DUTCH ELM DISEASE

FUNGICIDE

INJECTION MANUAL

(Revised June 1982)

E. S. KONDO

Great Lakes Forest Research Centre

Sault Ste. Marie, Ontario

Canadian Forestry Service

Department of the Environment

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

Since Dutch elm disease (DED) was first discovered in North America in 1929 and its full impact on our native elms became obvious, many control methods have been developed and implemented in an effort to save the elm. At first attempts were made to eradicate this disease; when this failed and it became apparent that DED was here to stay, attempts were made to restrict the spread of the disease by quarantine and sanitation measures. The quarantine measures were essentially designed to prevent movement of elm material from a diseased to a non-diseased region. Sanitation measures were designed to reduce the elm bark beetle populations by removal and destruction of all suitable elm material which could be used by the bark beetles to breed. In spite of these measures, the disease continued its rapid spread; insecticide spray programs were initiated but largely failed when DDT was banned. None of these measures used alone, to date, has proved successful over the long run. Witness the countless cities, towns, villages and countrysides which have lost much of their elms to this disease. DED now extends from the Atlantic to Pacific Oceans in North America. The latest control method which has now received wide acceptance is that of injection of various fungicides directly into elm trees to either prevent infection of healthy elms, or arrest the disease in a recently infected elm. However, it is unlikely that injections will prove any more effective on a broad scale than those employed in the past. This statement is made because it is both physically and economically impossible to properly inject enough of the remaining elms in North America in time. The purpose of this manual is to provide the most up-to-date information on the proper use of methyl-2-benzimidazole carbamate-phosphate (MBC-P) for effective treatment of high-value elms. Although the information contained in this manual is basically designed for use with MBC-P, the principles of injection apply to other similar water soluble systemic fungicides.

II. APPROACHES IN DISEASE THERAPY AND PROTECTION

A clear understanding of why and how an elm succumbs to DED and what we are attempting to accomplish by injection of chemicals into the elm in various ways will greatly increase the chances of successful treatment. In other words, treatment is not as simple as cutting a few roots or drilling a few holes and injecting the chemical into the elm and hoping for the best.

(a) The Infected Elm

Dutch elm disease is caused by a fungus, *Ceratocystis ulmi* (Buism.) C. Moreau, which in the living elm is found primarily as spores. These fungus spores are microscopic in size and are found in the infected elm in the sapwood tissue or the water conducting part of the elm wood. The spores are minute enough to travel readily up and down the water conducting vessels in the sapwood, thereby infecting the entire elm. These spores are capable of multiplying in number by simple division. If one spore can divide into two spores every six hours, then a single spore can give rise to 65,536 spores in four days, or in five days 1,048,576 spores. This gives one a rough idea of how rapidly the fungus can grow under an unchecked condition. More importantly, treatment of a diseased elm must be undertaken as rapidly as possible after detection of the disease.

Research has shown that during growth and division chemical compounds are given off by this fungus. These chemical compounds from the spores have been shown to be toxic to the elm tree. It has further been demonstrated that the elm reacts violently to the presence of these secreted toxic chemical compounds. This reaction is really a defensive mechanism which the elm possesses. It is this defensive reaction which results in the elm dying back. The elm is attempting to isolate the attacking organism from the rest of the healthy part of the tree. That is, the tree is attempting to save itself by sacrificing a branch or two. However, in the case of the white elm, *Ulmus americana* L., this reaction does not occur rapidly enough and therefore the elm's own defensive mechanism ultimately results in its death.

(b) Disease Therapy and Protection

Our research understanding of DED suggests that preventing growth and division of the fungus spores would be easier than attempting to somehow alter the defensive mechanism of the tree to obtain successful disease therapy or protection of a healthy elm. Ideally, the chemical compound should be able to move actively within the live elm tissues and not just passively in the water conducting system of the tree. Unfortunately all of the systemic fungicides that we are dealing with at present in control of DED appear to be largely passive within the elm and therefore heavy emphasis must be made on injection techniques to obtain the best possible distribution of the chemical under the circumstances. For the chemical to affect growth of the spores it must be introduced into at least the outer annual growth layer where the active spores are found in the infected tree. Various methods have been attempted, such as soil drenches, foliar and bark applications and systemic injections under pressure. Thus far systemic injections have been shown to be the only practical method by which the water soluble chemicals could be introduced into the water conducting vessels of the tree. Also, from our understanding of what is happening in the elm, we know that the chemical must also be distributed throughout the majority of the elm, in the roots, trunk, branches and even the leaves. It can easily be seen that if the chemical is to be injected into the water stream of the elm the best distribution would be obtained if the chemical was totally water soluble. Otherwise, the minute water conducting vessels would soon become plugged with the particles of the introduced chemical.

