

Remedial treatment of creosoted railway
sleepers of redwood by selective application
of boric acid

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REMEDIAL TREATMENT OF CREOSOTED RAILWAY SLEEPERS OF REDWOOD BY SELECTIVE APPLICATION OF BORIC ACID

1. INTRODUCTION

The species of timber used in Sweden for railway sleepers is predominantly Baltic redwood (*Pinus sylvestris* L). The sleepers are usually impregnated with creosote oil to a retention of 130-140 kg/m³ sapwood. The heartwood is difficult to treat and is hardly ever penetrated.

The average service life for a creosoted sleeper is approximately 28 years according to the Swedish State Railways (SJ). However, there is considerable variation from the mean, principally because of large differences in quality of both the wood and the impregnation. Already after 7-8 years, some sleepers occasionally have to be replaced because of decay. This is a great disadvantage as the maintenance cycles nowadays are longer than before.

The main cause of damage due to premature decay is incomplete impregnation, i.e. the sapwood has not been fully penetrated or the retention of creosote has been insufficient. Both can also occur in combination, often as a consequence of the sleeper being already damaged before impregnation, which has resulted in areas of increased moisture content. Blue-stain is the most common problem and the attacked parts of the sleeper are difficult to season and frequently resulting in an excessively high moisture content at impregnation.

Particularly vulnerable to decay by fungi are the parts of the sleeper situated under the rail baseplate and around the spikes or screws. The zone of the treated/untreated wood interface is especially liable to decay. Mechanical stress and a high localised moisture content contribute to this.

By selective remedial treatment, where preservative is supplied after installation to untreated parts of the sleeper and/or parts with low creosote retention, fungal attack can be stopped and the service life extended. As indicated above, the sections under the rails determine the service life of the sleeper, and are thus of special interest for remedial treatment. Besides the use of an effective preservative, the timing of the treatment will affect the period of extension of the service life, and hence determine the profitability of the treatment.

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Remedial treatment of creosoted sleepers in track has not, so far, been practised to any great extent in Sweden. During the nineteen fifties a series of preliminary tests on the remedial treatment of sleepers (Rennerfelt, Nyberg 1955) was carried out. Eventually, approximately 500 000 sleepers were treated and it was shown (Borup, Rennerfelt 1961) that the service life of the sleepers could be extended by an average of five years. The limit for economic profitability was then estimated to be three years.

Impregnation was effected using cartridges and paste containing soluble fluorine salts. The use of these types of preservative had certain disadvantages. For instance, they could not be extensively employed for sleepers in tracks where the rails were used as a circuit for electric signals. Na^+ and F^- ions were found to reduce the electrical resistance of the sleepers and thus interfere with the signalling system. The cartridges were also hygroscopic and brittle, which caused some problems in handling. Another disadvantage was also the fairly high toxicity of the fluorides. Therefore, the use of fluorine preservatives was abandoned and in the early nineteen sixties SJ began to look for alternatives. It was recognized that a new preservative

- should be at least as effective against decay fungi as the fluorides
- could be used for sleepers in a track with signalling systems
- should be safe to handle

In March 1970, a co-operative project between SJ and the Danish firm Kai R Spangenberg was established in order to look for a suitable method of treatment. After a preliminary survey it was decided to study in further detail preservatives based on boric acid.

An ideal preservative for remedial treatment must primarily be characterized by two requirements. First, it must have an ability to diffuse and distribute evenly into the wood and secondly, it must be fixed properly so that it does not leach out too fast. However, these two characteristics conflict with each other, and the choice of preservative must of necessity be a compromise.

Wood preservatives based on boric acid have excellent diffusibility but like the fluorides they are not appreciably fixed in the wood. It was therefore considered important to study the progress of the boric acid diffusion in creosoted sleepers in full scale tests. Impregnation equipment and technique were of course also of interest in the study.

The tests started in September 1970, when approximately 100 creosoted sleepers, after being in service for 13 years, were treated with a boric acid paste and installed in a test track at the marshalling yard at Nässjö (the Nässjö test). To obtain an indication of the effect of the treatment for a track in use and to study the developed method and equipment, in April 1974, approximately 1 000 seventeen years old creosoted sleepers on the main line south of Kungsbacka (the Kungsbacka test) were treated.

Samples of timber have been extracted from the sleepers on the two sites and analysed after different times of exposure in order to follow the progress of diffusion of the boric acid. In total, more than 2 000 chemical analyses have been carried out by Borax Holdings Ltd in England.

In order to establish whether the boric acid treatment adversely affected the electrical resistance of a sleeper, a small scale trial was carried out with 11 sleepers from the Nässjö test. In May 1971 they were installed in a test track near the SJ Civil Engineering Laboratory in Stockholm.

As the study progressed, a large amount of data from the chemical analyses was obtained, and to evaluate the fungicidal effect of the boric acid in the sleepers a series of biological tests was carried out at the Swedish University of Agricultural Sciences in Uppsala.

The Swedish Wood Preservation Institute has been responsible for the final revision and editing of the results as well as compiling this report.

Acknowledgements

The assistance of Mr Joseph Dulat, Mr Len Arthur and Miss Barbara Kimber, Borax Holdings Ltd; Mr Jan Lundin and Mr Rolf Magnusson, Swedish State Railways; Miss Christina Lundberg, Swedish University of Agricultural Sciences and Mr Kai R Spangenberg and Mr Knud Andersen in the form of contributions and discussions during the course of this work is gratefully acknowledged.

2. STUDIES OF THE DIFFUSION OF BORIC ACID IN CREOSOTED REDWOOD RAILWAY SLEEPERS

2.1 The Nässjö test

Materials and methods

In September 1970, 105 creosoted redwood (*Pinus sylvestris* L) sleepers were treated with a boric acid paste. The sleepers had been in service in a main line track for approximately 13 years. The reason for the choice of age of the sleepers was that SJ considered that a remedial treatment might be carried out about 15 years after installation.

Two different pastes were used in the beginning, one based on methyl cellulose and 60 % boric acid (H_3BO_3), and the other based on soap/ethanol with a 50 % boric acid content. As the latter proved to give better retentions it became the one exclusively used. The paste was injected with a standard equipment used for the Cobra treatment of poles at 26 sites around each of the two baseplates on each sleeper as shown in Fig 1.

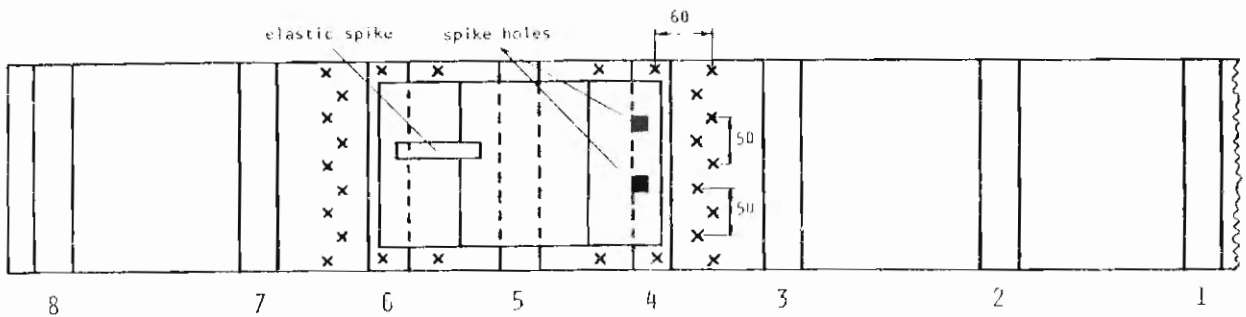


Fig 1. Pattern for the injection of boric acid paste around the baseplate in the Nässjö test. Some characteristic measurements (mm) are shown. The baseplate (dimensions 170 x 300 mm) was joined to the sleeper by only one spike. The holes in the sleeper corresponding to the unutilized holes in the plate were plugged with impregnated wood plugs. It must be pointed out, that the spike was not always to the left as in the figure but sometimes to the right.

The amount of paste consumed per injection was calculated by dividing the total amount of paste consumed, by the number of injections. The average obtained was 5.75 g 50 % boric acid paste per injection or 2.87 g boric acid/injection. In total, approximately 75 g boric acid were injected around each plate. However, some paste remained on the surface at the injection points, cf Fig 10, and the paste actually supplied to the sleeper was less. When the

injections were completed the sites were treated with coal tar whereupon the sleepers were installed in a simulated track test bed in Nässjö. The test bed had a ballast of crushed stone and a sub-ballast of gravel as in a regular main line track. The test bed was considered to be well drained.

The rail baseplate (170 x 300 mm) were for elastic rail spikes. Usually, three spikes are used for mounting. The same mounting system was used as in normal practice, i.e. the old spike holes were used. However, only one spike was used and the unused holes were plugged with an impregnated wood plug, see Fig 1. None of the sleepers had rails mounted on them.

To register the diffusion of the boric acid and its distribution within the wood, it would have been preferable to extract samples from the same sleeper after various times of exposure and analyse their boric acid content. This sampling procedure, however, was impractical and instead one half of each of 10 different sleepers was analysed at each sampling. Samplings were made after 9, 12, 15, 27, 39, 51, 63, 75 and 87 months' exposure after treatment. The sleepers were sectioned as shown in Fig 2, and samples were taken from each section for chemical analysis of the boric acid content according to the pattern in Fig 3. Each section was photographed after sectioning, see Fig 4.

Sectioning was carried out as shown in Fig 2 in order to obtain the maximum amount of information on the diffusion of the boric acid. The sections 4 and 6 were chosen to give information on the diffusion in those parts of the

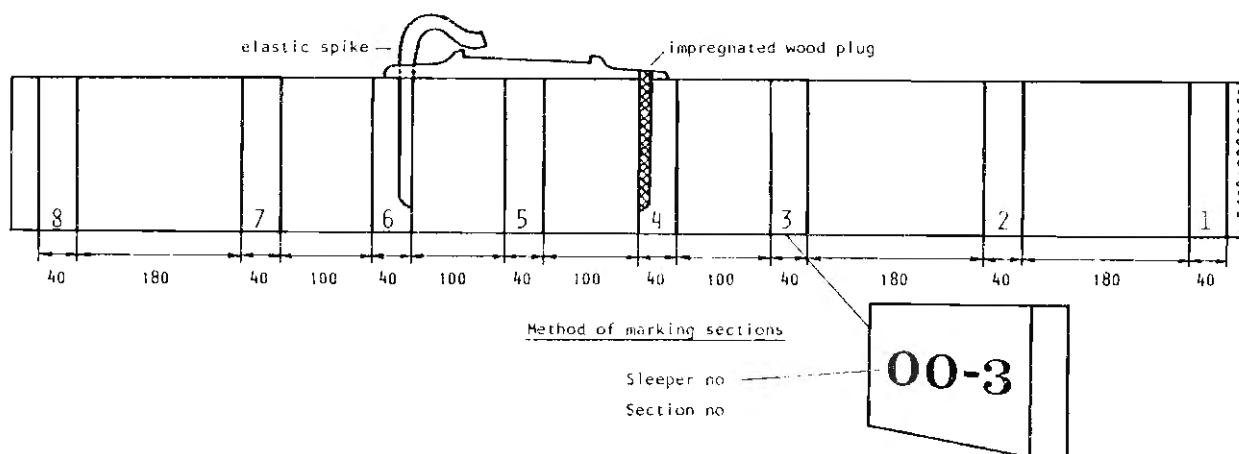


Fig 2. Pattern for sectioning the sleepers in the Nässjö test. Measurements in mm.

sleeper where the spikes or screws usually are, and section 5 to give information on that part of the sleeper covered by the plate. The sections 1, 2, 3, 7 and 8 were chosen to give information on the diffusion further away from the treated zone.

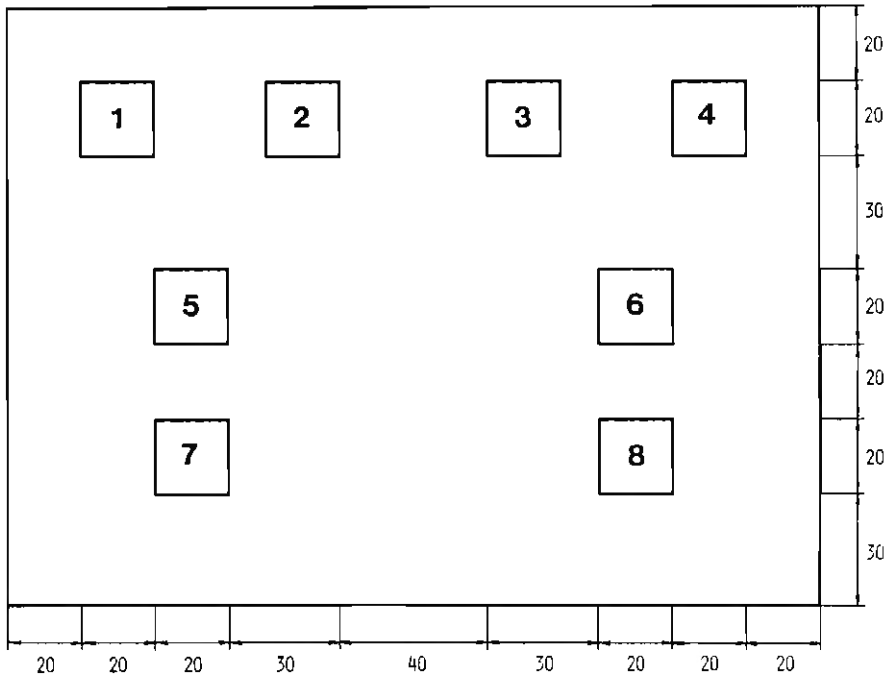


Fig 3. Square samples were removed from sections as shown above. Measurements in mm.

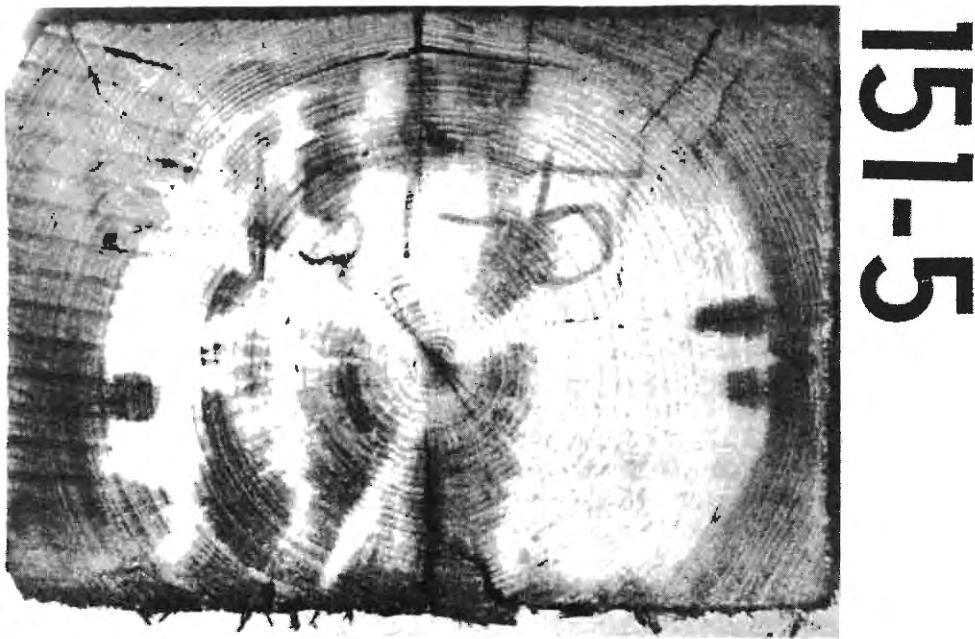


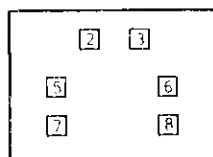
Fig 4. Photograph of section no 5 of sleeper no 151.

As to the sampling of the sections, samples 1, 2, 3 and 4 were considered to represent the vulnerable zone between impregnated sapwood and untreated heartwood. The samples 5, 6, 7 and 8 were taken out, mainly from sections 4 and 6, to give information on the boric acid content in the wood close to the spikes. As the number of samples extracted varied each time the sampling scheme is given in Table 1.

Table 1. Sampling scheme - the Nässjö test.

Section	Samples (nos) taken out after various exposure times								
Nr.	9	12	15	27	39	51	63	75	87 months
1	2 + 3 ¹	-	2 + 3 ¹	2 + 3 ¹	2 + 3 ¹	2 + 3 ¹	-	-	-
2	2 + 3 ¹	2 + 3 ¹	2 + 3 ¹	2 + 3 ¹	2 + 3 ¹	2 + 3 ¹	-	-	-
3	2 + 3 ¹	2 + 3 ¹	2 + 3 ¹	2 + 3 ¹	2 + 3 ¹	2 + 3 ¹	-	-	-
4	1-8	2, 3, 5-8	2, 3, 5-8	2, 3, 5-8	2, 3, 5-8	2, 3, 5-8	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6
5	1-4	2, 3	2, 3	2, 3	2, 3	2, 3	2, 3	2, 3	2, 3
6	1-8	2, 3, 5-8	2, 3, 5-8	2, 3, 5-8	2, 3, 5-8	2, 3, 5-8	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6
7	-	-	-	-	2, 3, 5-8	2, 3, 5-8	-	-	-
8	-	-	-	-	2, 3, 5-8	2, 3, 5-8	-	-	-

¹The samples were bulked into one for analysis



Sleeper section

Samples 20 x 20 x 40 mm in size were extracted but only half of each, i.e. a cube 20 x 20 x 20 mm was actually used for analysis. Generally, the front half in relation to the numbered face of the section specimen was used. If specimens had spike holes running across the faces it was necessary to use the rear half of the sample for analysis. A number of the specimens had V-splits and in some instances the split ran through the zone from which a sample was to be taken. To cope with this, the section was broken and the split closed up and held with sealing tape while the sample was extracted.

Two methods were available for the determination of the boric acid content, viz the leaching (as used at the laboratories of Borax Holdings Ltd; Anonymous 1970) and ashing (BWPA 1972) methods. With both, boric acid contents $\geq 0.10 \text{ kg/m}^3$ can be determined. The methods were compared (Appendix 1) and

as the results showed good agreement, the leaching method was chosen as it is both easier and cheaper to use.

Results

All data from the chemical analyses are presented in tables in Appendix 2. To facilitate an evaluation of the results the values from the samples 2 and 3, 5 and 6, and 7 and 8, respectively, for the ten equally numbered sections analysed at each sampling have been added, and the mean ($\bar{x}$) calculated.

For instance, the average boric acid content (kg/m^3) in the combined samples 2 and 3 for the ten sections numbered 4 at a certain sampling has been calculated according to the following formula:

$$\bar{x} = \left(\frac{\Sigma(\text{boric acid content})_{\text{sample 2}} + \Sigma(\text{boric acid content})_{\text{sample 3}}}{20} \right)$$

In Appendix 2 the average values with their standard deviations are presented. The average values have then been used for a graphical illustration of the progress of diffusion.

In Fig 5 a the average boric acid content is shown for the combined samples 2 and 3 of all sampled sections after 12, 27, 39 and 87 months' exposure. The figure gives information on the horizontal distribution of boric acid in the upper part of the sleeper at various times after the treatment. As could be expected, the diffusion has progressed symmetrically from the injection points. A consequence of this was that a maximum of 50 % of the injected boric acid (approx 37 g) was actually supplied to the wood under the rail baseplate.

In Fig 5 b the changes of boric acid content in the upper parts of sections 4, 5 and 6 are shown. The means for the combined samples 2 and 3 have been plotted as a function of time. The changes have been assumed to proceed according to a function of the type $y = a + b/x$, and the graphs have been fitted to the calculated mean values by regression analysis. For section 5 the curve has been fitted for data available between 27 and 87 months, while the first part of the curve has been estimated.

Fig 6 a shows the corresponding changes of boric acid content somewhat further down in the sleeper, viz the combined samples 5 and 6 from sections 4 and 6. Regression analysis was used to draw the curves.

