retention kg /m^3	Average index of attack		Average service life
			4.5 years	13 years	year
ACCA	4.3	32	0.07	1	8.3
	6.0	44	0	0.87	
	8.5	67	0.07	0.49	
	11.9	91	0	0	
Basilit CFK	1.6	12	0	1	11
	2.2	17	0	0.40	
	3.2	25	0	0	
	4.5	35	0	0	
Boliden K33	2.0	15	0	0	
	2.8	20	0	0	
	4.0	29	0	0	
	5.6	42	0	0	
Boliden P50B	2.5	18	0	0.80	
	3.5	26	0	0.20	
	5.0	36	0	0	
	7.0	54	0	0	
Celcure AP5	2.0	15	0	0	
	2.8	20	0	0	
	4.0	27	0	0	
	5.6	42	0	0	
Cuprinol Tryck	3.5	23	0.93	1	5.3
	4.9	32	0.80	1	4.7
	7.0	45	0.50	1	6.4
	9.8	66	0.20	1	7.5
Gufa 521	3.0	23	0.27	1	7.1
	4.2	31	0.33	1	7.1
	6.0	45	0 33	1	7.5
	8.4	62	0.13	0.87	
Hylosan PT (Permapruf T)	0.8	4	0	0.33	
	1.1	6	0	0	
	1.6	9	0	0	
	2.2	12	0	0	
	3.2	17	0	0	
Wolmanit CB	3.0	22	0	0.53	
	4.2	31	0	0	
	6.0	46	0	0	
	8.4	64	0	0	

Table 6. NWPC Marine trial 1976. Results after 4 and 13 years' testing. Wood species: Norway spruce, water-stored sapwood.

Preservative	Concentration % m/m	Retention kg /m^3	Average index of attack exposure period		Average service life
			4 years	13 years	years
Boliden K33	2.0	15	0	0.07	
	2.8	21	0	0	
	4.0	32	0	0	
	5.6	42	0	0	
Untreated controls					0.4

preservatives in the trial viz. Cuprinol Tryck and KP Cuprinol were destroyed at all retention levels, with exception of the highest retention for KP Cuprinol. The average service life for the middle concentration was 3.9 years for Cuprinol Tryck and 5.0 years for KP Cuprinol.

Blocks of European beech and birch treated with KP Cuprinol were destroyed at all concentration levels during the exposure period of 16 years (Table 3). The average service life at the middle concentration was 5.4 years for European beech and 4.7 years for European birch. The blocks treated with Boliden K33 were completely destroyed at the lower retention levels. At higher retention levels the blocks were only slightly to moderately attacked.

Trial started in 1976

After exposure of 4.5 years, blocks of European redwood treated with the preservatives Basilit CFK, Boliden K33, Boliden P50 B, Celcure AP5, Hylosan PT and Wolmanit CB were free from attack at all concentration levels (Table 5). The preservative ACCA, which is an ammoniacal CCA, suffered slight attack in one block at two concentration levels. The two ammoniacal copper-preservatives in the test did not perform as well as ACCA. Gufa 521 received slight attacks at all concentration levels while Cuprinol Tryck had servere attacks at the two lower levels and slight to moderate attacks at the two higher retention levels. Water-stored sapwood blocks of Norway spruce treated with Boliden K33, were free from attack after 4 years of exposure (Table 6).

After 13 years of exposure Boliden K33 and Celcure AP5 were still free from attack at all concentration levels. The preservatives Hylosan PT and Wolmanit CB had slight to moderate attacks at the lowest concentrations. Hylosan PT consists of TBTO (tributyltin oxide) and AAC (alkyl ammonium compounds). Basilit CFK and Boliden P5OB were attacked at the two lowest concentrations. Blocks treated with ACCA were attacked at all concentrations except the highest. For Gufa 521 all blocks were destroyed at the three lowest concentrations, while for Cuprinol Tryck all blocks were destroyed at all concentrations. The average service life of the next lowest concentration was 4.7 years for Cuprinol Tryck and 7.1 year for Gufa 521. In addition to copper, Cuprinol Tryck contains caprylic acid and Gufa 521 boron. The water-stored sapwood blocks of Norway spruce treated with Boliden K33 were still unattacked at all concentrations except the lowest, where one block was slightly attacked.

DISCUSSION

Good protection against marine borers is determined by the applied concentration of the treating solution and by the amount of active components in the preservative. For the concentrations chosen in the 1972 and 1976 trials on European redwood the preservatives may be listed in decreasing degree of protection against marine borers as follows (cf. Tables 2 and 5):

Preservatives exposed for 16 years	Type of preservative
Kemira K64	CCA + P
Celcure O	CC
Kemira C64	CCP
Tanalith C	CCA
Celcure SM	CCB
Boliden K33	CCA
Celcure AP1	CCA
Boliden APUS	CCA
Celcure M	CCB
Tanalith NCA	CCA
Boliden P50	CCP
KP Cuprinol	Cu+Na-PCP, ammoniacal
Cuprinol Tryck	Cu+Caprylic acid, ammoniacal