(c) Injection Methods

There are three methods currently being employed in systemic fungicide injections, namely trunk injection, root-flare injection and root injection. Figure 1 depicts the relative injection areas. The root-flare injection area comprises the transitional area between the trunk and root. It would appear that the wood tissue in this area is functionally different from either the trunk or root tissues. Wounds created in this root-flare area heal rapidly without developing wet-wood problems. Whereas wounds created in the trunk of the

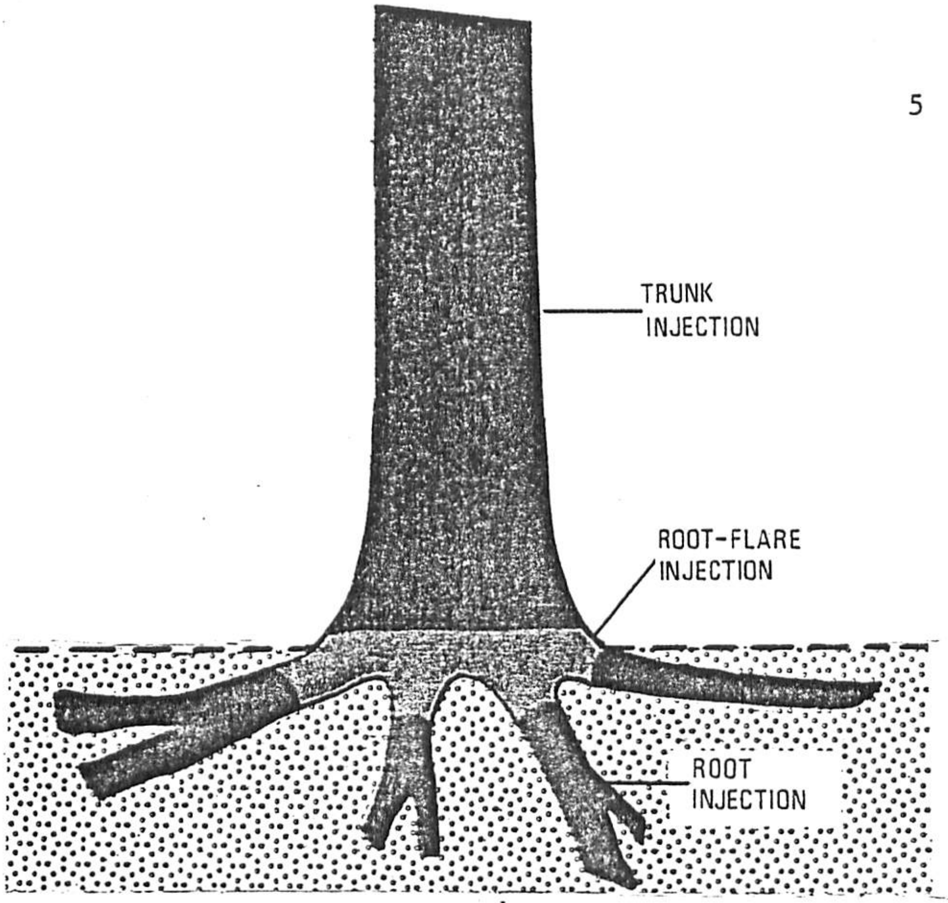


Figure 1 Systemic fungicide injection areas on elm.

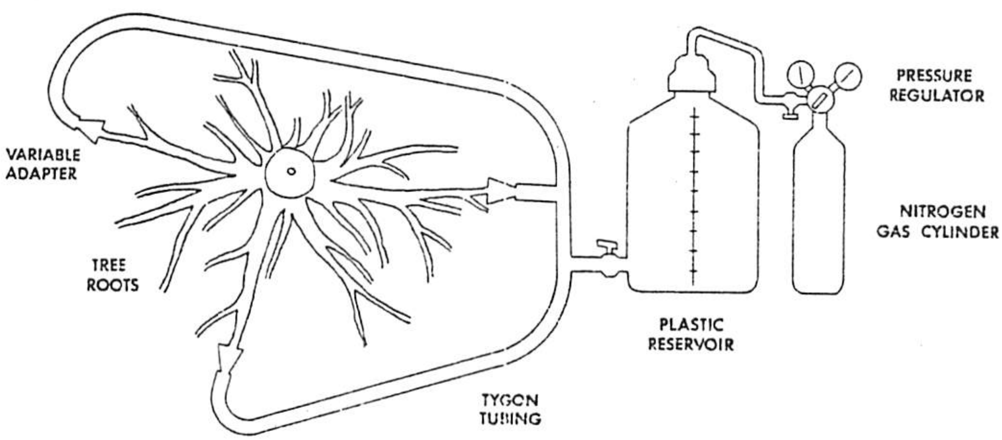


Figure 2 Apparatus and set-up for root injection of mature elms in the field.