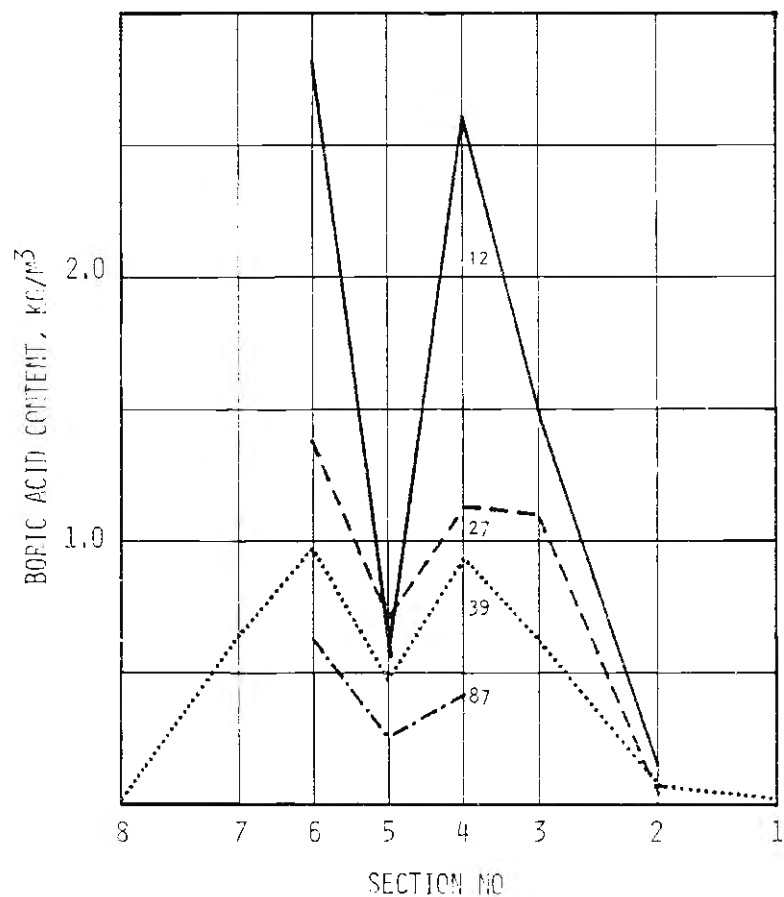


Fig 5 a. The average boric acid content (kg/m³) in samples 2 + 3 from all extracted sections at sampling intervals of 12, 27, 39 and 87 months.

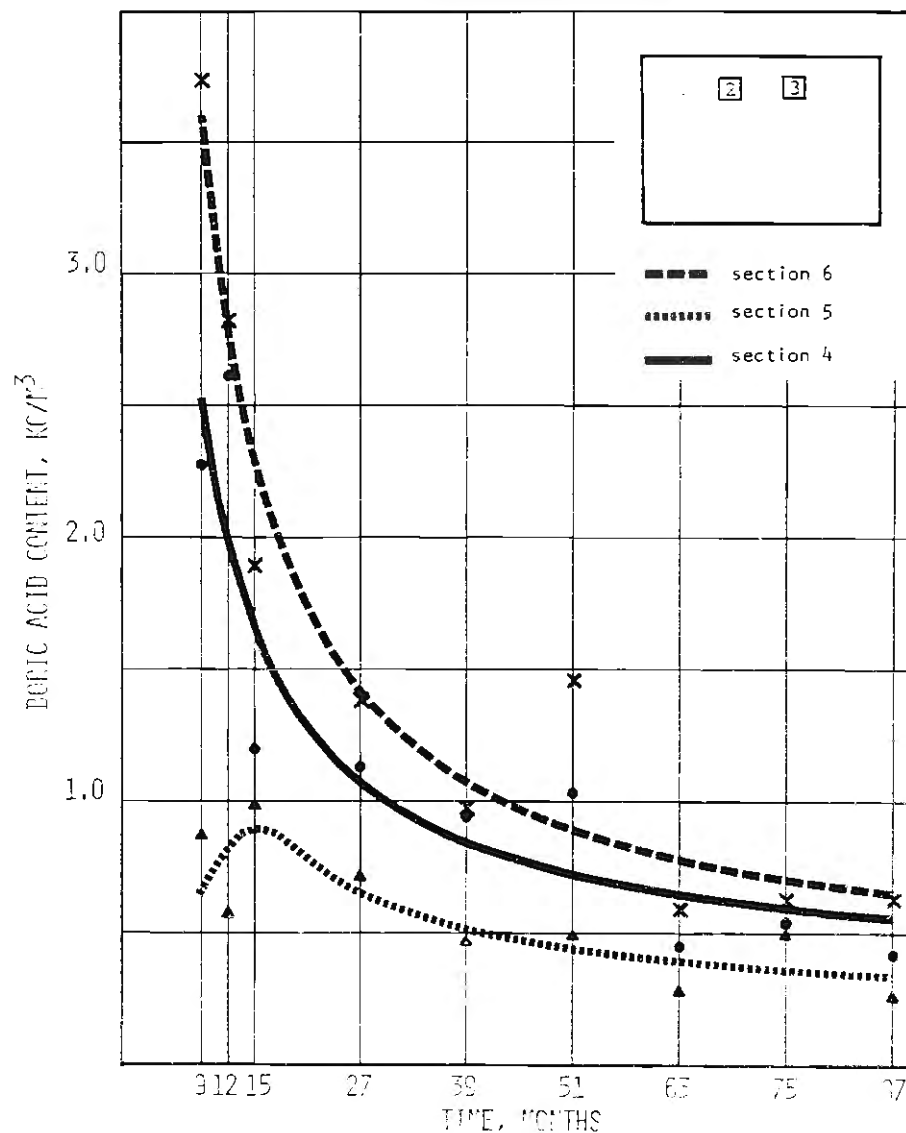


Fig 5 b. Graphs showing the horizontal diffusion in the Nässjö test. The average boric acid content (kg/m³) in samples 2 + 3 from sections 4, 5 and 6 at different samplings plotted as a function of time.

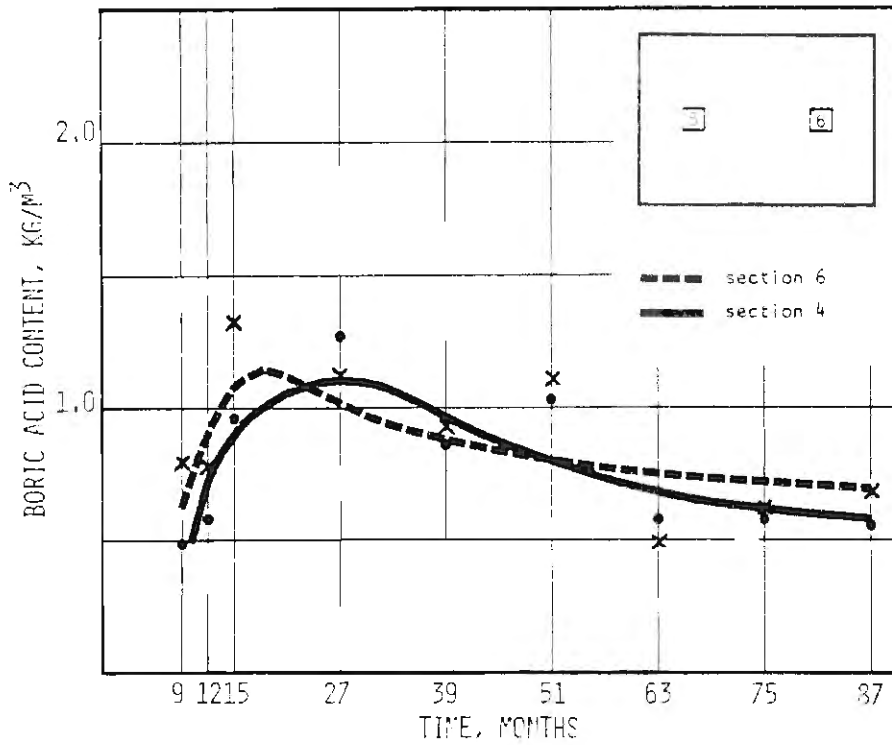


Fig 6 a. Average boric acid content (kg/m^3) in samples 5 + 6 from sections 4 and 6 at different samplings plotted as a function of time.

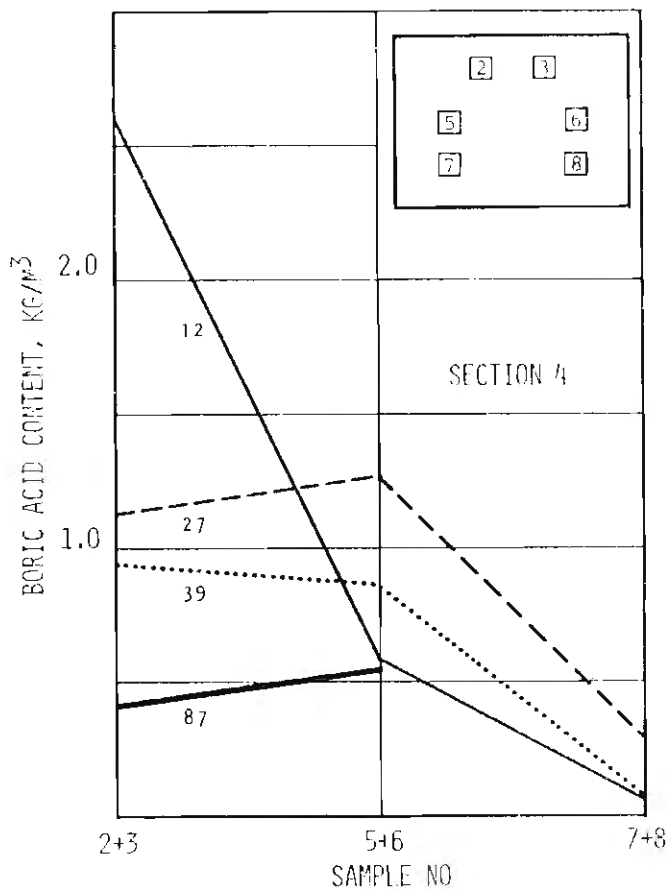


Fig 6 b. Average boric acid content (kg/m^3) at different levels in sections 4 and 6 at sampling intervals of 12, 27, 39 and 87 months.

It can be seen from Fig 5 b that during the first 25-30 months after the treatment, a remarkable decrease of the boric acid content occurred in those parts of the sleeper under the baseplate, which are closest to the injection points (sections 4 and 6). There are two main reasons for this. First, the boric acid diffused and became distributed within the sleeper; from Fig 5 b and 6 a it is clear that the boric acid content increased further from the injection points both in horizontal (section 5, Fig 5 b) and vertical directions (Fig 6 a). Secondly, some boric acid obviously leached out and disappeared. That a considerable amount of the originally supplied boric acid disappeared is obvious. Regarding Fig 5 b and 6 a and at the same time bearing in mind that if roughly 50 % (the diffusion progressed symmetrically from the injection points!) of the original boric acid (about 37 g) had distributed evenly under the baseplate and no leaching had occurred, the boric acid content in the volume of wood under the plate would have been about 3.3 kg/m^3 .

However, the greatest losses were probably not caused by leaching. A considerable amount of boric acid was lost before it even had started to diffuse into the wood. During the treatment it was observed, as mentioned above, that paste had oozed out from the injection points as the injection needle was drawn back. Moreover, some paste could have been injected into big splits and thereby have been washed away the first time it rained after the treatment. Under all circumstances, the "effective" amount of boric acid which was really capable of diffusing into the wood under the rail baseplate was far less than expected and probably did not exceed 25 g.

After about 40 months a more stable phase began with very small changes in the boric acid content. As can be seen from Fig 5 b and 6 a the boric acid content in the upper part (to about 10 cm depth) of the sleeper under the plate was then between 0.4 and 1.0 kg/m^3 . It is interesting to see that such an obvious equalization of the boric acid content of the upper and middle layers had occurred and, even though the samples 5 and 6 were never taken from section 5, it appears that the boric acid had been distributed well within this upper zone. Fig 6 b and Fig 7 (in the latter the percentage average boric acid content in the combined samples 5 and 6 in relation to the corresponding values of the combined samples 2 and 3 from sections 4 and 6 has been plotted as a function of time) show clearly the equalization between the upper and middle layers of the sleeper.

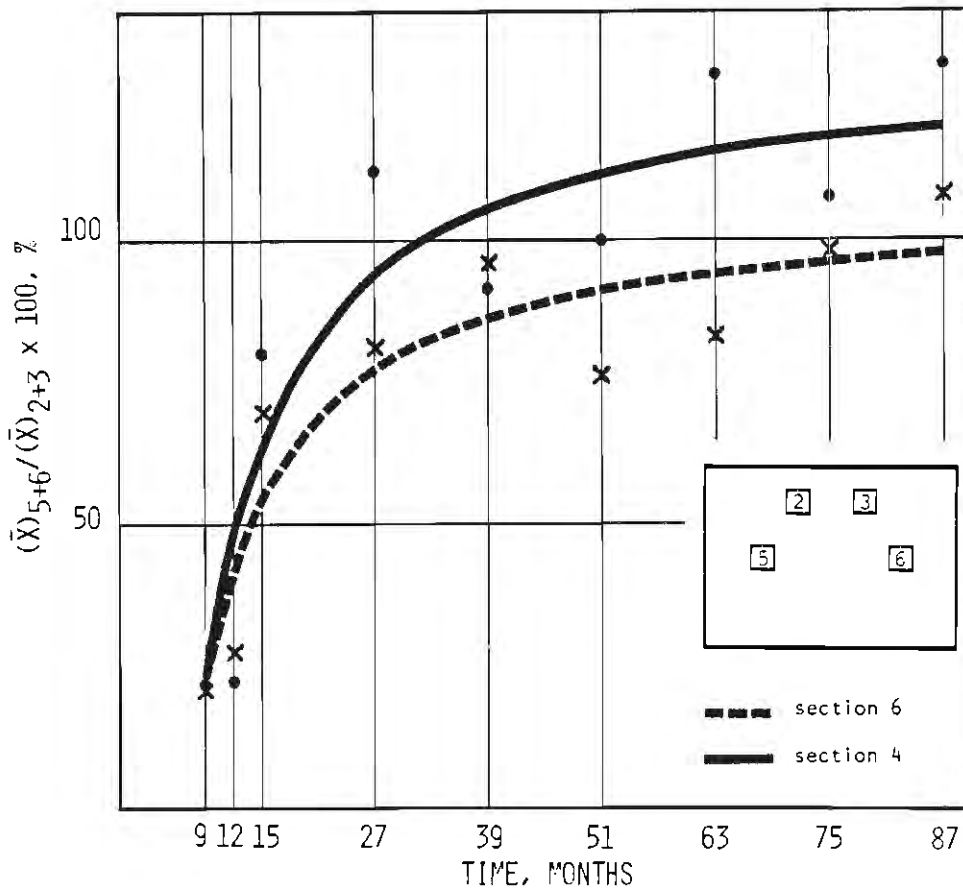


Fig 7. The equilibrating process between upper and middle layers for sections 4 and 6 from the Nässjö test.

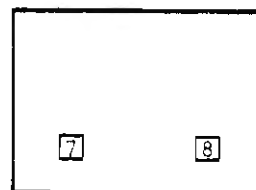
Average percentage boric acid content of samples 5 + 6 in relation to the corresponding average value for samples 2 + 3 from sections 4 and 6 after different times of exposure.

Regarding the boric acid content further down in the sleeper (samples 7 and 8; analyses were carried out for sections 4 and 6 on six occasions) very low values were found, see Table 2 and Fig 6 b. After 27 months the level was $0.1-0.3 \text{ kg/m}^3$. A complete equalization of the boric acid content in the vertical direction had thus not been obtained. The low values for the samples 7 and 8 can be explained by the distance from the injection points; the needles penetrated to 5-6 cm depth and moreover, the boric acid had to diffuse there vertically. The diffusion vertically seems to be not as good as that in the horizontal direction.

The upper part of the sleeper, however, must be considered more vulnerable to decay because of greater split formation and influence from the weather. The lower boric acid content in the lowest part of the sleeper need not be

Tabell 2. Average boric acid content in the combined samples 7 and 8 from sections 4 and 6.

Exposure time, months	Boric acid content, kg/m ³	
	section 4	section 6
9	0,06	0,14
12	0,06	0,08
15	0,06	0,22
27	0,29	0,11
39	0,07	-
51	0,30	0,20



viewed with too much concern although it certainly had been hoped to obtain a higher boric acid content in the wood close to the lowest parts of the spikes.

In Fig 5 b an interesting observation can be made. The boric acid content in the samples 2 and 3 from section 6 was higher than that from section 4 during the course of the investigation. There is probably no simple explanation for this. One possibility is that the samples from section 6 always were extracted from the numbered face of the section, i.e. very close to the injection points (cf Fig 1 and 2), whilst the samples from section 4 were extracted from either the face or the rear of the section. Samples extracted from the face were situated further away from the injection points than was the case for section 6. On average, the boric acid content ought to have been somewhat lower for section 4. Additionally, a higher creosote content in the end of the sleeper could have slowed down the diffusion and thereby contributed to a higher boric acid content in section 6.

Summarizing, it can be said that the boric acid seems to have become distributed fairly well in the zone under the baseplate. In the upper part (to about 10 cm depth) a boric acid content of at least 0.4 kg/m³ was available during the whole period of investigation (about 7 years). Further down the content was lower. The variations in boric acid content were large to start with, but after about three years they stabilized. This indicates that losses caused by leaching thereafter were moderate. However, it must be emphasized, that very big variations appeared between the sleepers. As can be seen in Appendix 2 the standard deviation of the mean was large and on average about 70 % of the mean. This is not surprising as the properties of the wood vary greatly; viz sapwood/heartwood ratio, splits, knots, density, annual growth rings, moisture

content etc. Moreover the varying creosote content as well as mechanical barriers such as spikes or screws can influence the diffusion.

2.2 The Kungsbacka test

Materials and methods

A test site on the line Gothenburg-Malmö south of Kungsbacka was chosen to study the technique developed for remedial treatment under practical conditions and to study the progress of diffusion in a track in use. About 1 000 creosoted redwood sleepers, which had been in service for 17 years, were treated in April 1974. The traffic on the line is roughly 10 million gross tonnes annually.

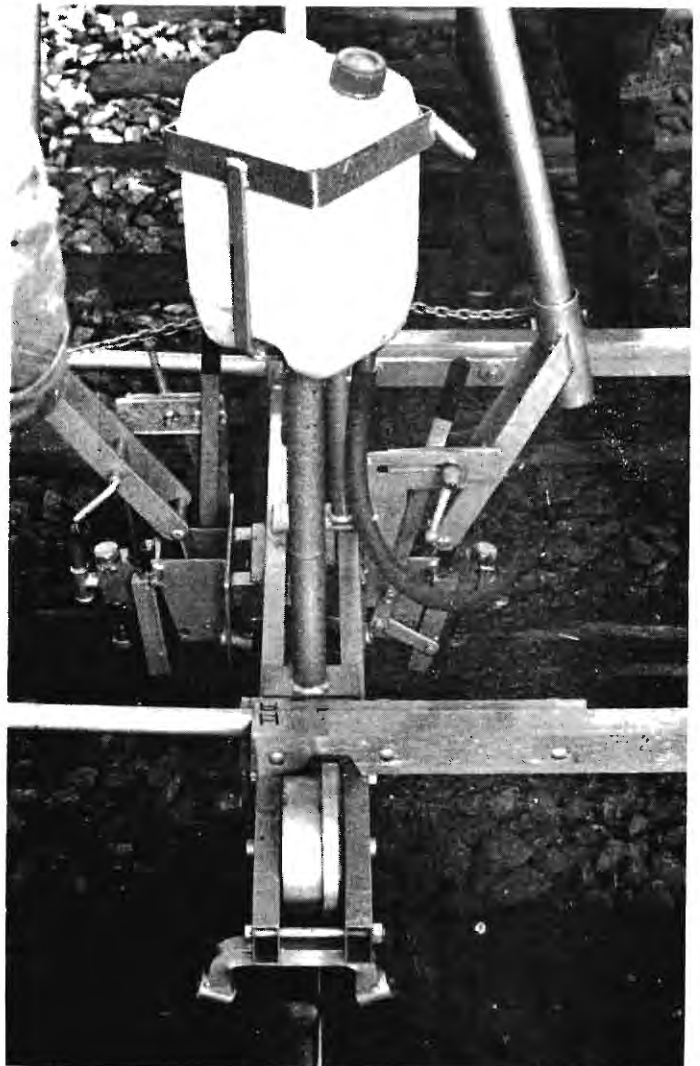
The paste was injected by means of a specially made piece of equipment, Fig 8. The injections were made around the baseplate as shown in Fig 9. The plates were of the Hey-Back type and they were attached to the sleeper by two pairs of symmetrically placed screws. The Hey-Back plate is 50 mm longer (170 x 350 mm) than the plate for the elastic spikes. The ballast was crushed stone class I (30-60 mm) with sub-ballast of gravel and the track was considered to be very well drained.