Preservatives exposed for 13 years	Type of preservative
Boliden K33	CCA
Celcure AP5	CCA
Hylosan PT	TBTO + AAC
Wolmanit CB	CCB
Boliden P50B	CCP + B
Basilit CFK	CCF
ACCA	CCA, ammoniacal
Gufa 521	Cu+B, ammoniacal
Cuprinol Tryck	Cu+Caprylic acid, ammoniacal

The difference in performance between the CC, CCA, CCB and CCP preservatives was not very great with the exception of the CCP preservatives Boliden P50 in the 1972, trial and Boliden P50B in the 1976 trial. The latter preservative also contains boron. The CCP preservative, Kemira C64 gave excellent protection compared to Boliden P50. The applied concentration of the two preservatives was the same, but the amount of copper and chromium in Kemira C64 was about twice that of Boliden P50. In the world-wide IRG marine trial recently reported by Eaton (1989), no apparent difference in performance was found between CCA and CCB preservatives. Leightley (1987) presents from the same trial the chemical analyses of the treated wood samples after six years of exposure. He found the most severe losses for boron. Arsenic and copper were also lost, but chromium was the chemical that remained best in the treated wood. Although boron and arsenic leach out of the wood the efficacy of the CCB and CCA preservatives persists. This explains to some extent the good result which was produced by the CC preservative, Celcure O, in the 1972 trial (Table 2). Celcure O has also a high amount of chromium.

The CCF preservative, Basilit CFK in the 1976 trial seems to give less protection than the CCB preservative Wolmanit CB (Table 5). However, at equal retentions Basilit CFK shows a somewhat better performance than Wolmanit CB. It must be observed that the amount of chromium in Basilit CFK is twice that of Wolmanit CB, while the amount of copper is almost equal (Table 4). At a test site in Italy where the same CCF and CCB preservatives were used in equal concentrations, no clear differences were observed between the two preservatives after 12 years exposure (Gambetta and Orlandi 1986).

The TBTO + AAC preservative, Hylosan PT in the 1976 trial protected the wood very well against marine borers. The lowest retention which was free from attack was 6 kg/m^3 for Hylosan PT compared to 15 kg/m^3 for Boliden K33 (Table 5). In ground contact, higher retentions are needed for Hylosan PT than for Boliden K33 to reach the same efficacy (Bergman and Jermer 1989). Good performance of TBTO compounds in marine trials have earlier been reported by Kühne and Becker (1970), Gambetta and Orlandi (1986) and Gambetta **et al.** (1988). Hylosan PT also consists of an alkyl ammonium compound (AAC). A marine trial which included Permapruf T (the same as Hylosan PT) and some AAC formulations was started in 1977 in New Zealand. After two and a half years, Permapruf T was performing well at a retention of 12 kg/m^3, while the AAC formulations had completely failed (Preston and Chittenden 1980).

The ammoniacal CCA preservative, ACCA in the 1976 trial did not give good performance compared to the CCA preservatives Boliden K33 and Celcure AP5 (Table 5). The copper content in the wood at the lowest retention level is 1.9 kg/m^3 for ACCA and 1.8 kg/m^3 for Boliden K33. The chromium content for ACCA is 0.7 kg/m^3, while it is 2.1 kg/m^3 for Boliden K33. This may possibly explain the difference in efficacy against marine borers.

The ammoniacal copper preservatives Cuprinol Tryck and KP Cuprinol in the 1972 trial, and again Cuprinol Tryck and Gufa 521 in the 1976 trial, failed to protect the wood at all retentions (Tables 2 and 5). The concentration of the copper component in these formulations is nearly the same as in Boliden K33 (Tables 1 and 3), but the applied concentrations are almost twice that of Boliden K33. The fact that the ammoniacal copper preservatives in this test failed even at the highest retentions suggests that the copper was ineffective compared to the CCA preservatives. Ruddick (1987) has also reported a somewhat inferior performance of an ammoniacal copper arsenate (ACA) preservative than for a CCA preservative after eight years marine test at Vancouver. The retention levels for the ACA preservative were double that of the CCA preservative. There was also considerably more copper in the ACA preservative than in the CCA preservative.

European redwood treated with the CCA preservative, Boliden K33 performed considerably better than European beech and birch treated with the same preservative. At the 4 % concentration level, European redwood is still free from attack after 16 years, while all samples of beech are destroyed (av. service life 12 years) and birch has reached an average index of attack of 0.83 (Table 3). However, when KP Cuprinol was used, there were no remarkable differences between the wood species. At the 7 % concentration level the service life was 5.0 years for European redwood, 5.4 years for European beech and 4.7 years for European birch. This may indicate that CCA preservatives obtain better fixation in softwoods than in hardwoods, while the ammoniacal copper preservatives fix to the same extent in both softwoods and hardwoods. Similar differences in performance between CCA and CCF treated pine and beech at a Mediterranian test site has been reported by Fougerousse and Lucas (1976) and between CCA treated Radiata pine and eucalypt in Papua New Guinea by Tamblyn **et al.** (1978). In the earlier referred IRG marine trial (Eaton 1989), CCA and CCB treated European beech samples were more extensively attacked at all test sites than European redwood treated with the same concentrations of the two preservatives.

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