elm may develop excessive wet-wood problems resulting in persistent "bleeding" or "fluxing". This is one of the most serious drawbacks to trunk injections of mature elms.

In root injection (Figure 2), the roots are carefully excavated outward from the trunk of the tree, until roots approximately 1.25 to 4.0 cm in diameter are found. Elm roots commonly fork and are close to the soil surface so that appropriate roots can be easily selected. Care must be exercised during excavation because the injection solution will leak from any injuries to the roots.

To obtain the best chemical coverage of the entire elm, the main root of each major root-flare must be excavated. If the main root forks the larger diameter root is excavated. If the main root cannot be used for injection an alternative branch root is selected.

The selected roots are washed and severed. An anvil-type cutter should be employed to avoid crushing the root and to obtain a smooth-cut surface. The rubber root adapter is slipped on the severed root and clamped. Immediately, the solution is fed into the tubing system carefully, to avoid the formation of air bubbles. The time interval between severing the root and applying the liquid should only be a few minutes. Finally the reservoir is pressurized to *ca.* 0.7 kg/cm^2 and maintained for the duration of the injection period (24-48 hours).

Basically there is no technical difference between root-flare injection and trunk injection, except where the injector heads are placed on the tree. There are many different types of injector heads available commercially. The injector head should be so designed and employed to meet the following important criteria:

(1) the injection wound and hole should be no larger than 1 cm in diameter

(2) the injector heads should be spaced no greater than 15 cm apart

(3) the injector head's anchoring system in the drilled hole should create a "well" in at least the outer growth ring, to insure chemical distribution in the outer growth ring (Figure 3)

Correct positioning of the injection holes for root-flare injection to minimize injection damage must be observed. No holes should ever be made in the root-flare area between adjacent flares, termed the flare-valley area in Figure 3A. The annual growth rate of new wood is extremely slow in the flare-valley area as compared to the actual flares. Therefore, mechanical wounds made in flare-valleys tend to heal very slowly and may require several years to heal fully, if at all. As much as possible, holes should only be made on the actual flare.

There is the temptation to attempt a pseudo-root injection by drilling a hole into a relatively large diameter root, a term referred to as "pegging a root", the hypothesis being that since root injection is superior to root-flare injection, then "pegging a root" must be superior to root-flare injection. Unfortunately, a serious wound "healing" problem results whenever a root is drilled as opposed to being completely severed. Roots "heal" differently than the root-flare area. Large-diameter roots do not have the ability to form callus tissue to close a drill hole wound. The normal "healing" process in the roots is for the tissue to dieback to an appropriate area or distance and then the root initiates new adventitious roots or stimulates smaller diameter roots to grow more rapidly. Therefore, under no circumstances should a healthy root be "pegged" for injection purposes.

Consideration must also be made for future injection holes which must be placed no closer than 25 cm either above or below the initial injection holes. Injection holes in successive years should be staggered as shown in Figure 3A. The dotted lines on the trunk depict the water movement pattern. It is important that holes not be drilled "above" or "below". Since once a hole is drilled that "line" of water movement is rendered unusable to the elm forever. It must be emphasized, however, that elms possess a tremendous ability to "rearrange" its water conducting patterns if one pattern is damaged and to lay down new water conducting lines by growth of annual rings.