For the first batch of 116 treated sleepers 22 injections were applied around each baseplate; the remaining sleepers were given 26 injections around each plate. The paste consumption was calculated as for the Nässjö test. The average amount of boric acid/injection was 4.23 g giving about 110 g around each plate. However, not all the paste was applied to the sleeper; a certain excess remained on the surface at the injection points, Fig 10. This surplus had to be removed before the injection area was brushed with coal tar, in order to ensure that the tar adhered fully to the wood.

In order to study the diffusion in the horizontal and vertical directions, samples from five sleepers (10 half sleepers) were analysed after 21, 32 and 44 months of exposure. As the sleepers were taken from a track which was part of a signalling system, sleeper halves from the positive and negative rail were sampled separately in view of the fact that the signalling current might influence the mobility of the ions.



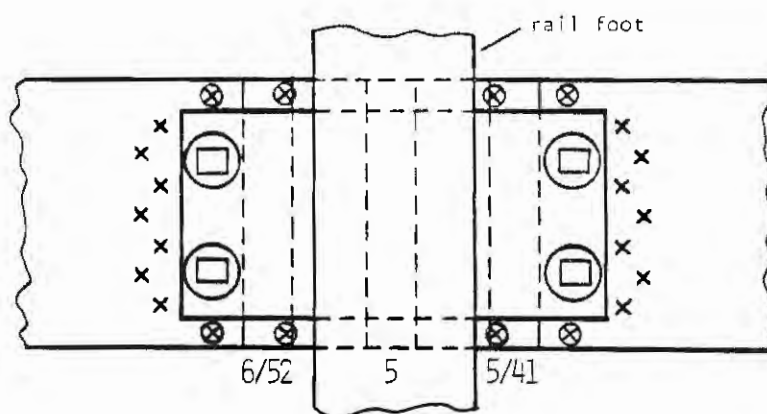
a



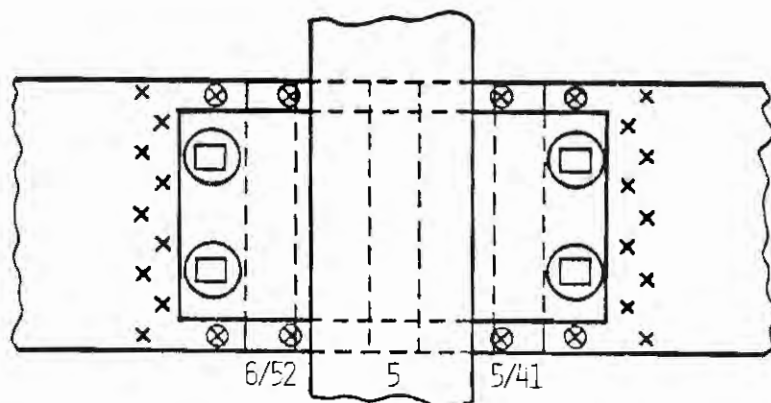
b

Fig 8 a. The equipment used for remedial treatment in the Kungsbackå test.

b. Detail.



a



b

Fig 9 a. Injection pattern of boric acid around the baseplate (170 x 350 mm) of the first batch of 116 treated sleepers in the Kungsbacka test.

b. Injection pattern in the rest of the sleepers in the Kungsbacka test.

Some injections (marked $\otimes$) have been made at approximately 60° angle to the sleeper.

At the first sampling after 21 months of exposure, sections were sawn according to the same pattern as in the Nässjö test, Fig 2. This, however, turned out to be inconvenient as sections 4 and 6 were distorted by the presence of screw holes, making extraction of samples difficult. This was because the dimensions of the rail baseplates in the Kungsbacka test were different from the ones in the Nässjö test. Therefore, a new pattern for sectioning the sleepers was made, Fig 11. Sections 4 and 6 were replaced by sections 5/41 and 6/52. To complete the analyses from the first batch of

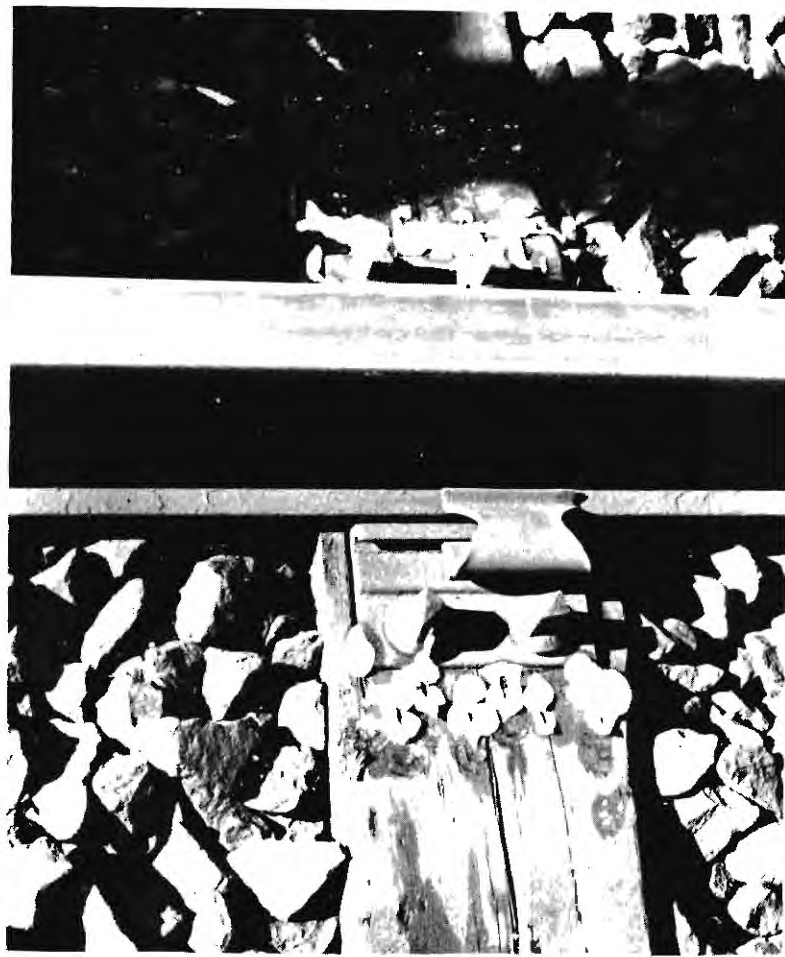


Fig 10. Freshly treated sleeper. Notice the excess paste on the surface at the injection points.

of samples, sections 5/41 and 6/52 were taken from the sleepers of interest.

Samples were taken from each section according to the Nässjö test pattern. In Table 3 the sampling scheme is presented. The leaching method was used for the chemical analysis.

Results

In Appendix 3 all the data from the chemical analyses are given. Average values for the combined samples 2 and 3, 5 and 6 respectively, were calculated as in the Nässjö test.

As only three inspections were made, the data cannot be presented graphically as for the Nässjö test. Fig 12 shows the average boric acid content for

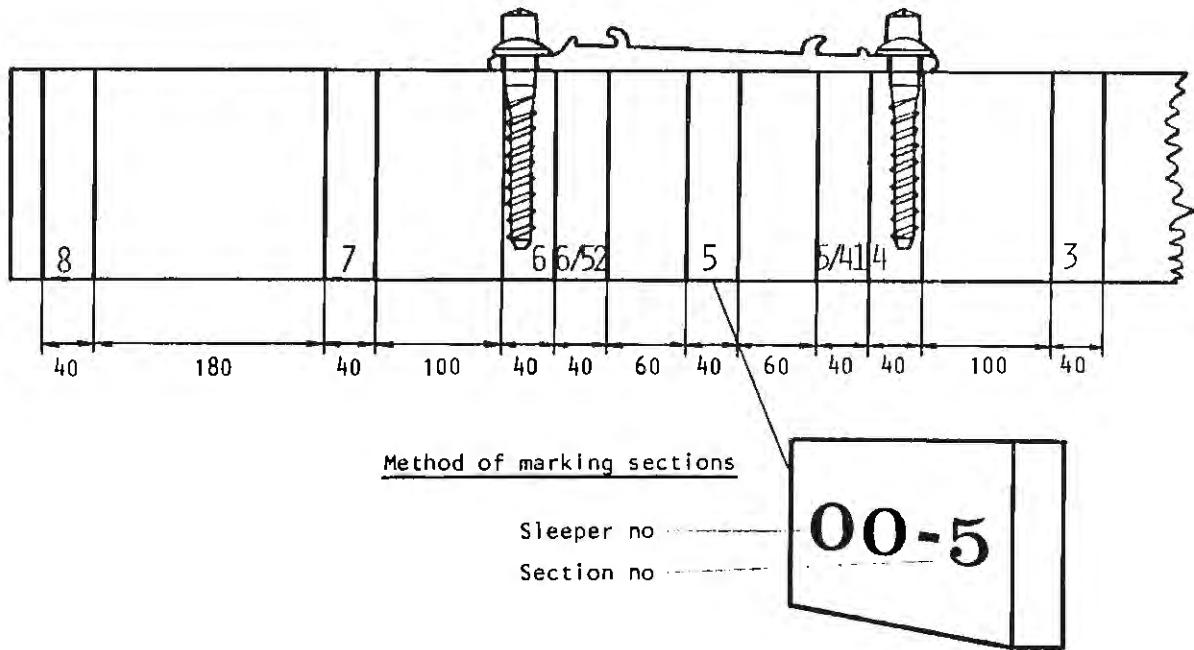
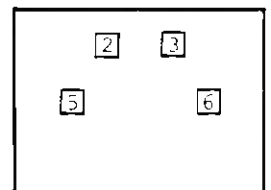


Fig 11. Sectioning pattern for sleepers in the Kungsbacka test.
Measurements in mm.

Table 3. Sampling scheme - the Kungsbacka test

Section No	Samples (nos) taken out after various exposure times			
	21	32	44	months
3	-	2, 3	2, 3	
4	2, 3, 5, 6	-	-	
5/41	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6	
5	2, 3	2, 3	2, 3	
6/52	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6	
6	2, 3, 5, 6	-	-	
7	-	2, 3, 5, 6	2, 3, 5, 6	



Sleeper section

samples 2 and 3 from the sections of interest in the same way as in Fig 5 a. It shows reasonably well the pattern of the horizontal diffusion. Fig 13 shows the vertical diffusion for sections 5/41 and 6/52. There was a difference between the boric acid contents in sleeper halves from positive and negative rails, the boric acid content around the negative rail being generally somewhat higher. This difference has been considered of minor importance. The average boric acid contents presented in Fig 12 and Fig 13 are therefore

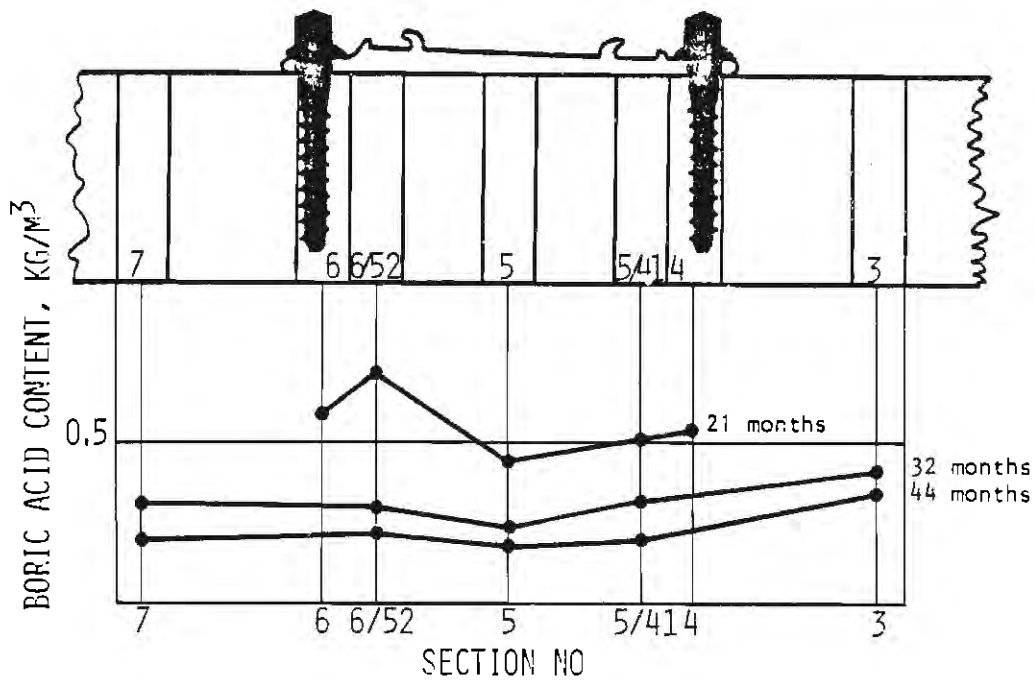


Fig 12. Horizontal diffusion in the Kungsbacka test. Average boric acid content of samples 2 + 3 for the different sections after 21, 32 and 44 months of exposure.

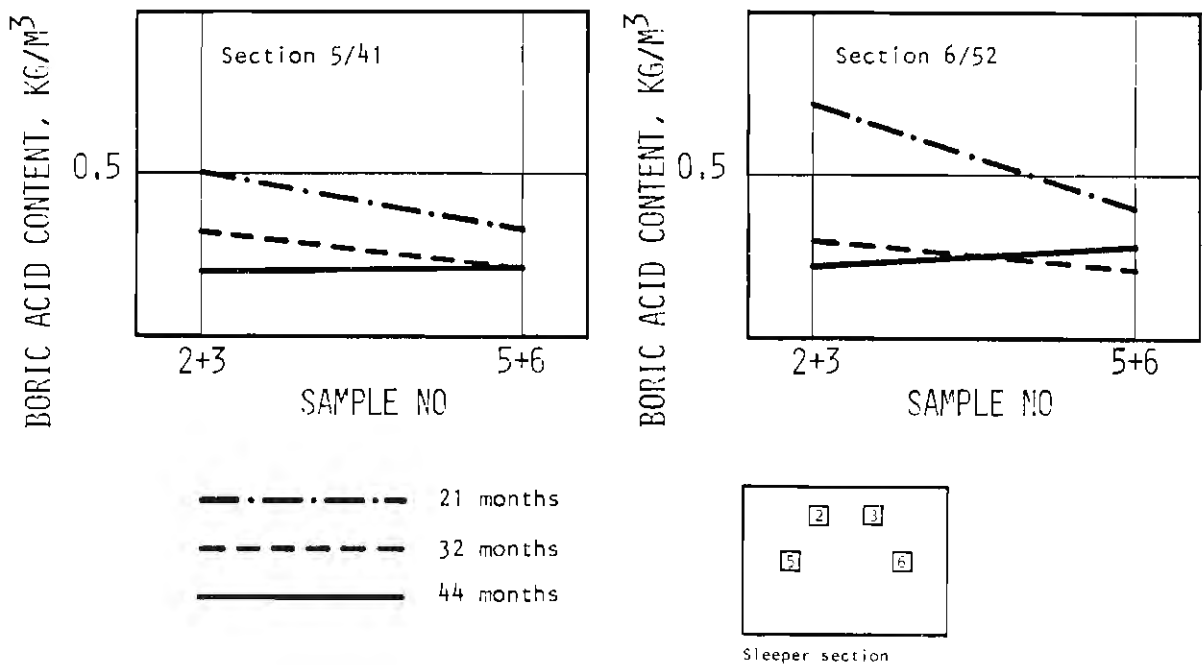


Fig 13. Average boric acid content (kg/m³) in upper and middle layers in (a) section 5/41 and (b) section 6/52 after different exposure times in the Kungsbacka test.

calculated for all sleeper halves involved.

As can be seen from Fig 12 and 13 the boric acid content in the sleepers was already very low at the first sampling after 21 months of exposure (0.5 kg/m^3) and decreased notably at the next sampling at 32 months. The retention levels were considerably lower than those in the Nässjö test and far from adequate for good protection against decay, cf chapter 3. No satisfying explanation to this can be given. However, more boric acid than expected, and more than in the Nässjö test, had probably been lost during the injection, cf Fig 10. Another possible explanation could be the influence of traffic, which might have caused a kind of pumping action leading to paste losses through injection holes and splits during a short period after the injection and before diffusion had started.

The conclusion is that the injection of paste turned out to be inadequate for remedial treatment of sleepers, mainly because a sufficient net amount of boric acid could not be supplied to the sleepers, and also because the procedure was too laborious.

3. BIOLOGICAL TESTS

3.1 Introduction

If a water soluble diffusion-type preservative like boric acid is to be used for remedial treatment of redwood sleepers (*Pinus sylvestris* L) it is necessary to obtain information on the amount of preservative needed to prevent decay in

- untreated sapwood
- sapwood impregnated with low (sub-effective) creosote retentions
- heartwood

A number of reports have been published in the past on the effectiveness of boron compounds against the decay activity of several Basidiomycetes. Various test methods have been used in these studies, e g ASTM 1413, BS 838, DIN 52176 and NF X 41-502 (Becker 1959, Gallagher 1968, Harrow 1950, Jacquot et al 1960, Smith 1969).

Among Basidiomycetes studied in this respect, *Coniophora puteana*, *Lentinus lepideus*, *Gloeophyllum trabeum*, *Antrodia sinuosa*, *Antrodia serialis* and *Poria xantha* are of special interest as potential decay fungi in railway sleepers of redwood. In the studies referred to above these fungi were tested on Baltic redwood and some other *Pinus* species.

Boron compounds involved were boric acid (H_3BO_3), borax ($Na_2B_4O_7 \cdot 10H_2O$) and Timbor^{®1} (disodium octaborate tetrahydrate, $Na_2B_8O_{13} \cdot 4H_2O$). The toxic limits, determined as kg boric acid equivalent/m³, varied considerably from one study to the other. The variations may result from differences in the test methods, fungal strains, wood species and the origin of the timber. With few exceptions the toxic limits were below 1.5 kg/m³ boric acid equivalent for the fungi of interest in the present study.

Generally ASTM 1413 resulted in higher toxic limit values than did the corresponding DIN 52176 and BS 838. In the study by Gallagher (1968) sapwood and heartwood of redwood were compared for resistance to *Coniophora puteana* and *Poria xantha*. The results indicated that the toxic limit in heartwood was about half or less of that in sapwood. However, neither of these two

¹ Registered trade mark of US Borax

fungi are known as heartwood attacking organisms. A fungus like *Lentinus lepideus* may be expected to react differently. The levels of effectiveness obtained in the studies referred to were used for the selection of concentrations and retentions in the present study.

The effect of creosote on the decay of redwood has also been examined in many investigations. Of special interest are studies involving creosoted timber in service. Becker and Hoffmann (1966) studied the decay resistance of creosoted beech and redwood sleepers which had been in service for various periods (3-30 years). Samples extracted from the sleepers were tested according to DIN 52176 and ASTM D 1413-61 against three Basidiomycetes. Analyses showed that creosote-impregnated redwood sapwood resisted decay at retentions above 50 kg/m³. Retentions below that figure as well as attack by the decay fungi were found in redwood sleepers that had been in service for 14 years or more. So there was a good correlation between laboratory tests and sleepers in service.

Becker and Starfinger (1967) examined the effect of artificial ageing on the decay resistance of creosoted redwood sapwood. Different fractions (low and high-boiling) from different creosote oils were used in the test. The authors concluded that ageing of creosote is mainly characterized by the loss of low-boiling fractions. This, however, does not significantly influence the durability of the fungicidal efficacy, for which "the quantity of high-boiling compounds of the oil remaining in the wood is determinative".

Smith and Savory (1964) examined aged creosote extracted from impregnated wood after 30 years of service. They found that the old extracted creosote was as effective as new creosote against *Lentinus lepideus*, when wood blocks were impregnated and tested in the laboratory. The studies on creosote referred to show that, with the exception of the low-boiling types, creosote oil remains effective against decay fungi even after a considerable number of years in service. This verification justified the use of fresh, non-aged creosote in the present investigation.

The protective effect of diffusible wood preservatives on creosoted wood with low creosote retentions has partly been studied by Fahlstrom (1964). By using the American soil-block technique (ASTM D 1413) with southern pine specimens he could show that, compared with non-creosoted wood, the toxic

limit for borax against *Lentinus lepidus* was reduced from 0.80-1.12 kg/m³ to 0.16-0.48 kg/m³ for creosote retentions of about half (32 kg/m³) the effective level (78 kg/m³). He thus found that the combined effect of borax and creosote oil was considerably higher than each of the preservatives used separately. This has also been borne in mind in the present study.

3.2 Materials and methods

This study was divided into two parts:

- testing of the combined effect of creosote oil and boric acid on the decay of redwood sapwood (*Pinus sylvestris* L)
- testing of boric acid with redwood heartwood

In addition chemical analyses were carried out to complement the biological tests.

For the first part of the test, sapwood blocks 20 x 20 x 20 mm were treated according to a full cell process with creosote oil dissolved in toluene in the following concentrations: 10, 6.7, 3.3, 1.7 and 0.8 %. These concentrations were estimated to give the following approximate retentions of creosote in the blocks: 60, 40, 20, 10 and 5 kg/m³. One hundred blocks were treated with each concentration. One hundred blocks were also treated with toluene only. The creosote was obtained from the Swedish State Railways and it complied with the requirements of the Scandinavian specification for creosote from 1936.

After complete evaporation of the toluene, the creosote-impregnated blocks were submitted to a full cell impregnation with aqueous solutions of boric acid of the concentrations: 0.17, 0.08, 0.03 and 0.017 % to give approximate retentions of 1.0, 0.5, 0.20 and 0.10 kg/m³. Twenty blocks of each creosote retention were treated with each boric acid concentration.

The toluene-treated blocks represented the creosote retention of 0 kg/m³. The set of samples of "varying creosote retentions, boric acid retention 0 kg/m³" was obtained by treating 20 blocks of each creosote retention and 20 toluene-treated blocks with distilled water. In the same way "varying boric acid retentions, creosote retention 0 kg/m³" was obtained

by treating 20 toluene-treated blocks with each boric acid solution. Untreated blocks were used as controls.

After the second impregnation the blocks were air-seasoned at room temperature and then dried at 102 °C for 24 hours whereupon the dry weights were determined. The blocks were then stored in sterile Petri dishes. Two days before the decay test started the Petri dishes were transferred to a heating cabinet and kept at 50 °C. The blocks were then introduced in the culture vessels. The vessels consisted of 500 ml glass jars fitted with cotton plugs. The jars, which were kept horizontally, contained approximately 150 ml malt extract agar (1.5 % agar-agar and 2.5 % malt extract). A nylon net was placed on the agar surface. The culture vessels were inoculated with one of the following Basidiomycetes fungi:

Lentinus lepideus, strain BK C-1

Gloeophyllum trabeum, strain A 570

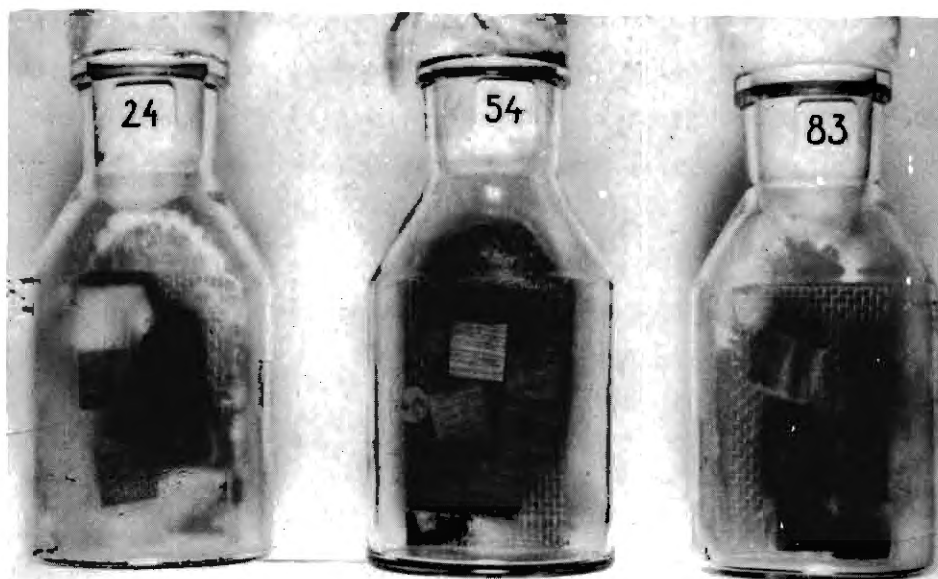
Antrodia sinuosa, strain BK C-196

The inoculation took place two weeks before the introduction of the test blocks.

Six blocks were introduced into each culture vessel, see Fig 14. Five of the blocks were treated with the same creosote concentration but representing the whole range of boric acid retentions. The sixth block was an untreated control. Five blocks per creosote/boric acid combination were used for each test fungus. The incubation period was six months. The blocks were then removed from the culture vessels and the weight changes and moisture contents determined. Impregnated blocks not used in the decay test were saved for chemical analysis.

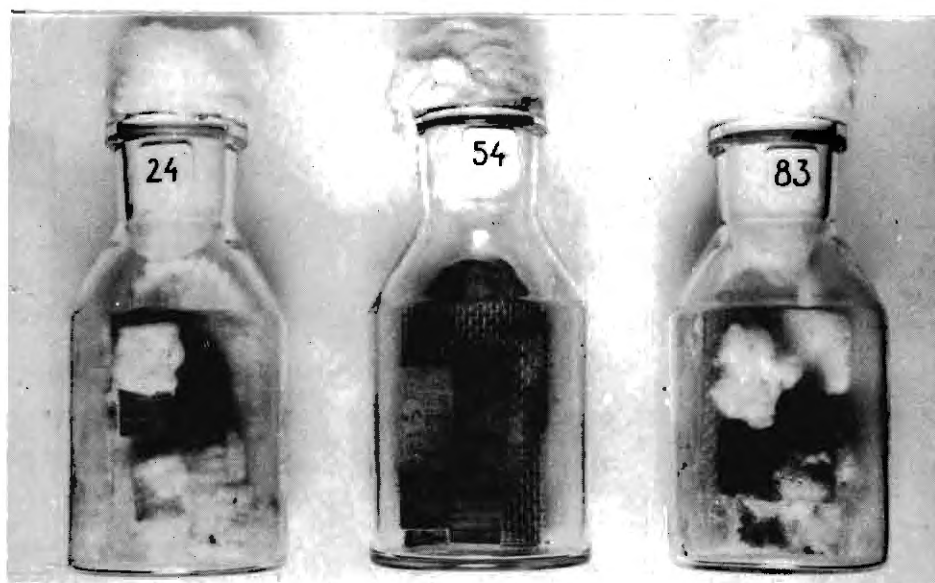
In the second part of the test, heartwood blocks 20 x 20 x 20 mm of redwood were treated using the vacuum/pressure process with the same boric acid solutions as were used in the first part. After the impregnation the blocks were left in the solution for two weeks whereupon a second vacuum/pressure treatment was applied.

The retentions for all blocks were determined by weighing directly after impregnation, conditioning at room temperature, drying at 102 °C for 24 hours and reweighing. They were then stored and treated similarly to the blocks in the first part of the test. *Lentinus lepideus* strain BK C-1 and *Gloeophyllum trabeum* strain A 570 were used as test fungi.



Kreosotimpregnering i kombination med borsyra

a



Kreosotimpregnering i kombination med borsyra

b

Fig 14. The decay tests were carried out in culture vessels as shown above. The photographs show tests of some creosote and boric acid treated blocks after (a) one month and (b) two months.

As can be seen the fungal attack in vessels 24 and 83 has increased significantly during the period.

In addition to the biological testing, chemical analyses were carried out. A number of impregnated test blocks were sent to Borax Holdings Ltd for chemical analysis of the boric acid content. This was performed to check

if the retentions calculated on the basis of uptake and concentration of treating solution were reliable. The leaching method was used. In order to get an idea of the amount of creosote remaining in the boric acid treated sleeper a number of sleepers from the Nässjö test were analysed during the autumn of 1978. From the section between section 4 and section 5 (see Fig 2) samples corresponding to the positions of samples 2 and 3 (see Fig 3) were taken out and sent to Borax Holdings Ltd for analysis of the creosote content according to AWP Standard A6-59.

3.3 Results

Decay tests with sapwood samples

The results of the decay tests with sapwood samples are shown in Tables 4, 5 and 6. From these it is evident that *Lentinus lepideus* was more resistant than the other fungi to both creosote oil and boric acid. *Gloeophyllum trabeum* and *Antrodia sinuosa* were so sensitive to creosote oil that the weight losses of the control samples were strongly reduced in culture vessels containing samples treated to the highest creosote retentions. The broken lines in the tables indicate approximate toxic limits, i.e. the minimum tested retention for prevention of attack for various combinations of creosote oil and boric acid. The toxic limit for the creosote/boric acid combination is therefore considered as that which corresponds to an average maximum weight loss of 2.5 %. At the same time the weight loss for an individual sample must not exceed 3 %.

Neither creosote nor boric acid in the tested retention range was alone able to prevent attack from *Lentinus lepideus*. On average, creosote retentions of 50 and 35 kg/m³ in addition to 0.5 and 1 kg/m³ boric acid, respectively, were needed. Lower creosote and boric acid retentions resulted in measurable attack even though the weight losses were relatively small for all the series with the highest boric acid retention. All retentions were calculated on the basis of uptake and concentration of the treating solutions used for impregnation. For *Gloeophyllum trabeum* and *Antrodia sinuosa* no decay was noted at creosote retentions above 33 kg/m³ and at boric acid retentions above 0.46-0.48 kg/m³.

Table 4. Percentage loss in dry mass of redwood sapwood samples treated to various retentions with creosote oil and boric acid after 6 months' exposure to *Antrodia sinuosa*.

Figures in brackets indicate minimum and maximum retentions and weight losses respectively. K = untreated controls.

Boric acid retention, kg/m ³	Creosote retention, kg/m ³					
	49,7 (39,5 - 50,1)	33,2 (26,7 - 38,4)	16,0 (11,6 - 18,6)	8,7 (5,8 - 10,5)	4,5 (3,5 - 4,7)	0
1,00 (0,92 - 1,10)	0,3 (-2,9 - 1,8)	-0,5 (-1,5 - 0)	0,3 (-0,3 - 0,8)	0,2 (-1,5 - 0,3)	0,6 (0 - 1,1)	0,2 (0 - 0,43)
0,48 (0,44 - 0,50)	2,3 (1,8 - 2,9)	0,9 (-0,3 - 2,2)	1,2 (0,6 - 1,6)	1,2 (0,8 - 1,6)	0,3 (-0,9 - 0,9)	0,7 (0 - 1,3)
0,17 (0,13 - 0,19)	2,1 (1,8 - 2,7)	1,6 (0,7 - 2,4)	0,9 (0,3 - 1,7)	1,7 (-0,3 - 4,2)	18,4 (5,6 - 23,8)	9,8 (3,6 - 21,1)
0,10 (0,08 - 0,11)	2,3 (1,8 - 2,8)	1,8 (1,4 - 2,1)	8,2 (1,4 - 16,9)	10,4 (1,9 - 18,9)	20,4 (16,3 - 37,4)	40,2 (31,0 - 49,8)
0	2,3 (0,3 - 2,9)	1,4 (0,4 - 2,0)	14,4 (8,8 - 20,5)	20,6 (13,3 - 29,5)	34,6 (20,3 - 60,8)	39,4 (32,6 - 47,8)
K	5,4 (-0,3 - 12,9)	6,0 (3,0 - 10,3)	23,7 (0 - 49,2)	20,9 (-6,6 - 44,5)	24,4 (15,1 - 33,8)	14,11 (9,9 - 22,4)

Table 5. Percentage loss in dry mass of redwood sapwood samples treated to various retentions with creosote oil and boric acid after 6 months' exposure to *Gloeophyllum trabeum*.

Figures in brackets indicate minimum and maximum retentions and weight losses respectively. K = untreated controls.

Boric acid retention, kg/m ³	Creosote retention, kg/m ³					
	50,0 (40,7 - 53,5)	33,6 (23,3 - 39,5)	16,7 (11,6 - 20,9)	8,5 (5,8 - 10,5)	4,4 (3,5 - 4,7)	0
0,97 (0,90 - 1,00)	1,8 (1,4 - 2,1)	2,0 (1,5 - 2,5)	1,1 (0,8 - 1,4)	0,8 (0,6 - 1,1)	0,7 (0,5 - 1,2)	0,7 (0,5 - 0,9)
0,46 (0,40 - 0,52)	2,8 (1,7 - 3,0)	1,5 (1,3 - 1,7)	0,9 (-2,0 - 2,11)	0,7 (-0,3 - 1,0)	0,9 (0,3 - 1,2)	1,0 (0,5 - 1,5)
0,17 (0,13 - 0,19)	2,2 (1,1 - 3,0)	2,0 (1,7 - 2,2)	1,4 (0,9 - 2,2)	3,4 (1,4 - 6,3)	6,2 (1,4 - 9,2)	12,6 (5,6 - 24,5)
0,10 (0,08 - 0,11)	2,5 (2,0 - 3,2)	2,1 (1,3 - 2,6)	3,5 (1,6 - 7,8)	8,6 (2,6 - 14,6)	12,9 (7,9 - 16,1)	16,0 (12,7 - 19,2)
0	2,2 (0,5 - 3,5)	2,0 (1,6 - 2,7)	7,2 (2,5 - 10,2)	16,1 (12,1 - 19,0)	14,9 (12,2 - 17,2)	19,8 (14,3 - 24,8)
K	2,5 (-0,3 - 5,6)	6,4 (3,6 - 10,0)	9,6 (4,9 - 12,2)	7,3 (5,1 - 9,2)	9,2 (4,4 - 10,7)	12,3 (7,6 - 15,1)

Table 6. Percentage loss in dry mass of redwood sapwood samples treated to various retentions with creosote oil and boric acid after 6 months' exposure to *Lentinus lepideus*.

Figures in brackets indicate minimum and maximum retentions and weight losses respectively. K = untreated controls.

Boric acid retention, kg/m ³	Creosote retention, kg/m ³					
	48,9 (30,2 - 59,0)	35,0 (29,1 - 41,9)	14,8 (11,6 - 18,6)	8,6 (7,0 - 10,5)	4,3 (3,5 - 4,7)	0
0,96 (0,90 - 1,02)	2,1 (2,0 - 2,4)	1,8 (1,4 - 2,2)	2,4 (1,1 - 4,5)	2,3 (1,2 - 4,0)	4,0 (-3,7 - 10,9)	5,2 (0,8 - 9,4)
0,46 (0,40 - 0,52)	2,3 (1,9 - 2,8)	3,2 (2,1 - 4,2)	8,7 (2,4 - 17,2)	12,6 (3,5 - 20,1)	21,4 (12,1 - 26,9)	26,4 (15,3 - 42,6)
0,17 (0,13 - 0,20)	2,7 (2,4 - 3,1)	5,2 (3,0 - 10,1)	21,4 (17,9 - 26,4)	33,6 (29,1 - 43,9)	26,0 (18,9 - 35,3)	28,9 (21,8 - 32,9)
0,10 (0,08 - 0,11)	2,9 (2,2 - 5,3)	8,3 (3,2 - 11,2)	31,7 (30,3 - 34,4)	37,3 (33,3 - 44,1)	30,4 (24,2 - 42,9)	33,1 (26,0 - 38,0)
0	4,2 (3,6 - 6,1)	14,4 (8,8 - 20,9)	35,5 (30,0 - 40,8)	38,6 (34,8 - 45,4)	35,1 (25,5 - 40,1)	33,9 (26,3 - 37,7)
K	26,2 (20,2 - 33,5)	31,0 (28,1 - 35,4)	31,6 (17,6 - 42,7)	22,9 (17,3 - 27,9)	19,5 (11,9 - 26,4)	20,6 (17,8 - 25,1)

Table 7. Percentage loss in dry mass of redwood heartwood samples treated to various retentions with boric acid after 6 months' exposure to *Lentinus lepideus* and *Gloeophyllum trabeum*.

Figures in brackets indicate minimum and maximum retentions and weight losses respectively.

<i>Lentinus lepideus</i>		<i>Gloeophyllum trabeum</i>	
Boric acid retention, kg/m ³	Loss in dry mass, %	Boric acid retention, kg/m ³	Loss in dry mass, %
1,25 (1,13 - 1,57)	2,7 (0 - 14,5)	1,20 (1,13 - 1,38)	0,3 (0 - 0,6)
0,69 (0,63 - 0,75)	14,7 (2,7 - 33,2)	0,72 (0,61 - 0,92)	2,2 (0,6 - 6,0)
0,22 (0,19 - 0,25)	26,1 (16,6 - 32,2)	0,21 (0,19 - 0,24)	3,6 (0,3 - 12,3)
0,13 (0,01 - 0,15)	31,0 (26,3 - 39,5)	0,12 (0,09 - 0,13)	5,4 (1,1 - 13,5)
0	35,6 (29,2 - 44,5)	0	16,7 (7,1 - 30,3)

Decay tests with heartwood samples

Results are presented in Table 7. The boric acid retentions calculated from the uptake and concentration of the treating solution are corrected for the difference between calculated retention and the actual amount of boric acid found by analysis (see Table 9). *Lentinus lepideus* was clearly more resistant to boric acid in redwood heartwood than was *Gloeophyllum trabeum*. Retentions of 1.13-1.38 kg/m³ were sufficient to completely prevent decay from the latter fungus. The toxic limit for *Gloeophyllum trabeum* is probably within the range of 0.61-0.92 kg/m³ and that for *Lentinus lepideus* within the range of 1.13-1.57 kg boric acid/m³.

Boric acid analyses

The retentions determined by chemical analyses of the test blocks were compared with the retentions calculated on the basis of uptake and concentration of the treating solution. For the sapwood samples the calculated values generally corresponded very well with those obtained by analysis, see Table 8. For heartwood samples, however, the calculated boric acid contents of the treated samples differed significantly from those found by chemical analysis, see Table 9. It can be suspected that the unexpectedly high figures for loadings of boric acid shown in the last column of Table 9 are ascribable to a cumulative error incurred in the determination of the strength of the boric acid solution used and in the analysis.

Creosote analyses

The results from the creosote analyses are presented in Table 10. As can be seen the retention figures vary from below 10 to approximately 70 kg/m³. The average retention is 22 kg/m³ with a standard deviation of 17.3 kg/m³. The high value of the standard deviation can be due to e.g. different retentions from the beginning, gradient factors depending on the depth of the penetration and whether the sample was taken from heartwood or sapwood. At the sampling it was often very difficult to see if the sampling sites (corresponding to positions 2 and 3, cf Fig 3) were in sapwood or heartwood. The section surfaces were often so dark either due to the creosote itself or through ageing, that the boundary between heartwood and sapwood could not be detected. Several of the analysed samples, however, originated from heartwood, which partly explains the low retentions. Under all circumstances, the analyses verified that the retentions used in the biological tests were realistic compared with retentions for sleepers in service.

Table 8. Boric acid analyses. Comparison of retention calculations for sapwood samples.

Concentration of treating solution		Boric acid content in test blocks ¹	
Creosote oil, %	Boric acid, %	Calculated on retention and concentration of solution at impregnation, % w/w	Determined by chemical analysis, % w/w
10,0	0,017	0,019	0,019
6,7	"	0,021	0,014
3,3	"	0,019	0,019
1,7	"	0,022	0,022
0,8	"	0,027	0,025
0	"	0,024	0,022
10,0	0,03	0,027	0,030
6,7	"	0,037	0,037
3,3	"	0,037	0,030
1,7	"	0,047	0,030
0,8	"	0,043	0,030
10,0	0,08	0,083	0,100
6,7	"	0,097	0,100
3,3	"	0,090	0,100
1,7	"	0,127	0,140
0,8	"	0,117	0,117
0	"	0,107	0,130
10,0	0,17	0,173	0,180
6,7	"	0,237	0,217
3,3	"	0,183	0,200
1,7	"	0,187	0,210
0,8	"	0,213	0,223
0	"	0,220	0,223

¹ average for 3 blocks

Table 9. Boric acid analyses. Comparison of retention calculations for heartwood samples.

Boric acid concentration of treating solution, %	Boric acid content in test blocks ¹	
	Calculated on retention and concentration of solution at impregnation, % w/w	Determined by chemical analysis, % w/w
0,017	0,023	0,031
0,03	0,038	0,047
0,08	0,096	0,147
0,17	0,210	0,252

¹ average for 5 blocks

Table 10. Creosote analyses. Creosote content of some examined sleepers from the Nässjö test.