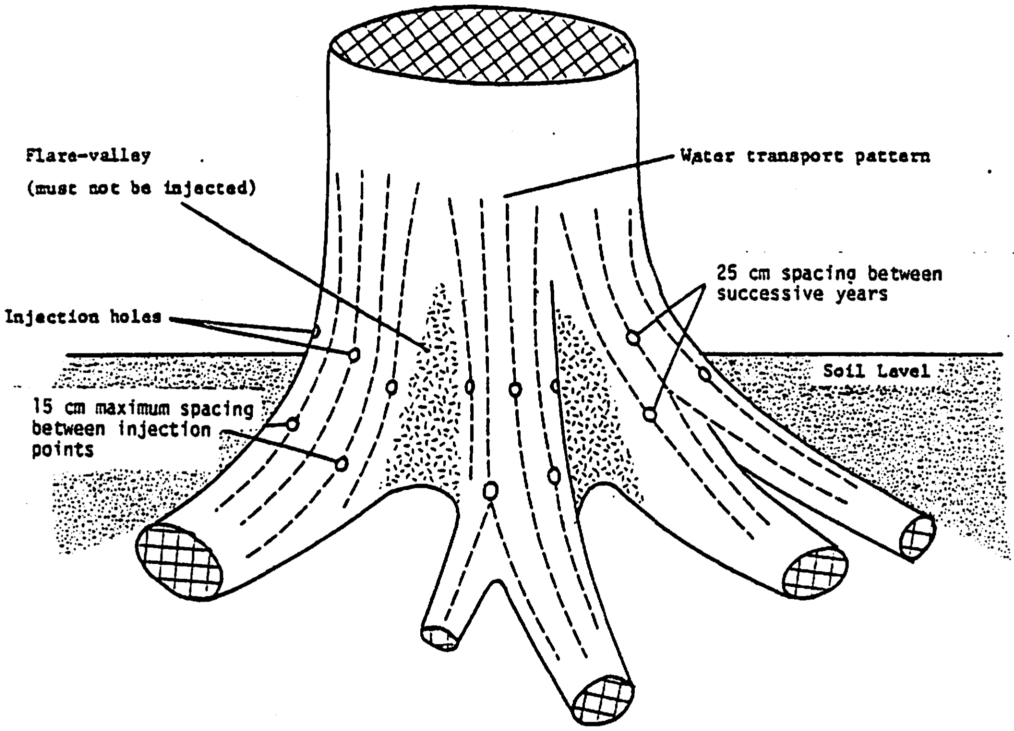


Figure 3(a): Diagram of elm root flare area showing positioning of injection points in two successive years. Note: Injection holes are avoided in the flare-valley area.

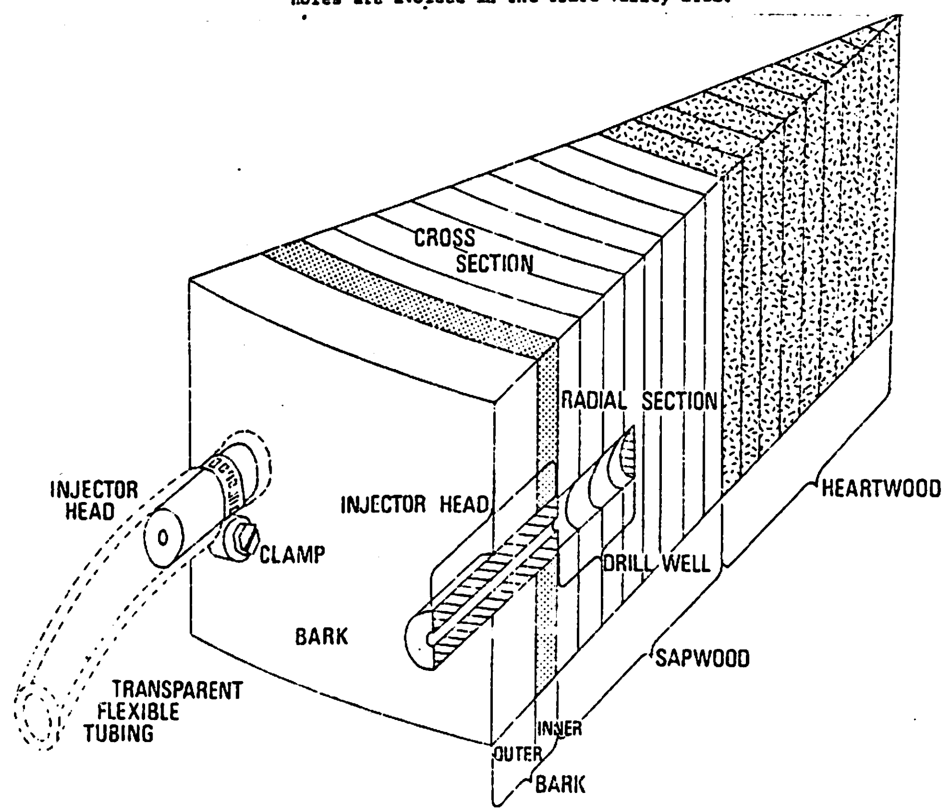


Figure 3 Radial section of portion of elm bark, sapwood and injector heads showing position of heads with respect to

By correctly positioning the injection holes, one facilitates this process for the elm and at the same time the wounds heal rapidly.