Sleeper no	Sample no	Creosote content ¹ , %	Creosote content ² , kg/m ³
4	2	5,1	24,5
4	3	9,7	46,5
6	2	12,6	60,5
6	3	8,5	40,8
8	2	3,6	17,3
8	3	7,9	37,9
10	2	9,0	43,2
10	3	9,1	43,7
20	2	8,5	40,8
20	3	3,3	15,8
42	2	1,9	9,1
42	3	1,9	9,1
44	2	2,9	13,9
44	3	3,8	18,2
49	2	9,5	45,6
49	3	15,7	75,4
50	2	2,8	13,4
52	2	2,3	11,0
52	3	5,8	27,8
57	2	2,4	11,5
57	3	3,6	17,3
58	2	4,9	23,5
58	3	4,6	22,1
61	2	0,5	2,4
61	3	4,5	21,6
69	2	2,6	12,5
69	3	0	0
73	2	2,5	12,0
73	3	5,6	26,9
77	2	4,1	19,7
82	2	1,5	7,2
86	2	3,5	16,8
86	3	12,8	61,4
92	2	2,5	12,0
92	3	2,1	10,1
94	2	0	0
94	3	8,0	38,4
96	2	0	0
96	3	1,2	5,8
98	3	0	0
100	2	1,4	6,7
100	3	1,5	7,2
143	2	1,5	7,2
143	3	1,7	8,2
145	2	7,5	36,0
145	3	4,4	21,1
147	2	7,8	37,4
147	3	5,4	25,9
151	2	0	0
153	2	5,7	27,4
155	2	4,6	22,1
155	3	6,3	30,2

¹The samples were extracted from the remaining section between sections 4 and 5, of Fig 2.

The quantity of each sample supplied for analysis was quite small, in some cases less than 1 g. To eliminate the need for separate condensing and measuring of the water present in such small samples prior to analysis, each sample was conditioned at 65 % RH. After such conditioning the moisture content would normally be 12 % by weight of oven dry wood. This assumption was made in the calculation of the creosote retention based upon the weight loss recorded after toluene extraction in AWP Method A6-59.

²By calculating the creosote content in kg/m³ *sapwood* the density of the sapwood has been assumed to be 480 kg/m³.

3.4 Summary and discussion

The biological tests have clearly shown that *Lentinus lepideus* is more resistant to creosote-boric acid combinations than the other two fungi investigated. Therefore, this fungus is particularly relevant for the discussion of the results.

To obtain an acceptable additional protection of the inner parts of the creosoted sapwood, boric acid retentions of at least 0.5 kg/m^3 , see Tables 6 and 10, are required. However, no complete retardation of the growth is obtained in all parts with a creosote content below 35 kg/m^3 , i.e. $1/4$ of the normal retention. Nevertheless, the possibilities for the fungus to grow are so strongly reduced, that attack can only develop very slowly, at least down to creosote retentions of $8-9 \text{ kg/m}^3$. If there are untreated zones in the sapwood, retentions of at least 1 kg/m^3 , probably 1.5 kg/m^3 , are required to completely stop the growth of fungi.

The results from the tests with redwood heartwood showed significant variations of weight loss even for the highest boric acid retentions. A number of various factors can have caused this variation; different original content of pino-sylvinphenols, differences in penetration and diffusion of the boric acid etc. However, it seems that retentions of $1-1.5 \text{ kg/m}^3$ are necessary to give an effective protection against *Lentinus lepideus*.

If the levels mentioned are compared with the results from the creosote and boric acid analyses from the Nässjö test, one can say that the most critical parts (corresponding to position 2 and 3 in section 4 and 6) in the creosoted sapwood after remedial treatment retained an acceptable protection during the whole period of the investigation, see Fig 5 a-b, Fig 6 a-b and Table 10.

As to the untreated sapwood and heartwood, a sufficiently high boric acid was never obtained just under the baseplate (section 5), whilst a fairly good protection (about 1 kg/m^3 or more) was obtained for 40-50 months for sections 4 and 6, see Fig 5 a-b and Fig 6 a-b.

The boric acid analyses from the Kungsbacka test (Fig 13) show that a fairly good protection was obtained only for the upper layer of the sleeper for approximately 20 months, assuming that the wood contained some creosote. The

boric acid content was too low to give an acceptable protection in untreated parts of the sapwood and in the heartwood.

An interesting question is how much boric acid is required to kill the mycelium of an established attack. In other words: what is the lethal dose? In an investigation by Roff (1969) such phenomena have been studied for Western hemlock (*Tsuga heterophylla*). He inoculated a number of various fungi in fresh pieces of roundwood. When the fungi were properly established in the wood samples, these were treated with Timbor. After 12 months' incubation the samples were investigated for living mycelia and boric acid content. Roff found that the lethal dose for the most resistant fungi, to which both *Coniophora puteana* and *Gloeophyllum trabeum* belonged, was 0.40-1.06 % boric acid equivalent based on oven-dry wood. This would correspond to 2-5 kg/m³. As the density of Baltic redwood is close to that of Western hemlock, one can assume that these figures are relevant also for Baltic redwood.

If the assumed lethal doses are compared with the observed boric acid retentions in the Nässjö test, it is evident that the wood around sampling points 2 and 3 in sections 4 and 6 was sterilized during the first 15-20 months after the treatment. Any attack by decay fungi in this zone has not just been retarded, but growing mycelia have been killed. A recolonization is required for the rotting process to continue when the boric acid content drops below the toxic limits, see Tables 4-6.

4. EFFECT OF BORIC ACID ON THE ELECTRICAL RESISTANCE OF A SLEEPER

A wooden railway sleeper conducts electric current to a certain extent, depending on e.g. moisture content, wood species and type of impregnation, see Fig 15.

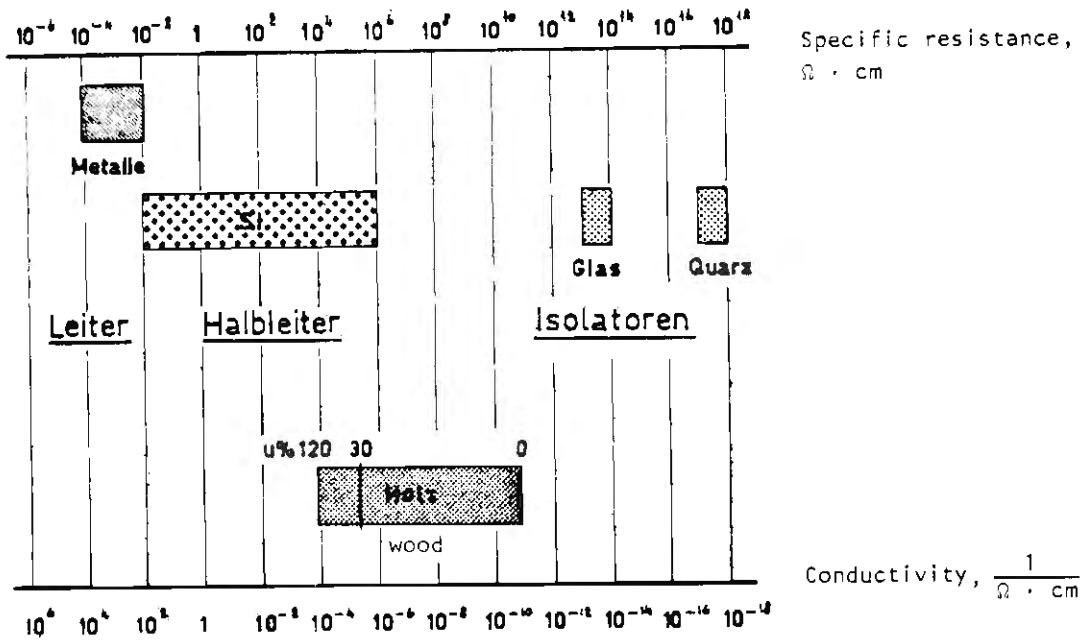


Fig 15. Specific resistance and conductivity outlined for wood and some other materials (Holzschwellenhandbuch, 1963).

In order to facilitate the use of rails as part of a signalling system it is necessary that the sleepers have a certain minimum electrical resistance. Otherwise, leakages of current can seriously interrupt the functioning of the signals. Generally, a minimum limit value is permitted per km of track. Different railway administrations have different requirements, usually varying between 1 and 4 ohm/km. The Swedish State Railways have 2 ohm/km as their limiting value.

When a remedial treatment of a sleeper is carried out with salt preservatives, the resistance can decrease significantly. An experiment on a limited number of sleepers was carried out to study the effect of boric acid on the resistance. After 6 months' exposure, 11 sleepers from the Nässjö test were selected for a test at the SJ Civil Engineering Laboratory. The sleepers were installed in May 1971 in a test track with heavily polluted gravel ballast. Between the plates on every sleeper a potential difference of 6 V was applied, Fig 16.

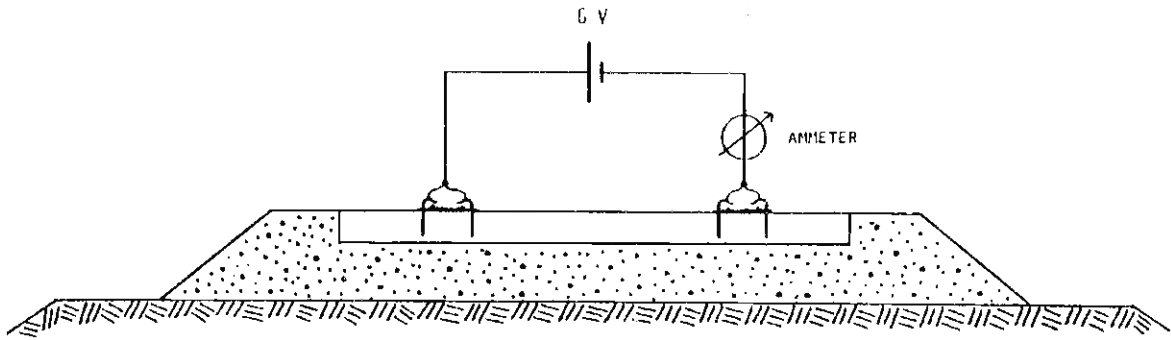


Fig 16. Measuring the electrical resistance of a railway sleeper.

Current and voltage were recorded for each sleeper after different times of exposure for about 4 years. Measurements were made at different seasons to get the extreme values. The resistance is dependent on many factors. In addition to the number of free ions, moisture content and temperature strongly influence the resistance. It is low when sleepers and ballast are very damp, which occurs during autumn and spring. Extremely high resistance is obtained at very low temperatures, below zero, when sleepers as well as ballast are frozen.

The resistance for each sleeper was calculated according to Ohm's law:

$$R_i = U_i / I_i \quad i = 1-11$$

In Table 11 and Fig 17 recorded minimum and maximum values as well as calculated average values for each point of measurement are presented. All recorded values have thus been considered. The calculated values of the resistance are expressed as electrical resistance (ohm) per km track, where the sleepers constitute a number of resistances connected in parallel. The distance between the sleepers was 650 mm giving 1540 sleepers per km track.

In Fig 18, the progress of the average, maximum and minimum resistance is schematically shown. The three graphs in this figure are based only on measurements made at temperatures (air) above 0 °C. Extremely high values have thus been excluded. As can be seen, the average resistance is well above the limiting value 2 ohm/km, and there was no evidence of any significant difference from the resistance in just creosoted sleepers of the same age.

The minimum curve in Fig 17 shows many very low values; however, nearly all minima were recorded for the same sleeper, viz no 11 in the test. The low values probably depended on the sleeper itself and it would undoubtedly have shown low values even without the boric acid treatment.

Table 11. Electrical resistance of sleepers in test track.

Date of measurement	Exposure time, months	Resistance, ohm/km track		
		Min	Max	Average
1971-05-28	0	2,0	27,8	9,60
06-10	0,4	1,9	20,2	8,28
06-21	0,8	2,5	18,4	8,66
06-28	1,0	1,5	18,2	8,93
07-15	1,6	1,5	20,3	6,79
08-13	2,5	1,2	29,8	7,99
09-06	3,3	1,4	27,8	10,25
10-29	5,0	1,58	48,75	11,97
12-31	7,1	3,03	60,0	20,66
1972-03-17	9,6	1,7	27,8	7,73
04-13	10,5	1,4	26,0	7,20
07-20	10,7	1,7	30,9	7,62
08-15	14,6	1,64	25,53	8,31
12-01	18,1	1,88	26,46	8,44
1973-04-04	20,2	1,98	23,97	7,97
06-20	24,7	2,03	27,50	8,24
08-17	26,6	1,57	33,09	8,65
09-28	28,0	3,99	35,10	11,38
11-22	29,8	1,85	26,93	7,91
1974-03-08	33,3	2,60	35,75	12,18
07-26	37,9	1,60	37,05	10,31
1975-02-28	45,0	3,01	31,91	10,89
05-30	48,1	2,30	33,09	9,39
08-28	51,0	1,27	37,70	11,08

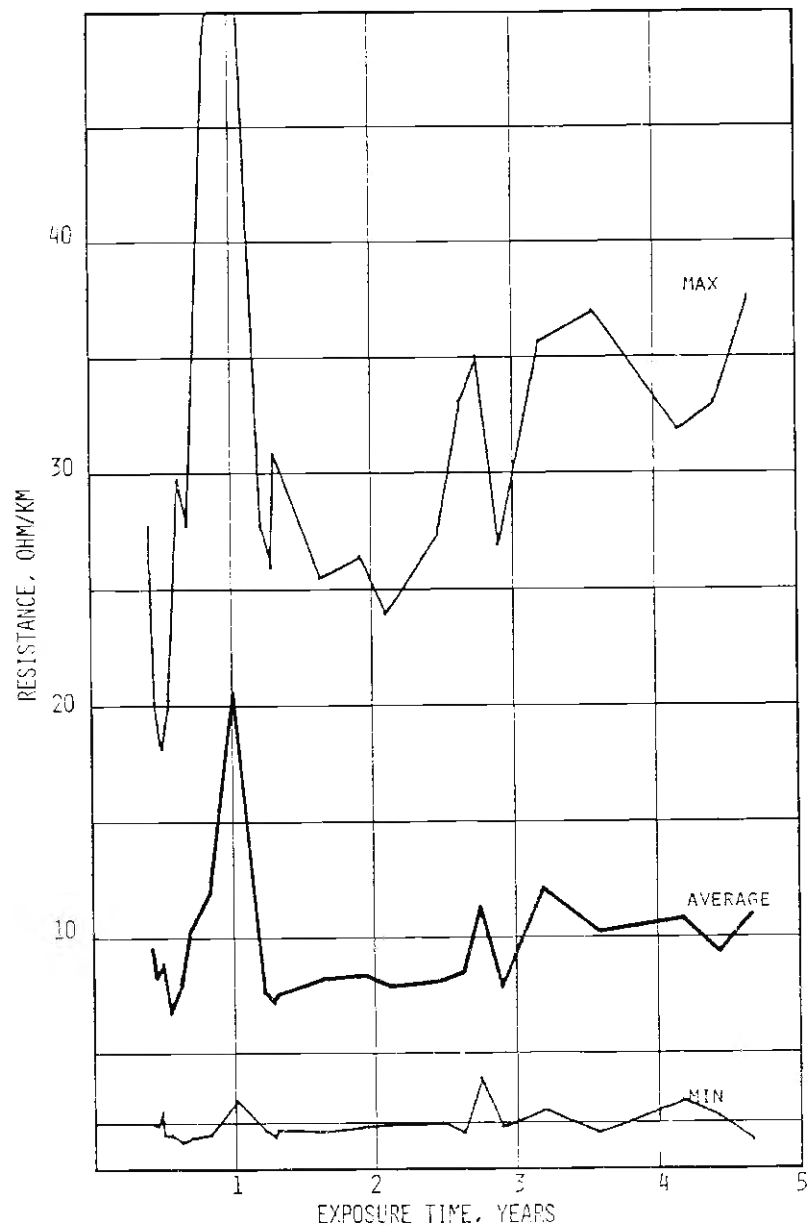


Fig 17. Electrical resistance (ohm/km) of sleepers in test track after different exposure times.

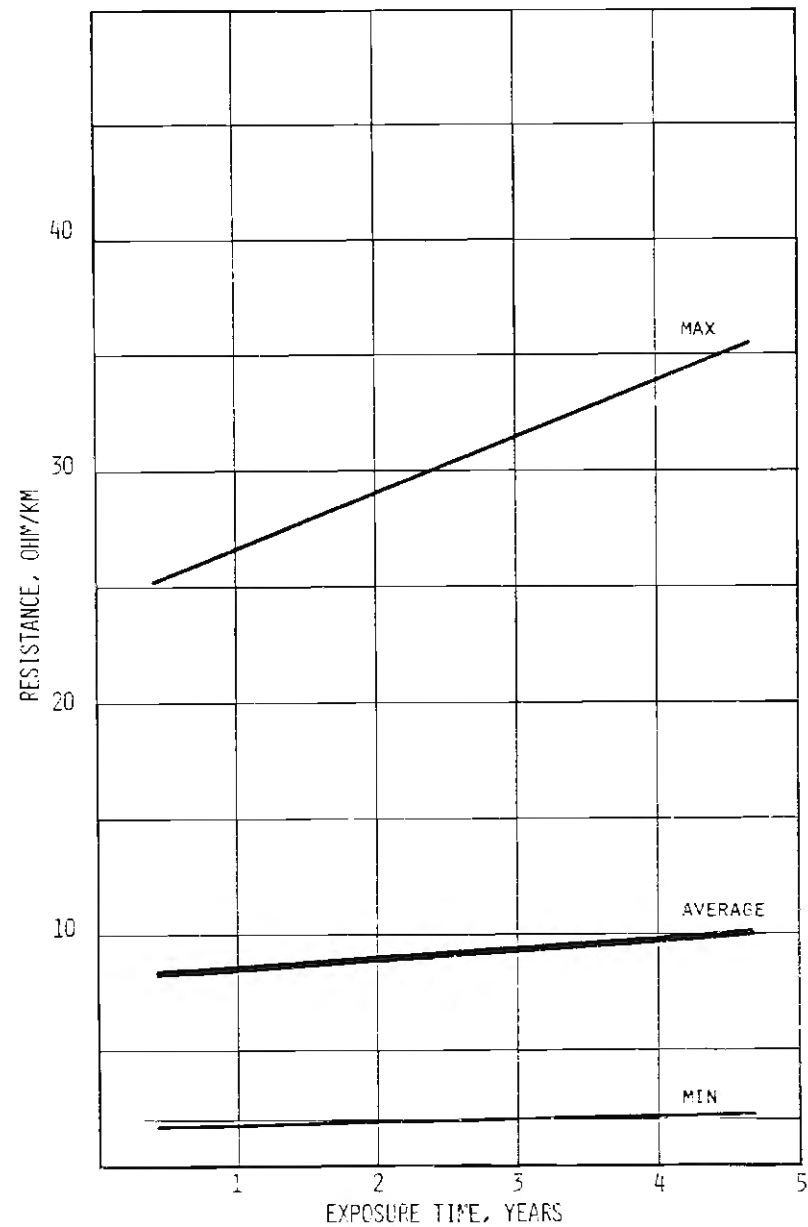


Fig 18. Electrical resistance (ohm/km) of sleepers in test track schematically outlined. Only measurements above 0 °C have been considered.

5. MOISTURE CONTENT OF SLEEPERS IN TRACK

The moisture content¹ of both sapwood and heartwood in a sleeper varies considerably. It varies with the age of the sleeper and the weather. It is also dependent on the construction of the track superstructure, the draining ability of the ballast and the location of the track (bank or cutting). As the normally used preservative for sleepers is creosote oil, variations in moisture content depending on the type of preservative can be neglected. Nevertheless the creosote content in the sleeper is of some importance.

Moisture content and its variation with time are critical to the function and durability of the sleeper. With increasing moisture content the possibility for mechanical as well as biological deterioration increases. Rapid fluctuations between dry and damp state promote the formation of splits. This affects adversely the functioning of the spikes and screws and, in combination with the ageing of the creosote oil, contributes to the uptake of water which makes the sleeper more susceptible to attack by fungi. As the moisture content increases, the corrosion of fasteners increases, which further contributes to their mechanical deterioration.

For a remedial treatment of the type discussed in this report the moisture content is critical. The method is based on the ability of the preservative to diffuse into the wood; for this a certain amount of water is required. A moisture content of at least 40 % is considered to be necessary for effective diffusion. It is therefore important to know the variation in the moisture content with time for determining the timing of a remedial treatment.

A study of the variation in the moisture content of sleepers has been carried out earlier by the Swedish State Railways (Borup, Magnusson). The study included several series of creosoted sleepers of various ages and a summary of the results is presented here. The sections of interest were on the main lines Stockholm-Gothenburg and Stockholm-Malmö, see Table 12. The test sections had essentially the same track superstructure and crushed stone ballast.

During the years 1958, 1959 and 1960 regular moisture content measurements were made on sapwood and heartwood, both during winter and summer in order to

¹ moisture content is defined as per cent w/w water on dry wood

Table 12. Sections of main line tracks chosen for investigation of the moisture content of sleepers.

Line section	Year of installation
Hässleholm	1938
Huddinge-Älvsjö	1941
Mjölby-Strålsnäs	1951
Vårgårda-Remmenedal	1954
Högsjö-Kilsmo	1956

determine extreme values. The measurements were made on increment cores from an upper corner at the middle of the sleeper, see Fig 19.

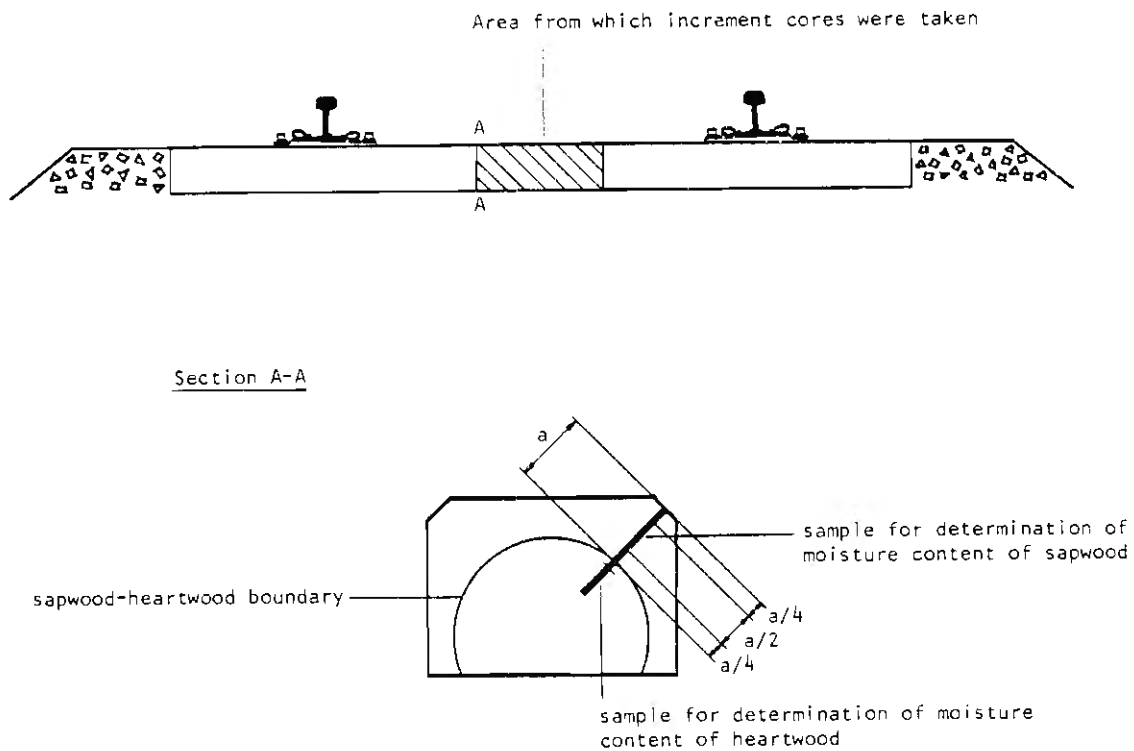


Fig 19. Sampling of increment cores for moisture content measurements.

To eliminate occasional influence of changes in weather the measurement of the moisture content of the sapwood was made in the centre part of the increment core. The heartwood sample was cut some millimetres from the sapwood to make sure the sample consisted of heartwood only. The samples were weighed immediately after sampling. The dry weight was determined in

the laboratory after drying the samples for 24 hours in a heating cabinet at 105 °C. 50 samples from each series were randomly taken at each sampling. In total, samples from 1 350 sleepers, corresponding to 2 700 moisture content determinations were included in the investigation. Sampling was carried out from March to December and the age of the sleepers varied from less than two years' (21 months) to just more than 21 years' (261 months) service life in track. The results are presented in Table 13 and Fig 21-22.

Table 13. Moisture content (%) of sleepers of different time in service. Average values for 50 sleepers at measurements in winter (Nov-May) and summer (June-Aug).

WINTER				SUMMER		
Year of installation	Time in service, months	Moisture content, %		Time in service, months	Moisture content, %	
		sapwood	heartwood		sapwood	heartwood
1956	21	24	25	24	23	23
1956	26	29	27	25	30	28
1956	32	35	28	35	19	24
1956	32	39	31			
1956	32	51	35			
1956	41	26	28			
1956	46	29	29			
1954	48	49	36			
1951	80	46	37	83	37	37
1951	89	54	43	85	39	39
1951	93	44	36	95	25	28
1951	101	33	34			
1951	105	41	35			
1941	201	99	101	203	86	86
1941	208	93	99	204	74	62
1941	213	95	127			
1938	257	43	102	251	42	80
1938	261	56	84			

The presentation is divided into "summer" and "winter". The average moisture content has increased significantly with the age of the sleepers. This is true for both sapwood and heartwood and the relation is the same for summer and winter. As can be seen, the variation is presented as a linear function. However, investigations by the Swedish State Railways have indicated that it is rather a non-linear function, i.e. the moisture content increases stepwise somewhere in the interval 100-200 months, possibly because of alterations in the wood which increase the moisture absorbing capability.

As mentioned above, the moisture content determinations were carried out on samples from an upper corner in the middle of the sleeper. Nevertheless the moisture content varies quite a lot within the same sleeper. An examination of the variation in moisture content within a sleeper has been carried out for

some normal sleepers. The result is shown in Fig 20. It is evident that those parts hidden below the rail baseplate have a higher moisture content than the other parts of the sleeper. The plates hamper drying of the wood and premature decay contributes additionally to moisture absorption.

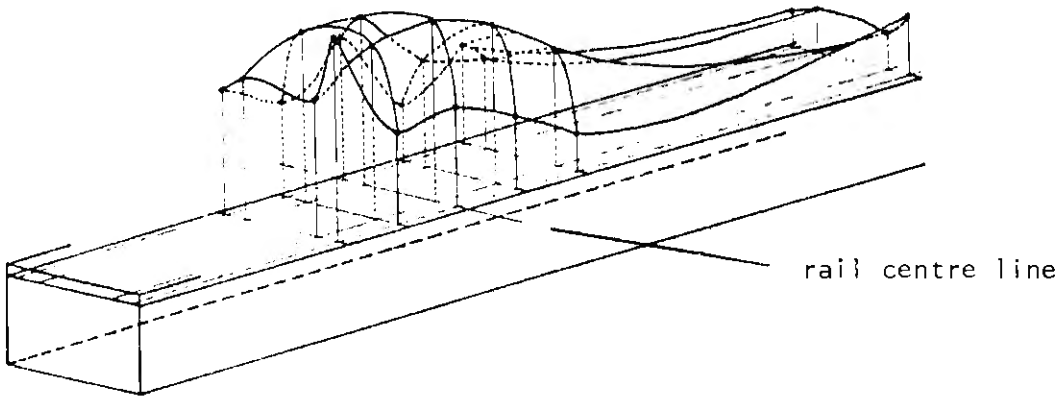


Fig 20. Variation of moisture content within a sleeper, graphically shown for a layer 20 mm from the surface. Notice that the highest moisture content is found under the baseplate.

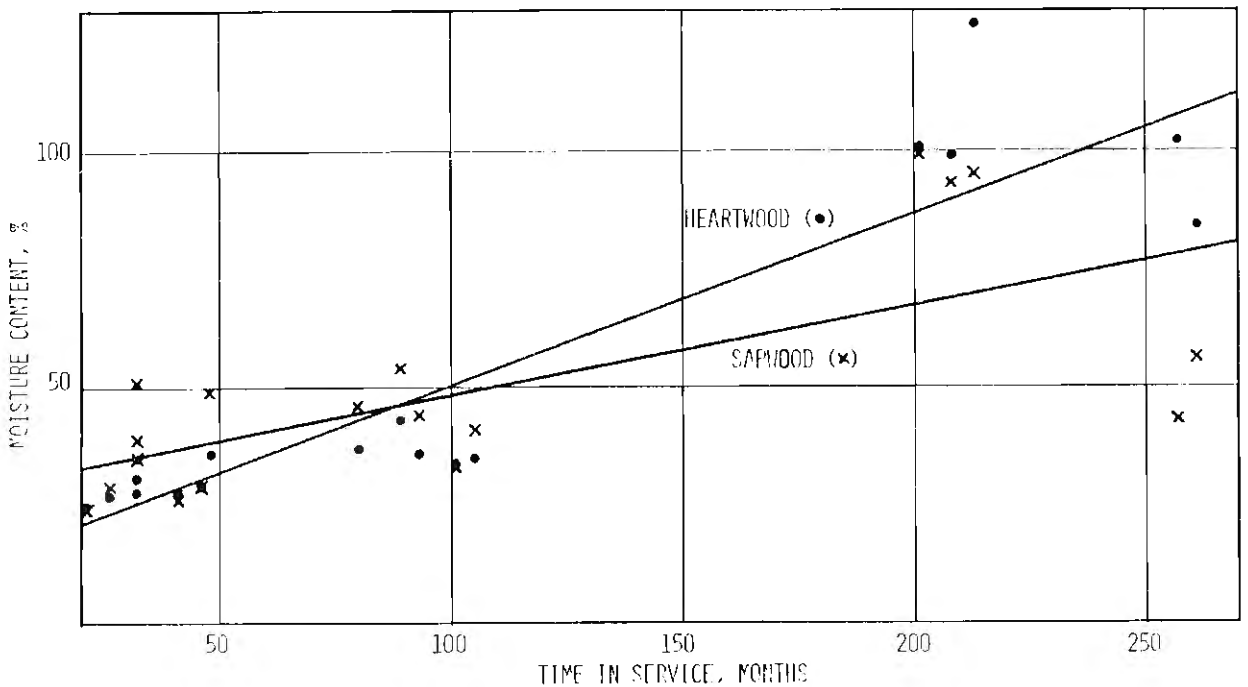


Fig 21. Moisture content of sapwood and heartwood as a function of the time in service; measurements in winter.

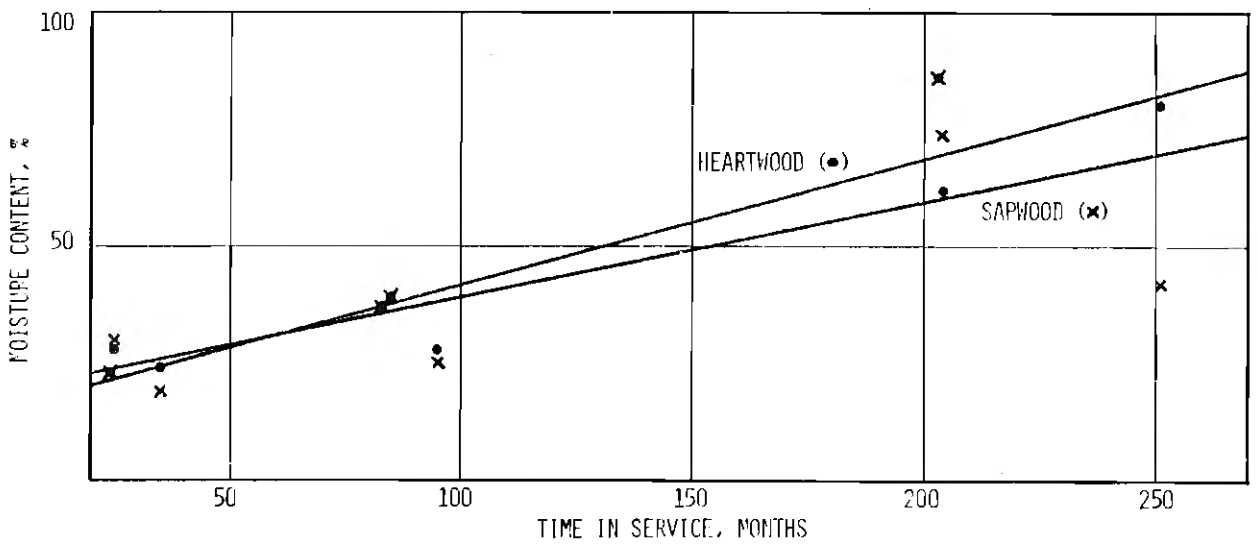


Fig 22. Moisture content of sapwood and heartwood as a function of the time in service; measurements in summer.

6. DURABILITY OF SLEEPERS IN TRACK

The durability of a creosoted sleeper in a track varies considerably with the quality of the sleeper and the forces it is exposed to. The constructional and geometrical design of the track in combination with the type of train-traffic, train weights, speeds etc, on the track all affect the forces to which a sleeper is exposed.

Of greatest significance to the durability, however, is the quality of the impregnated sleeper. The untreated new sleeper must be free from blue-stain and decay fungi. Any incorrect handling before impregnation can lead to localized attacks which often result in an excessively high moisture content, followed by insufficient impregnation with little or no creosote retention. The sleepers must be fully seasoned before impregnation. Bad weather conditions, i.e. rain during seasoning can often be recognized in the quality of a series of sleepers in the track.

As the State Railways before 1953 marked every sleeper with its installation year and registered replaced sleepers, it is possible to obtain statistical figures of the number of sleepers replaced from a series at different times. As the distribution within a series is great, it is necessary to go far back in time to include whole series. The advantage with this is, however, that in earlier days single sleepers were replaced as soon as they were found useless for the track. With modern maintenance methods, all sleepers of a section are now replaced, and any sound ones are subsequently reused in secondary tracks.

Statistics have been studied for the section Ängelholm-Gothenburg (Borup, Magnusson); sleepers installed in 1907, 1908 and 1911 have been considered as series of interest. All sleepers were made of redwood and creosoted (average retention about 135 kg/m^3 sapwood) according to a Rueping process.

Average service lives for the three series of sleepers are given in Table 14. The distributions of service life for the three series are presented in Table 15 and Fig 23. The curves show that the deviation from the mean is very large. The difference in average durability is also large but can readily be explained by the factors mentioned earlier. Up to the beginning of the nineteen fifties the State Railways assumed an average service life

of 22 years for a creosoted redwood sleeper. Today that figure is 28 years, mainly as a result of the higher quality of the impregnated sleeper. The handling of the new untreated sleeper is better, the quality requirements are more rigorous and the quality control after impregnation is better. Also, the fasteners and track maintenance are better and contribute to a longer service life.

An interesting point concerning the graphs in Fig 23 is that they all have three characteristic maxima. This indicates that they in fact consist of three superimposed Gaussian distributions, characterizing three different means for the durability. According to the State Railways the first group (A) represents those sleepers replaced due to decay, mainly caused by insufficient impregnation due to bad seasoning before treatment and incipient decay being present in the sleepers initially. Such a simple explanation can probably not be given for the two other groups (B, C), although biological deterioration is the main reason.

Table 14. Average service life for the three investigated series of creosoted redwood sleepers.

Installation year	Number of sleepers investigated	Average service life, years
1907	10 919	19,5
1908	9 616	16,5
1911	18 059	22,0

Table 15. Percentage of replaced creosoted sleepers for three series after various times of service in track.

Service life in track, years	Percentage of replaced sleepers			
	Series	1907	1908	1911
1				
2				
3				
4				
5		0,01		
6		-	0,05	
7		0,32	0,06	
8		0,47	0,63	0,64
9		0,71	1,73	-
10		1,91	4,44	-
11		1,10	7,79	2,89
12		3,73	1,70	3,02
13		8,37	3,07	1,95
14		1,22	4,58	6,24
15		2,86	6,01	3,43
16		2,39	16,56	2,57
17		3,82	8,79	4,18
18		7,48	8,25	9,17
19		10,18	5,05	3,67
20		10,52	3,92	3,90
21		6,17	3,71	3,69
22		4,85	3,66	5,07
23		4,95	3,30	4,10
24		4,23	2,68	3,52
25		3,61	2,53	5,88
26		3,25	6,52	8,01
27		3,06	2,63	4,33
28		4,57	0,93	4,21
29		4,90	0,56	3,67
30		1,98	0	2,98
31		0,41	0,17	3,08
32		0,27	0,20	2,79
33		0,65	0	1,12
34		0,16	0,16	1,55
35		0,13	0,19	1,33
36		0,20	0,04	1,12
37		0,86	0,03	1,40
38		0,23	0,04	0,35
39		0,29	0,02	0,11
40		0,14		0,02
41				0,01

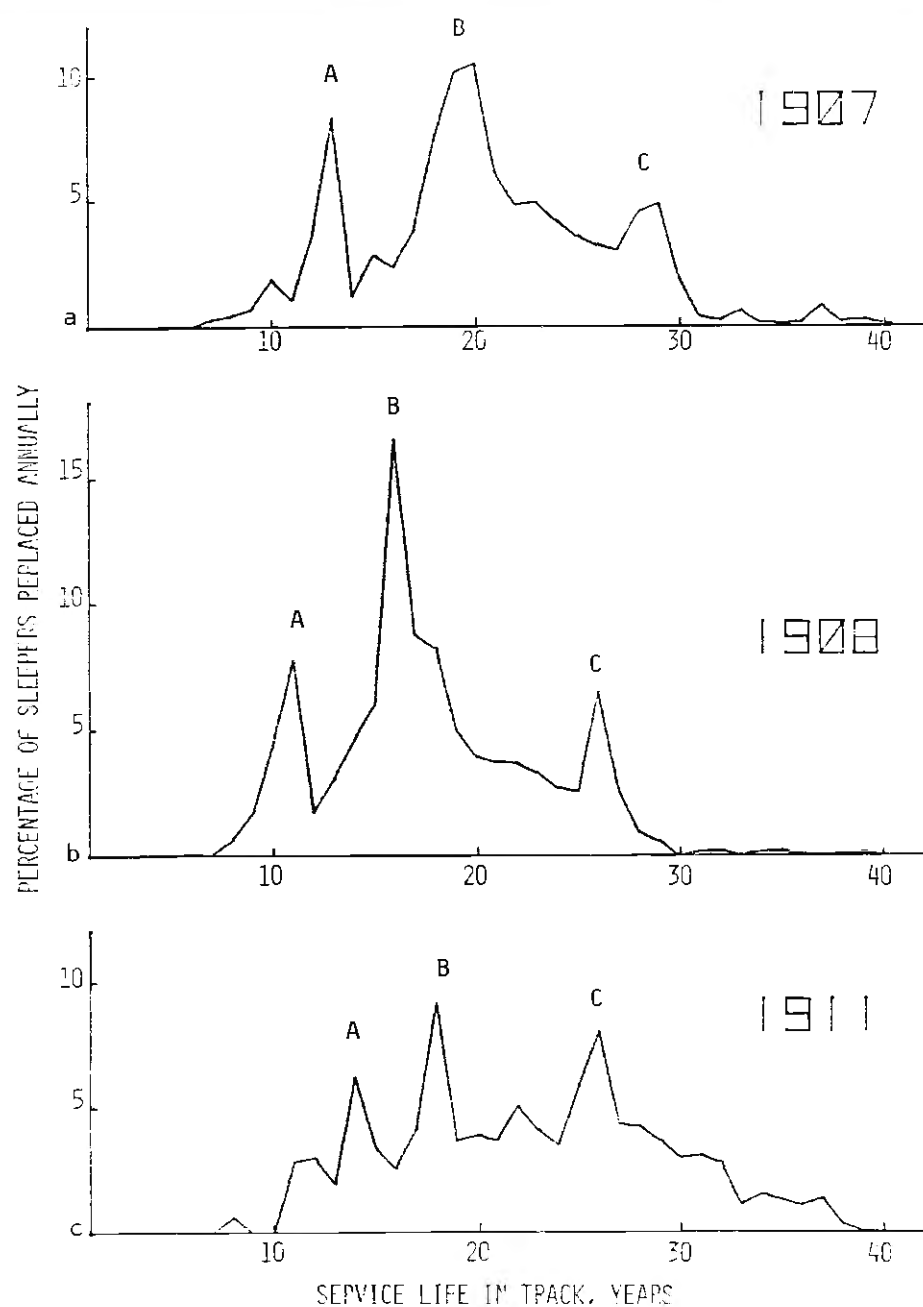


Fig 23. Distribution curves of service life for three series of sleepers.