All injection wounds[1] should be sealed with grafting wax immediately after completion of injection. Wooden plugs should not be employed unless they are countersunk in the injection drill-hole so that they are below the cambium. If improperly used, wooden plugs actually retard healing of the injection wound.

In cases of root-flare injections below grade and where re-injection is anticipated in the future, considerable time and effort can be saved in future injections if the excavated area is back-filled with gravel or similar loose material. Backfill material which retains excessive moisture should not be employed for several reasons: (a) material such as sawdust or mulch will promote adventitious roots in the back-fill area, even in mature elms; (b) good aeration is a requisite for proper healing of injection wounds.

(d) Injection Problems Related to Injection Methods

With the present level of knowledge in injection techniques, adequate chemical distribution can usually be obtained with any of the three methods of injection. Unfortunately serious problems are created in an attempt to obtain this adequate chemical distribution especially with trunk injection. Table 1 (Pros and Cons of the Different Methods of Injections) shows the required technique to

[1]Injection wound refers only to the mechanical wound created by drilling into the wood tissue. It is assumed that proper injection dosages are employed and hence no chemical wounding is involved.

Table 1: Pros and Cons of the Different Methods of Injection

Injection Method	Technique	Rationale for Technique	Problem Created
Trunk injection (protection only)	relatively large diameter injection holes and/or injection holes spaced relatively close together	to obtain adequate chemical distribution	excessive damage to cambium and water conducting vessels sometimes resulting in severe fluxing
	shallow injection wound, preferably into outer annual growth ring	to minimize fluxing from elms affected by wetwood	methods to anchor injector heads result in additional wounding of tissues
	relatively high chemical concentrations required	to obtain adequate chemical distribution or to increase the duration of chemical protection for more than 1 year	chemical toxicity especially at injection point, resulting in injection wound healing difficulties
	relatively high pressure for injection required	to obtain adequate chemical distribution throughout the growing period	damage to xylem and bark tissues problem in anchoring injector head
	low pressure injection	to avert high pressure injection problems	injection can only be undertaken after 3/4 leaf expansion
Root-flare Injection (protection only)	excavation of root-flare area	to obtain adequate chemical distribution and rapid healing of injection wounds	relatively higher costs than trunk injection. root-flare area may not be accessible
	techniques listed for trunk injection are employed	the rational is the same as with trunk injections	problems created are similar as in trunk injection with the following exceptions (a) no fluxing or wetwood problems (b) usually rapid healing of wounds on flare areas
Root injection (protection against and arrest of Dutch elm disease)	excavation of one root per major root-flare and supplement with root-flare injection in elms over 76 cm dbh	to obtain adequate chemical distribution and avoid any injury due to injection holes to arrest Dutch elm disease to avoid yearly injection wounds to avoid chemical phytotoxicity and injections can be carried out prior to bud break	excessive costs and time required for injection roots may not be accessible

obtain the desired effect and the problems created. The only real advantage of trunk injection is that it costs less to inject, but the problems it generates far outweigh the savings in labour. However, trunk injection can be successfully employed with very young and vigorous growing elms (15 years or younger and less than 30 cm dbh). Only under exceptional circumstances should trunk injection on mature elms be employed and then only with the full realization that problems will develop in the long run. It must be remembered that fluxing initiated in elms with wet-wood problems will never heal and will result in a relatively large portion of the trunk being killed.

(e) Injection of Large Elms

For the purpose of this manual, large elms are those over 30 inches dbh. Research has shown that elms, as they grow in size, develop more complicated water transport systems to meet the ever increasing demands for water uptake and distribution. For instance, a large healthy elm can transpire 450 to 700 litres of water during a single day under ideal conditions. The tree must make up this transpired water loss by uptake of water through the root system. In young elms which transpire much smaller volumes of water, this can easily be undertaken by a simple root system. However, for the large elms it must exploit a greater volume of soil for water to support its greater requirement. Therefore, at some point in time during the elm's development into a large tree, a secondary root system begins to play a major role in water uptake and distribution.