7. CONCLUSIONS AND DISCUSSION

As can be seen from Fig 23 a-c the service life of sleepers of a particular series is roughly divided into three groups. The first group, resulting mainly from insufficient impregnation, lies in the interval 8-15 years and includes 15-20 % of all sleepers investigated which were installed in 1907, 1908 and 1911. If the sleepers installed later are considered to be of higher quality, the percentage of decayed sleepers constituting the first group should be less, but still of sufficient economic significance to justify attempted reduction.

Two principal ways to achieve this are possible. First, the requirements of the raw material, storage, seasoning, impregnation and quality control can be increased. Secondly, remedial treatment of the sleepers can be carried out after a number of years in service.

There are two main reasons why remedial treatment could be of interest from an economic point of view. First, the cost of increasing the original quality of the sleepers in the ways mentioned above could be higher than that of a remedial treatment which could give a corresponding increase in service life. Secondly, further improvement of the original quality might not be possible and remedial treatment can give a considerably longer service life. However, it was not within the scope of this project to consider any economic ramifications.

Disregarding the possibility that certain improvements might be obtained in the original quality of the sleepers and considering only remedial treatment, it can be concluded from the graphs in Fig 23 a-c that if the first group is to be significantly reduced, the remedial treatment must be carried out not later than 8 years after installation in the track and must be effective for at least 5 years, preferably longer, according to the State Railways' requirements. The treatment should preferably be carried out earlier as decay goes on for some time before a sleeper is rejected.

Is it then possible to achieve the expected results by selective remedial treatment with boric acid? The question cannot be answered positively without some reservations. However, in combination with later developments of the technique the investigations carried out indicate with a high degree of probability that it might be possible. When discussing the results achieved it

must be borne in mind that because of significant losses of boric acid during and immediately after the treatment, far less boric acid than expected was introduced into the sleepers. Two important requirements for the practicability of the method are however fulfilled. First, the investigations of the variations of moisture content of the sleeper with time show that the sleepers after approximately 5 years in service have an average moisture content of at least 30 % all year round, which is sufficient to permit diffusion of the boric acid. Secondly, the electrical resistance of a sleeper treated with boric acid is not reduced.

The results from the Nässjö and Kungsbacka tests indicate that a comparatively good distribution of boric acid is achieved under the baseplate and that the boric acid content in this zone, following a sharp decrease after the impregnation, seems to become stable after 25-30 months. In the Nässjö test relatively moderate changes occurred in this zone from this time to the end of the test. The boric acid content was then between 0.4 and 0.8 kg/m³ in the upper part of the sleeper (about 10 cm from the surface). Further down from the surface the boric acid content was lower, about 0.1-0.3 kg/m³. The Kungsbacka test showed a similar tendency, but due to large losses of boric acid during treatment, the level was considerably lower, viz about 0.2 kg/m³ after 4 years.

The biological tests show that, if a completely effective protection of the untreated sapwood and heartwood and of sapwood with low creosote retentions (< 30 kg/m³) is to be obtained, a boric acid retention of about 1.2-1.5 kg/m³ is required. It follows from the considerations regarding the expected duration of efficacy of the remedial treatment in practice, that the boric acid content preferably must not be allowed to drop below 1.5 kg/m³ for at least 5 years after treatment. Of course, a lower boric acid content gives a certain reduction of fungal growth, but to obtain good protection against the most important fungus, *Lentinus lepideus*, and to allow for an uneven distribution of boric acid, the retention ought to be at least 1.5 kg/m³. Neither in the Nässjö nor in the Kungsbacka test was this level obtained under the rail baseplate during the whole period of the investigation.

The stabilizing effect of time on the concentration gradient indicates, however, that if a sufficiently large amount of boric acid were intro-

duced from the beginning the level could probably be kept above 1.5 kg/m^3 for the required period. As the boric acid content in the zone close to the points where the boric acid is to be supplied will be well above or of the order of the lethal dose for the fungi of interest at least for the first 20-25 months, then fungi which have attacked the wood will be killed and a recolonization will be necessary for decay to progress.

Regarding the method of treatment, an injection of paste does not seem to be the most suitable way for introducing boric acid into the wood, but a more concentrated supply is necessary. Moreover, the method must not allow big losses to occur during and immediately after the treatment. One way to overcome this problem could be to supply the boric acid in a solid state, either as pure boric acid or as boric oxide, B_2O_3 . The latter compound form boric acid on dissolution in water and correspond to 1.78 boric acid equivalent. Recent developments of the technique have been in accordance with this idea.

By using cast cartridges of boric oxide and placing them in holes bored around the rail baseplate, the amount of boric acid supplied can be considerably increased compared with the paste injection method. If the supply of cartridges is concentrated into the zone shown in Fig 24, further advantages can be obtained. Then all boric acid will be available initially under the baseplate. The distance from the boric acid source to the zone just under the rail (corresponding to section 5 in the Nässjö and Kungsbacka tests) will be reduced while the distance to the fasteners will be the same.

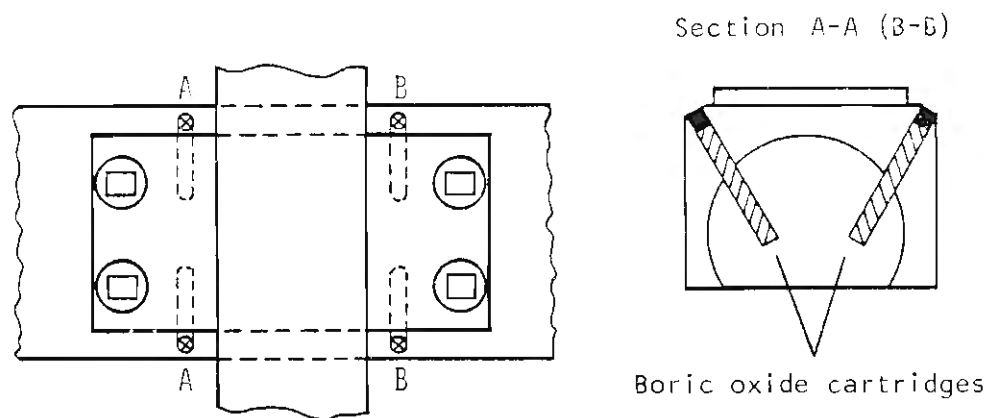


Fig 24. Example of introducing cartridges of boric oxide for the remedial treatment of sleepers. The holes are to be plugged with a removable plug, lid etc.

The dimensions of the cartridges which were found to be realistic for a sleeper's strength requirements are 100-120 mm in length and 10-12 mm in diameter. By applying, for example, four such cartridges (100 mm in length, 12 mm in diameter) in accordance with Fig 24, 144 g boric acid equivalent will be supplied to the zone under the baseplate. This is considerably more than was supplied in both the Nässjö and Kungsbacka tests, where approximate maximums of 37 and 55 g respectively were supplied.

The leaching can be expected to be significantly reduced by using cartridges instead of paste. The application of these under the baseplates, which have a load distributing and split reducing influence, contributes also to this. The almost four-fold increase in the supply of boric acid compared with the Nässjö test, in combination with the new insertion sites, increases the probability of maintaining a boric acid content above the preferred retention of 1.5 kg/m^3 for at least 5 years in the entire most decay susceptible upper part of the sleeper under the baseplate. This should be confirmed by further full scale trials however.

When discussing the use of cartridges made of boric oxide an interesting question arises. What effect from a protective (and economic) point of view could be obtained if a number of cartridges were applied under the baseplates when the sleepers were installed and if the procedure possibly were repeated after some years? An answer to this question is of interest in view of the fact that single sleepers are usually not replaced nowadays but the track superstructure of a line section is totally replaced when maintenance is carried out. It is therefore of importance to have as long period as possible without any decay in the sleepers. On the first occasion the cartridges could be applied at the same time as the mounting of plates and rails in holes bored before impregnation. The holes should then be plugged and reused at the next treatment.

Regarding safety and health aspects, the handling of cartridges is preferable to the handling of paste and has not so far proved to give any health or safety problems (Noyes 1977). Generally, preservatives based on boric acid are less toxic to man than preservatives based on fluorides. The acute toxicity, often expressed as LD_{50} -values, are 200 mg/kg (rat) for sodium fluoride and 3 000-5 000 mg/kg (rat) for boric acid.

The method, if it can be adequately mechanized, seems to conform to the requirements for an effective selective remedial treatment method for railway sleepers. Moreover, the technique can be applied in other fields. Experiments are going on in many countries, not only with sleepers but also with poles and window joinery (Dickinson 1979). So far reported results have been positive.

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APPENDIX 1

COMPARATIVE STUDIES OF THE LEACHING AND ASHING METHODS FOR BORON ANALYSIS

Two alternative methods, the leaching and ashing method (Anonymous 1970, BWPA 1972), were available for the analyses of boric acid content in the Nässjö and Kungsbacka tests. Both methods have a titration stage and the limit of determination of boric acid in solution at this stage is 1 mg. For a sample weight of about 5 g corresponding to a sample size of 10 cm^3 this is equivalent to a loading of 0.1 kg/m^3 .

In order to compare the two methods as to the suitability for creosoted wood, analyses of samples from three sections (4, 5 and 6) from one sleeper were carried out. The sleeper had been exposed for 6 months in the Nässjö test.

Five samples from each section were extracted as shown in Fig 1. One half of the sample was analysed according to the leaching method and the other according to the ashing method. The results are presented in Table 1.

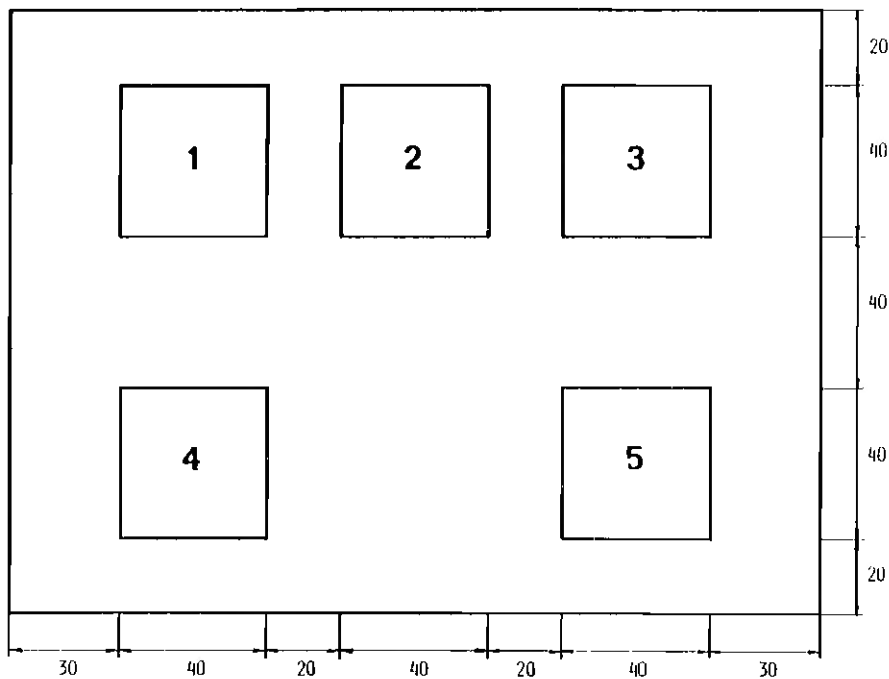


Fig 1. Pattern for extracting samples. Measurements in mm.

Table 1. Comparison between the ashing and leaching methods.

Sleeper section, no	Sample, no	Ashing method	Leaching method
15-4	1	2,58	2,10
	2	1,33	1,26
	3	5,60	5,65
	4	0,16	0,19
	5	0,11	0,13
15-5	1	0,18	0,20
	2	0,17	0,21
	3	0,20	0,30
	4	0,10	0,10
	5	0,16	0,14
15-6	1	6,73	6,75
	2	< 0,10	< 0,10
	3	0,98	0,94
	4	< 0,10	< 0,10
	5	< 0,10	< 0,10

Because of the variable distribution of creosote in the sections and its effect on sample weights, it was not possible to express conveniently the results on the usual basis of percentage of oven dry wood. The analytical samples were therefore carefully cut square and their volumes measured with a mercury volu-
meter and the boric acid contents expressed on weight/volume basis, i e kg/m^3 .

As one can note from the table, agreement between both methods was very good. As the leaching method is less expensive to use, it was chosen for the analyses.

APPENDIX 2

RESULTS OF CHEMICAL ANALYSES - THE NÄSSJÖ TEST

Table 1. Results after 9 months' exposure.

Section	Sample	Boric acid content, kg/m ³ , in sleeper no										Average	Standard deviation
No	No	21	23	25	27	29	31	33	35	37	39	kg/m ³	kg/m ³
1	2 + 3	0,12 ¹	0	0	0	0 ¹	0	0	0	0	0		
2	2 + 3	0,22 ¹	0	0	0	0	0	0	0	0	0		
3	2 + 3	1,68	0,85	3,01 ¹	0,42 ¹	0,66	0,18	0,85	0,94	1,14	0,93	1,07	0,79
4	1	1,09	8,18	3,70	1,92	8,32	2,92	18,61	20,04	14,97	4,06		
	2	2,04	2,17	2,34	0 ¹	5,24	1,39	1,22	3,75	1,61	3,74	2,27	1,25
	3	1,66	2,66	1,90 ¹	1,47 ¹	1,35	2,36	2,33	3,89	3,57	0,68		
	4	8,90	1,69	7,82	5,79 ¹	8,33	16,82	35,28	31,77	2,35	4,31		
	5	1,16	0,83	0,97	0 ¹	0,12	0,74	0,26	0,35	0	0,13	0,49	0,56
	6	0,56	0	2,33	0,86 ¹	0	0,30	0,42	0,53	0,10	0,18		
	7	0	0,26	0,56	0 ¹	0	0,11	0	0	0	0	0,06	0,14
	8	0,22	0	0	0	0	0	0	0	0	0		
5	1	5,09	0,65	2,69	3,21	2,97	2,42	0,95	0,18	2,25	0,89		
	2	0,59	0,88	0,56	0,31	0,30	1,28	0,63	0,27	0,35	0,61	0,87	0,98
	3	1,34	0,41	0,83	0,54	4,80	1,11	0,64	0,39	0,86	0,78		
	4	2,37	0,17	1,93	1,43	2,42	1,79	1,00	2,90	3,06	1,57		
6	1	29,98	9,42	11,71	2,72	44,92	6,67	14,10	11,08	18,99	7,57		
	2	1,52	0,71	4,77	5,93	1,31 ¹	3,00	5,60	1,80	1,12	2,51	3,74	2,54
	3	4,05	2,54	3,45	1,55	4,61	2,67	4,49	10,86	8,31	3,99		
	4	4,93	26,26	13,17	8,52	14,89	17,78	36,84	27,27	4,57	12,86		
	5	0,62	0,63	3,08	1,36	0,49	0,47	0,53	0,82	0,28	0,49	0,79	0,76
	6	0,44	0,10	0,78	0,66	0,29	0,46	0,19	2,60	0,98	0,50 ¹		
	7	0	0	0	0	0	0	0	0,66 ¹	0	0	0,14	0,28
	8	0,28	0	0	0,94	0	0	0	0,33	0,62	0		

0 = retention < 0,10 kg/m³¹split or knot in sample

Table 2. Results after 12 months' exposure.

Section	Sample	Boric acid content, kg/m ³ , in sleeper no										Average	Standard deviation
No	No	41	43	45	47	49	51	53	55	57	59	kg/m ³	kg/m ³
2	2 + 3	0,21	0 ¹	1,18	0	0 ¹	0	0 ¹	0	0,10	0 ¹	0,15	0,37
3	2 + 3	1,79 ¹	1,15 ¹	1,53	1,14	1,34	1,45	0	0,51	2,84	3,05	1,48	0,93
4	2	5,61	1,80	1,70 ¹	2,06	3,29	0,77 ¹	3,65 ¹	3,48	2,94	1,35 ¹	2,61	1,78
	3	8,18	1,52	3,14	2,92	0,65	2,25	1,97	2,13 ¹	0,47	2,33 ¹		
	5	0,51	0,22	0,94 ¹	0,65	0,53	0,97	0	0	0,88	0,65	0,58	0,50
	6	1,11	0	2,16	0,69	0,59	0	0,26	0,36	0,56	0,43		
	7	0	0,99	0	0	0,11	0,18	0	0	0	0 ¹	0,06	0,22
	8	0	0	0	0	0	0	0	0	0	0		
5	2	0,46 ¹	0,79	0,77	0,34	0,61	0,18	0,10 ¹	0,45	1,37	0,27	0,58	0,46
	3	0,61	1,37	1,12 ¹	0	0,56	0 ¹	0	0,92	1,42 ¹	0,32		
6	2	0,35 ¹	2,05	1,33 ¹	2,16 ¹	0,35	3,91 ¹	4,33	4,77	1,43	0,68 ¹	2,82	2,14
	3	3,47	1,86	2,93	1,87	3,70	10,01	3,60	3,56	1,60	2,48		
	5	0,36	0	0,92 ¹	1,15	0,89	0,71	0	0,13	1,15	0,74	0,78	0,67
	6	0,45	1,04	2,18	0,43	0,43	0,52	0,45	0,47	2,71	0,77 ¹		
	7	0	0	0	0	0	0	0	0	0	0 ¹	0,08	0,25
	8	0	0	1,00	0	0 ¹	0	0	0	0,59	0		

0 = retention < 0,10 kg/m³¹split or knot in sample

Table 3. Results after 15 months' exposure.

Section No	Sample No	Boric acid content, kg/m ³ , in sleeper no										Average kg/m ³	Standard deviation kg/m ³
1	2 + 3	0	0 ¹	0	0	0 ¹	0	0	0	0	0		
2	2 + 3	0,18	0,35	0,13	0	0,10 ¹	0	0,10	0	0 ¹	0	0,09	0,11
3	2 + 3	2,69	0,96 ¹	2,05	0 ¹	1,73 ¹	1,17	1,27 ¹	0,10 ¹	1,20	0,31	1,15	0,86
4	2	2,30	1,27	1,32	2,21	0,51 ¹	1,04	1,79	0,44	1,02	4,13	1,20	0,89
	3	1,51	0,62	0,74	1,12	0,89	0,48	0,93	0,40	0,43	0,84		
	5 ¹	1,84	0,18	1,29	0,12 ¹	1,05	0,62	0,79	0	0,97	1,38	0,96	0,77
	6 ¹	1,11	0,74	1,14	0,36 ¹	2,26	0,78	3,09	0	0,79	0,70		
	7	0	0	0,12	0 ¹	0,12	0	0	0	0	0	0,06	0,14
	8	0	0	0,30	0 ¹	0	0	0	0	0,57	0		
5	2	0,66	1,00	0,70	0,18	0,34 ¹	0,51	0,90	2,66	0,97	0,72	0,99	0,70
	3	0,65	0,74	0,83	0,65	1,09	0,62	1,45	2,97	0,64	1,46		
6	2	1,79	1,63 ¹	0,56	1,67	1,21	1,58	0,53	3,31	0,89	1,95	1,89	1,15
	3	1,38	1,10 ¹	0,70	1,86	4,01	1,56	2,91	4,57	1,19	3,32		
	5	1,53	0,48	0,87	0,51	0,99	1,35	1,88	1,25	1,01	0,65	1,32	0,80
	6	0,53	0,89	1,39	0,77	1,48	3,41	2,94	2,23	0,60	1,72		
	7	0	0	0	0	0	0	0	0	0,14	0	0,22	0,48
	8	0,12	0,13	0,18	0,43	0	0,68	2,05	0	0,58	0		

0 = retention < 0,10 kg/m³¹split or knot in sample

Table 4. Results after 27 months' exposure.

Section No	Sample No	Boric acid content, kg/m ³ , in sleeper no										Average kg/m ³	Standard deviation kg/m ³
1	2 + 3	0	0 ¹	0	0,17	0 ¹	0 ¹	0	0 ¹	0	0		
2	2 + 3	0	0	0,18	0,19 ¹	0 ¹	0 ¹	0	0	0	0 ¹	0,04	0,08
3	2 + 3	2,38	1,24 ¹	0,41	0,83	1,25	0,89	0,83 ¹	1,62	0,97	0,53 ¹	1,10	0,57
4	2	1,62	1,39	1,72	0,85	1,85 ¹	0,35	2,22 ¹	0,86	0,98 ¹	0,27 ¹	1,13	0,69
	3	1,38	0,85	0,35	2,57	2,02	0,38	1,06	1,09	0,59	0,23 ¹		
	5	1,32	1,64	0,82	1,08	0,84	2,83	0,69	0,33	0,38	2,21	1,27	1,20
	6	0,93	4,84	1,14	0,90	0,17	3,44	0,49	0,20	0,68 ¹	0,56		
	7	0,83	0,11	0,12	0,31	0,24	0,15	0,40	0,23	0,21 ¹	0,28 ¹	0,29	0,36
	8	0,10	0,26	0,33	0	0	1,60	0,19	0,12	0,13 ¹	0,18		
5	2	1,41	0,73	0,43	1,00	0,75 ¹	0,64	0,76	0,76	0,46	0,35	0,71	0,31
	3	1,11	0,78	0,18 ¹	0,69	0,54	1,14	0,82	0,84	0,27	0,50		
6	2	2,42	0,89	0,61	1,69 ¹	0,71 ¹	1,05 ¹	0,58	0,86	0,90	0,58 ¹	1,38	0,85
	3	1,41	0,59	1,16	3,13 ¹	3,17	2,47	1,95	1,78	0,53	1,16		
	5	0,89	1,39	1,62	1,21	0,98	2,50	0,38	0,19	0,56	1,19	1,12	0,73
	6	2,21	2,17	0,54	1,83	0,74	2,14	0,41	0,36	0,48	0,70		
	7	0,10	0,16	0,15	0,24	0,10	0,11	0,20	0	0	0	0,11	0,09
	8	0,20	1,11	0,35	0,13	0	0	0,13	0,10	0,10	0		

0 = retention < 0,10 kg/m³¹split or knot in sample

Table 5. Results after 39 months' exposure.

Section	Sample	Boric acid content, kg/m ³ , in sleeper no										Average	Standard deviation
No	No	141	143	145	147	149	151	153	155	157	159	kg/m ³	kg/m ³
1	2 + 3	0	0	0	0,12	0	0	0,11	0	0	0	0,02	0,05
2	2 + 3	0	0	0	0,29	0	0,16	0,29 ¹	0 ¹	0	0	0,07	0,12
3	2 + 3	0,45	1,03	0,81	0,64	0,15	0,53	0,34	0,73	0,84	0,72	0,62	0,26
4	2	0,51	0,81	0,79	0,43	0,17	0,43	0,33	1,08	1,77	1,40	0,94	0,66
	3	0,91	2,60	1,26	0,29	2,10	0,49	0,24	1,56	0,95	0,77		
	5	0,72	0,98	0,80	1,12	1,80	0,13	0,67	0,63	0,80	1,30		
	6	0,64	0,60	0,73	0,85	1,10	1,12	0,50	0,81	1,59	0,35		
	7	0,15	0,17	0	0	0	0	0,13	0	0,12	0		
	8	0	0	0	0,22	0	0	0,37	0	0,12	0,12		
	2	0,40	0,51	0,85	0,31	0,27	0,43	0,34	0,55	0,41	0,71		
	3	0,32	0,94	0,28	0,40	0,72	0,46	0,38	0,19	0,78	0,16		
5	2	0,98	0,58	0,70	0,16	1,25	1,21	0,15	1,68	1,93	1,17	0,97	0,54
	3	0,30	0,96	0,98	1,83	1,70	0,70	0,30	0,93	0,94	0,96		
	5	0,79	1,35	0,62	0,79	1,08	1,30	0,42	0,90	2,52	1,35		
	6	0,11	0,71	0,54	0,85	0,99	1,65	0,63	0,59	0,72	0,63		
	7	0	0	0	0	0	0	0,16	0	0,78	0		
	8	0	0	0,12	0	0,19	0	0,13	0,18	0,11	0,26		
	2	0,37	2,27	2,18	0,45	0	1,43	0,10	0,16	0,26	0,70		
	3	0,18	1,46	0,65	0	0,43	0,79	0,13 ¹	0,39	0,75	0,10		
6	5	0,14	0,88	0,19	0,63	0	0,13	0,19	0	0,46	0	0,26	0,31
	6	0,10 ¹	0,29	0	0	0,31	1,14	0,21	0,22 ¹	0,10	0,30		
	7	0	0	0	0	0	0	0,13	0	0	0		
	8	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0,19	0	0	0	0	0	0		
	3	0	0	0	0	0	0	0	0	0	0		
	5	0	0	0	0,12	0	0	0,12	0	0	0		
	6	0	0	0	0	0	0	0	0	0	0		
7	7	0	0	0	0	0	0	0	0	0	0	0,01	0,04
	8	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0,19	0	0	0	0	0	0		
	3	0	0	0	0	0	0	0	0	0	0		
	5	0	0	0	0,12	0	0	0,12	0	0	0		
	6	0	0	0	0	0	0	0	0	0	0		
	7	0	0	0	0	0	0	0	0	0	0		
	8	0	0	0	0	0	0	0	0	0	0		

0 = retention < 0,10 kg/m³¹split or knot in sample

Table 6. Results after 51 months' exposure.

Section	Sample	Boric acid content, kg/m ³ , in sleeper no										Average	Standard deviation
No	No	2	4	6	8	10	12	14	16	18	20	kg/m ³	kg/m ³
1	2 + 3	0	0	0	0,16	0	0,10	0	0	0	0,18	0,04	0,07
2	2 + 3	0	0,12	0	0,24	0,36 ¹	0,11	0	0	0,18	0,37	0,14	0,15
3	2 + 3	0,34	0,37	0,93	0,47	0,42	1,37	0,26	0,63	0,22	1,19	0,62	0,41
4	2	1,09	0,34 ¹	0,54	0,40	0,43	1,36	0	2,02	2,39	0,68	1,03	0,74
	3	1,93	0,26	1,66	0,28	0,71	2,14	0,27	1,54	1,57	0,92		
	5	1,27	0	0,26	1,33	1,26	1,24	0,86	1,00	1,49	1,35		
	6	1,36	1,15	1,84	0,43	2,47	0,16	0,24	0,81	0,61	1,44		
	7	0,10	0,10	0	0,77	0,37	0,42	1,33	0	0,20	0,41		
	8	0	0,11	1,67	0	0	0,14	0,30	0	0	0		
	2	0,37	0,33	1,14	0,53	0,40	0,72	0,50	0,27	0	0,28		
	3	0,50	0,47	0,36	0,31	1,16	1,36	0,69	0,12	0	0,33		
5	2	0,14	1,63	2,04	0,53	0,70	0,92	0,14	3,76	1,98	1,38	1,46	1,21
	3	0,94	0,55	1,53	0,56	1,82	2,76	0,29	3,56	3,84	0,20		
	5	0,26	1,20	1,06	1,38	2,71	1,28	1,42	0,92	3,10	0,83		
	6	0,47	1,63	0,14	0,91	2,08	0,27	1,12	0,17	0,84	0,48		
	7	0	0,13	0	0	0,11	1,14	0,68	0	0,66	0,22		
	8	0	0	0	0	0	0,13	0,33	0	0,40	0,14		
	2	0	0	0	0	1,43	1,46	0,79	0	0,10	1,00		
	3	0	0	0	0	1,11	1,58	1,08	0,14	0,12	0,86 ¹		
6	5	0	0,37	0	0	0,14	0,51	0,42	0	0	0,95 ¹	0,23	0,32
	6	0	0,14	0	0	0	0	0,70	0	0,68	0,70 ¹		
	7	0	0	0	0,77	0	0	0	0	0,12	0,70		
	8	0	0,14	0	0,50	0	0	0	0	0,13	0,19		
	2	0	0,59	0	0,22	0	1,04	0	0 ¹	0,15	0,20		
	3	0	0	0	0	0,16	0	0	0,13	0	0		
	5	0	0	0	0	0	0	0	0	0	0,16		
	6	0	0	0	0	0	0	0,82	0	0	0		
7	7	0	0	0	0	0	0	0	0 ¹	0	0	0,12	0,26
	8	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0	0	0	0	0	0	0		
	3	0	0	0	0	0	0	0	0	0	0		
	5	0	0	0	0	0	0	0	0	0	0		
	6	0	0	0	0	0	0	0	0	0	0		
	7	0	0	0	0	0	0	0	0	0	0		
	8	0	0	0	0	0	0	0	0	0	0		

0 = retention < 0,10 kg/m³¹split or knot in sample

Table 7. Results after 63 months' exposure.

Section No	Sample No	Boric acid content, kg/m ³ , in sleeper no										Average kg/m ³	Standard deviation kg/m ³
		42	44	46	48	50	52	54	56	58	60		
4	2	0,45	0,15	0,65	0,35	0,11	0,94	0,27	0,45	0	0,56 ²	0,45	0,32
	3	1,32	0,22	0,28 ²	0,54 ²	0,12	0,83 ²	0,44	0,36 ²	0,27 ²	0,59		
	5	1,24	0,13 ²	1,27	0,23	0,67	0,48	0,27	1,31	0,56	0,52	0,58	0,38
	6	0,50	0,13	0,98	0,10	0,37	0,66	0,33 ¹	0,92	0,38 ²	0,52		
5	2	0,33	0	0,63	0,28	0,18	0,16	0,20	0,28	0	0,35 ²	0,28	0,23
	3	0,94	0,19	0,41	0,19	0,14	0,21	0,22	0,36	0	0,59 ¹		
6	2	0,80	0,16 ²	0,10 ²	0,39 ²	0,24	2,35 ²	0,10 ²	0,33	0,20	0,83	0,59	0,67
	3	0,32	0,47	0,51 ²	0,58	0,22 ²	2,52	0,24 ²	0,42	0,37	0,64		
	5	0,49	0,60	1,62	0,32	0,42	0,41	0,32	0,65	0,33	0,47	0,49	0,34
	6	0,52	0,57	0	0,25	0,55	0,79	0,40	0,76	0	0,37		

0 = retention < 0,10 kg/m³¹split or knot in sample²spike hole coincided with sample

Table 8. Results after 75 months' exposure.

Section No	Sample No	Boric acid content, kg/m ³ , in sleeper no										Average kg/m ³	Standard deviation kg/m ³
		82	84	86	88	90	92	92	96	98	100		
4	2	0,81	0,95	0,60	0,65	0,24	0,57	0,67	0,42	0,29	0,49	0,54	0,20
	3	0,30	0,85	x	0,61	0,25	x	x	x	0,32	x		
	5	0,21	0,41	0,59	0,65	0,31	0,29	0,33	0,82	0,82	0,50	0,58	0,25
	6	0,21	0,48	0,46	1,06	0,63	0,87	0,86	0,91	0,45	0,73		
5	2	0,43	0,72	0,24	0,45	0,43	1,06	1,05	0,62	0,66	0,32	0,50	0,30
	3	0,25	0,71	0,23	0,18	0,19	x	0,27	0,16	0,59	0,44		
6	2	0,22	0,47	0,27	0,60	0,51	0,34	0,20	0,40	1,86	0,31	0,63	0,47
	3	x	0,85	1,70	1,05	0,61	0,73	0,78	0,36	0,85	0,17		
	5	0,34	0,31	1,16	0,44	0,44	0,74	1,09	1,30	0,80	0,19	0,62	0,33
	6	0,14	0,48	0,62	0,59	0,75	0,96	0,78	0,28	0,70	0,26		

x = defect in section; no sample extracted. By calculation of the average the sample has been given the same value as the neighbouring sample.

Table 9. Results after 87 months' exposure.

Section No	Sample No	Boric acid content, kg/m ³ , in sleeper no										Average kg/m ³	Standard deviation kg/m ³
		122	124	126	128	130	132	134	136	138	140		
4	2	1,18	0,11	0,30	0,29	0,72	0,27	0,22	0,58	0,17	1,56	0,42	0,39
	3	0,42	0,13	0,18	0,18	0,32	0,75	x	0	0,15	0,55		
	5	1,04	0,18	0,43	0,34	0,41	0,37	0,63	1,25	0,58	1,05	0,55	0,33
	6	0,67	0,31	0,45	0,30	0,18	0,53	0,14	0,32	0,58	1,15		
5	2	0,41	0,10	0,27	0,10	0,55	0,24	0	0,39	0,19	0,74	0,26	0,19
	3	0,25	0,28	0,17	0,32	0,23	0,40	0	0	0,15	0,31		
6	2	2,77	x	1,04	0,17	0,58	0,57	0,33	0,32	0,33	0,41	0,63	0,63
	3	1,22	0,50	1,05	0,26	0,17	1,45	0	0,12	0,32	0,54		
	5	0,91	0,32	0,62	0,20	0,22	2,29	0,29	1,27	0,76	1,22	0,68	0,54
	6	0,58	0,34	0,31	0,36	0,70	1,19	0	0,40	0,39	1,22		

0 = retention < 0,10 kg/m³

x = defect in section; no sample extracted. By calculation of the average the sample has been given the same value as the neighbouring sample.

APPENDIX 3

RESULTS OF CHEMICAL ANALYSES - THE KUNGSBACKA TEST

Five sleepers which were cut in the middle have been taken at each sampling. One half had been in contact with the positive rail and the other with the negative, with respect to the poles of the signalling current. These were marked with a plus and minus sign, respectively, after the number of the sleeper half. The halves 201+ and 202- etc, came from the same sleeper.

Table 1. Results after 21 months¹ exposure.

Section	Sample	Boric acid content, kg/m ³ , in sleeper no										Average	Standard deviation
No	No	201+	202-	203+	204-	205+	206-	207+	208-	209+	210-	kg/m ³	kg/m ³
4	2	0,36	0,68 ¹	0,54 ¹	0,54 ¹	0,37	0,98 ¹	0,53 ¹	0,31 ¹	0 ¹	0,62	0,54	0,24
	3	0,57 ¹	0,54	0,29 ¹	0,98 ¹	0,74 ¹	0,70	0,58 ¹	0,33 ¹	0,32 ¹	0,73		
	5	0,18 ¹	0,46 ¹	0,45 ¹	0,28	0,33 ¹	0,28 ¹	0,18 ¹	0,30 ¹	0,41	0,41	0,36	0,19
	6	0,16 ¹	0,38 ¹	0,28 ¹	0,89	0,51 ¹	0,13 ¹	0,11 ¹	0,30	0,66 ¹	0,40		
5/41	2	0,41	0,93	0,43	0,35	0,88	0,31	0,45	0,75	0,42	0,59	0,51	0,19
	3	0,39	0,87	0,35	0,57	0,41	0,43	0,41	0,39	0,38	0,52		
	5	0,24	0,38	0,36	0,20	0,46	0,27	0	0,13	0,15	0,30	0,33	0,15
	6	0,25	0,54	0,61	0,36	0,54	0,21	0,35	0,39	0,44	0,34		
5	2	0,21	0,62	0,36	0,46	0,40	0,21	0,41	0,30	0,63	0,70	0,44	0,17
	3	0,66	0,14	0,28	0,42	0,59	0,70	0,54	0,30 ¹	0,47	0,32 ¹		
6/52	2	0,46	1,68	0,42	0,60	0,41	0,58	0,59	0,46	0,93	0,79	0,72	0,36
	3	0,61	1,18	0,46	1,16	0,62	1,34	0,50	0,52	0,41	0,65		
	5	0,43	0,51	0,34	1,10	0,31	0,60	0,33	0,18	0,33	0,48	0,40	0,26
	6	0	0,94	0,33	0,47	0,54	0,16	0,40	0,37	0,10	0,15		
6	2	0 ¹	1,17 ¹	0,87 ¹	0,68 ¹	0,78	1,29 ¹	0,72 ¹	0 ¹	0,53	0,92 ¹	0,59	0,37
	3	0,32 ¹	1,04 ¹	0,33 ¹	0,58 ¹	0,36 ¹	0,78 ¹	0,59 ¹	0 ¹	0,47 ¹	0,44		
	5	0,28 ¹	1,35 ¹	0,37	0,37 ¹	0,27 ¹	0,32 ¹	0,47 ¹	0,24 ¹	0,32	0,81 ¹	0,44	0,28
	6	0,18 ¹	0,68 ¹	0,35 ¹	0,81 ¹	0,29 ¹	0,52 ¹	0,34 ¹	0,21 ¹	0,44 ¹	0,18 ¹		

0 = retention < 0,10 kg/m³¹bolt hole coincided with sample

+ = sleeper half from positive rail (signalling current)

- = sleeper half from negative rail (signalling current)

Table 2. Results after 32 months' exposure.

Section	Sample	Boric acid content, kg/m ³ , in sleeper no										Average	Standard deviation
No	No	211+	212-	213+	214-	215+	216-	217+	218-	219+	220-	kg/m ³	kg/m ³
3	2	0,50	0,27	0,46	0	0,64	0,86	0,18	0,12	0,37	1,08	0,41	0,32
	3	1,19	0,16	0,47	0,37	0,17	0,30	0,21	0	0,39	0,48		
5/41	2	0,44	0,37	0,19	0,62	0,16	0,35	0,20	0,15	0,31	0,70	0,32	0,17
	3	0,31	0,39	0,36	0,37	0	0,31	0,26	0,13	0,25	0,49		
	5	0,19	0,11	0	0,12	0,27	0,33	0,33	0,13	0,31	0,19	0,21	0,13
	6	0	0,48	0	0,17	0,36	0,30	0,23	0,33	0,20	0,19		
5	2	0,28	0,35	0,38	0	0,24	0,31	0,26	0	0,31	0,36	0,24	0,15
	3	0,51	0,19	0	0	0,15	0,32	0,19	0,21	0,32	0,42		
6/52	2	0,52	0,60	0,10	0	0,34	0,29	0,30	0,23	0,40	0,47	0,30	0,16
	3	0,22	0,28	0	0,41	0,11	0,29	0,32	0,26	0,47	0,44		
	5	0,12	0,13	0	0,19	0,27	0,40	0,47	0,14	0,26	0,18	0,21	0,16
	6	0	0,14	0	0,21	0,33	0,17	0,20	0,64	0,27	0,16		
7	2	0	0,21	0	0	0,54	1,24	0,36	0,23	0,69	0,64	0,31	0,31
	3	0	0,17	0	0	0,33	0,43	0,18	0,44	0,40	0,38		
	5	0	0,10	0	0	0,20	0,14	0,22	0	0,90	0	0,15	0,21
	6	0	0	0	0	0,27	0,16	0,16	0,27	0,29	0,26		

0 = retention < 0,10 kg/m³

+ = sleeper half from positive rail

- = sleeper half from negative rail

Table 3. Results after 44 months' exposure.

Section	Sample	Boric acid content, kg/m ³ , in sleeper no										Average	Standard deviation
No	No	221+	222-	223+	224-	225+	226-	227+	228-	229+	230-	kg/m ³	kg/m ³
3	2	0,51	0,15	0,32	0,92	0,41	0,12	0,19	0	0,18	0,17	0,34	0,42
	3	0,26	0,37	1,90	0,10	0,14	0,47	0	0,18	0,13	0,26		
5/41	2	0,28	0	0,12	0,49	0,11	0,17	0,19	0,29	0,13	0,12	0,20	0,14
	3	0,48	0,22	0,36	0,18	0	0,15	0,17	0,36	0,11	0		
	5	0,19	0,26	0,13	0,19	0	0,20	0,17	0,19	0,21	0,20	0,21	0,13
	6	0,23	0	0,34	0,40	0,10	0,57	0,35	0,19	0,15	0,17		
5	2	0,29	0,48	0,20	0,24	0	0,48	0,31	0	0,14	0	0,18	0,15
	3	0	0,27	0,25	0,17	0,10	0,13	0,19	0,28	0	0		
6/52	2	0,10	0,15	0,15	0,32	0,14	0	0,75	0,53	0	0	0,22	0,19
	3	0,22	0,22	0,29	0,15	0,11	0,25	0,16	0,45	0,11	0,20		
	5	0,16	0,10	0,13	0,20	0,26	0,15	0,44	0,31	0,19	0,14	0,28	0,24
	6	0,17	0,23	0	0,39	0,11	0,45	1,15	0,30	0,31	0,32		
7	2	0,30	0	0,30	0,32	0,13	0,10	0,18	0	0,41	0,15	0,20	0,23
	3	0	0	0,10	0,13	0	1,01	0,22	0,12	0,31	0,28		
	5	0,13	0,12	0,10	0,29	0	0,32	0,16	0,13	0,42	0,13	0,17	0,11
	6	0,16	0,18	0	0,26	0,15	0,12	0	0,18	0,25	0,24		

0 = retention < 0,10 kg/m³

+ = sleeper half from positive rail

- = sleeper half from negative rail

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* T.o.m. 1973 utgavs meddelandena i Träskyddskommitténs regi.

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