Unfortunately the roots in the secondary system are not readily accessible, because they grow deep into the soil, to support the large crown and also in search of greater and stable amounts of water. The secondary root system cannot be economically injected. Therefore, with such elms it is necessary to supplement root-injection with flare injection in the "wall" of the secondary root system to obtain adequate chemical coverage. Research results show that such a combination of root and root-flare injection provides optimum chemical distribution and both prophylactic and therapeutic success can be achieved.

In therapy injection of large elms it is better to prune the infected branch flush at the main trunk 2 to 3 weeks after completion of injection in all cases except when the infected branch is located in the lower third of the crown. If the infected branch is located in the lower third of the crown the procedure for injection and pruning is the same as with small elms as described below.

(f) Injection of Small Elms

For the purpose of this manual, small elms are those under 38 cm dbh. Experience has shown that in cases of therapy injection of small elms it is better to prune the infected branch flush at the main trunk just prior to the injection. During the injection period the chemical solution should literally "bleed" from the wound. This appears to have the benefit of "flushing" any spores of *C. ulmi* and toxic metabolites out of the main trunk and consequently resulting in a more spectacular success of treatment.

If the chemical solution does not "bleed" from the wound, additional roots and flare areas should be injected until the "flushing" action begins.

(g) Injection Pressures

Research results generally show that high injection pressures (2.8-14.0 kg/cm^2) are unnecessary during the growing season of the elm. However, a low pressure of 0.35 to 1.4 kg/cm^2 appears to initially assist the elm in uptake of chemical solution especially in the early morning when transpiration rates are relatively low. During the hotter period of the day the elms' own uptake system usually takes over and the low pressure is merely a means to insure that adequate chemical solution reaches the injection points. Injection pressures do not have appreciable effect on the ultimate chemical distribution in the elm. However, high pressure results in considerable damage to the wood tissues in the trees.

III. THE FUNGICIDE

(a) MBC-phosphate

Chemical compounds showing the greatest potential in control of DED by direct injection fall into a group of chemicals called benzimidazoles. Methyl-2-benzimidazole carbamate (MBC) or carbendazim[2] is one of these compounds. However, in its structure as MBC the chemical is water insoluble. A prerequisite for direct injection of chemical into the water conducting system of the tree is that the compound must be wholly water soluble. Therefore, MBC was solubilized by acidification into

[2]Carbendazim is the common name given to MBC by the British Standards Institute.

five different water soluble derivations namely MBC hydrochloride, MBC-phosphate, MBC-sulphate, MBC-nitrate and MBC-sodio salts. Under laboratory and greenhouse conditions all five have been shown to be effective in control of DED. One of these water soluble compounds, MBC-phosphate or Carbendazim-phosphate is currently marketed in Canada under the name Lignasan[3]-BLP. In the United States, MBC-P is also marketed under several other trade names. Regardless of what the commercial name, they should contain a 0.7% content of MBC-P in water. The chemical concentrate should be absolutely clear with a slight amber colour. Any cloudiness or visible particles in the concentrate may indicate that the MBC is precipitating out of the solution. If this is observed, refer to the section on Trouble Shooting.

(b) Dosage and Formulation of MBC-phosphate

An important point to remember is that no chemical compound however helpful, is totally risk-free for the tree to which it is applied. A good example is over-fertilization. It must be kept in mind that since chemical intervention is a two-edged sword there is not much to protect the individual tree except the experience and judgement of the person treating it. One way of lessening the risk of chemical toxicity to the elm is to inject the chemical at very low concentrations and high volume over a period of time. We have found that this generally results in little or no toxicity at the injection point and also in better distribution of the chemical. Our studies of tree

[3]Lignasan is a DuPont registered trade mark.

injection with various types of equipment and different methods of injection have shown that injection of elms with large volumes of MBC-P over a period of 24 to 48 hours provides the optimum chemical distribution throughout the tree. Also, injection over a relatively long period of time at low concentrations of 250 to 500 ppm virtually eliminates any possibility of phytotoxicity to the elm. Substantial savings in time can be obtained by reducing the injection period, by increasing the chemical concentration and thereby proportionally decreasing the total volume injected. However, this usually results in inferior chemical distribution with relatively lower success rates in treatment of elms; therefore every effort should be made to inject elms at 250 ppm MBC-P solution.

Drastically increasing the concentration (2000 ppm or over) of the chemical greatly increases the chemical distribution in the elm. Also, the chemical can be detected in the elm for longer periods (over a year); however, chemical toxicity to the elm becomes a problem. (See section under Trouble Shooting - Phytotoxicity Symptoms.) With the concentrations recommended in this manual, there have been no documented cases of chemical toxicity. Most of the elms receiving treatment usually show an increased overall vigour in appearance of the foliage within a year of treatment.

Formulation of MBC-P is presented in Table 2. Normally the concentrate is commercially available at 7000 ppm. The amount of concentrate required to obtain a certain quantity of injection solution can be directly obtained from the table or alternatively it can be calculated as follows:

Table 2. Formulation of MBC-P*

Required litres of injection solution	Amount of MBC-P concentrate needed to obtain final injection concentrations of: 250 ppm (litres)	500 ppm (litres)
1	.0357	.0714
2	.07	.14
3	.11	.21
4	.14	.29
5	.18	.36
6	.21	.43
7	.25	.50
8	.29	.57
9	.32	.64
10	.36	.71
11	.39	.79
12	.43	.86
13	.46	.93
14	.50	1.00
15	.54	1.07
16	.57	1.14
17	.61	1.21
18	.64	1.29
19	.68	1.36
20	.71	1.43
21	.75	1.50

NOTE: Add enough water to the amount of MBC-P concentrate to bring volume to the corresponding gallons of required injection solution.

*Formulation based upon MBC-P concentrate of 7000 ppm.

Volume of concentrate required =

$$\frac{\text{Required final concentration x Required final volume}}{7000}$$

Example:

Question: How much concentrate to water is required to obtain 200 litres of injection solution at a concentration of 250 ppm?

Solution:

Volume of concentrate required =

$$\frac{\text{Required final concentration x Required final volume}}{7000}$$

$$= \frac{250 \times 200}{7000}$$

$$= 7.14$$

Volume of concentrate required = 7.14 litres

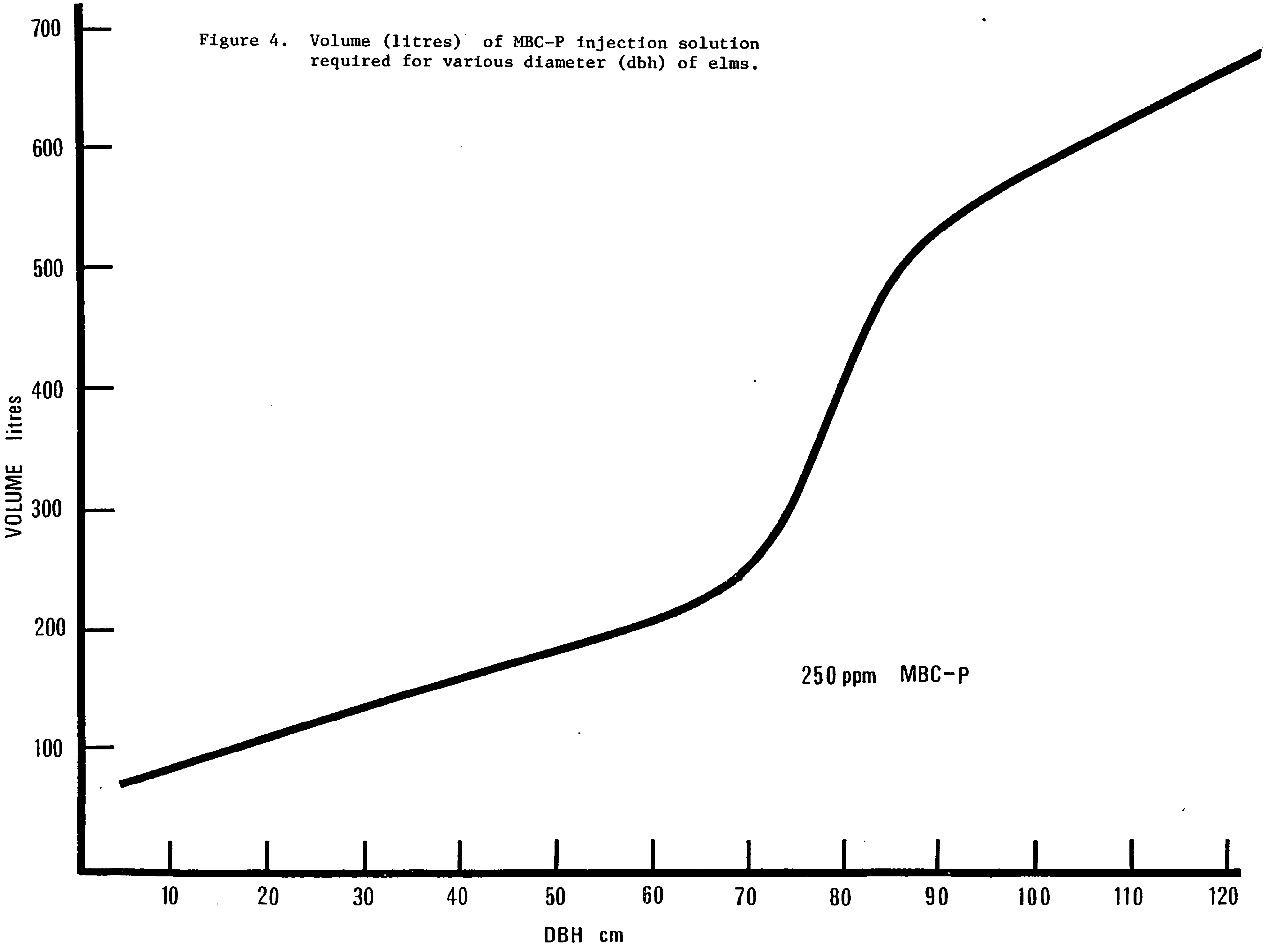
Since water is added to the 7.14 litres of concentrate to obtain a final volume of 200 litres, the amount of water required is 200-7.14 = 192.86 litres. Therefore, 7.14 litres of concentrate to 192.86 litres of water will provide 200 litres of injection solution at 250 ppm concentration.

Table 3 presents the chemical dosage at various concentrations for elms 10 to 750 cm in diameter at breast height (dbh) (1.3 metres above ground level). The chemical dosage is not a straight-line relationship but rather an "S" shaped curve (Fig. 4), which was obtained from field data ccumulated over a number of years on elms of various diameters. The reason for the "S" shaped curve lies in the differences between the complexity of the water transport system in large and small elms. That is, much more volume must be injected

Table 3. Dosage Schedule. Volume (litres) of MBC-P injection solution required for various diameter (dbh) of elms

dbh (cm)	Concentration of injection solution: 500 ppm	Concentration of injection solution: 250 ppm	dbh (cm)	Concentration of injection solution: 500 ppm	Concentration of injection solution: 250 ppm
10	one-half of corresponding 250 ppm volume	90	76	one-half of corresponding 250 ppm volume	327
12		96	78		368
14		102	80		415
16		106	82		453
18		110	84		481
20		114	86		502
22		118	88		525
24		124	90		536
26		129	92		537
28		134	94		558
30		138	96		567
32		142	98		575
34		146	100		594
36		150	102		593
38		154	104		602
40		158	106		611
42		163	108		620
44		168	110		628
46		173	112		637
48		178	114		646
50		182	116		655
52		196	118		664
54		190	120		673
56		194	122		682
58		198	124		691
60		203	126		699
62		210	128		708
64		218	130		717
66		225	132		726
68		233	134		735
70		247	136		744
72		263	138		753
74		289	140		762

Figure 4. Volume (litres) of MBC-P injection solution required for various diameter (dbh) of elms.



into large elms to compensate for "loss" of chemical solution within the elm.

(c) Scope and Limitations of MBC-P Injection for DED Control

Extensive research involving over a thousand mature field elms by researchers at the Canadian Forestry Service, Great Lakes Forest Research Centre and the Faculty of Forestry, University of Toronto, over the past 8 years show healthy elms can be protected from infection if properly root injected or root-flare injected with adequate amounts of MBC-P. There is a good chance of successfully arresting disease symptoms if the correct amount of chemical is properly root injected as soon as symptoms appear. Generally, we have been unsuccessful in arresting DED symptoms with trunk or root-flare injection alone.

Under the premise that MBC-P functions in infected elms solely as a fungitoxicant and from field experiments, the period of chemical effectiveness was established as two growing seasons for root injections and one growing season for root-flare injections. With repeated yearly root-flare injections of healthy elms, the treated tree is continuously protected against natural above ground infection if it is re-injected before full leaf expansion the following year.

Injected elms which are not re-injected can be expected to gradually return to the degree of susceptibility to natural infection considered normal for that particular area following the period of chemical effectiveness. In general, by the second or third year after injection, the rate of natural infection of these formerly protected elms will be similar to that of untreated elms in the vicinity. Thus, the importance of a continued re-injection program cannot be over emphasized once the decision is made to inject the elm.

Many cases of arrest of DED symptoms following root injection with MBC-P in lightly diseased elms (Disease Index less than 50) have been documented. In each case of remission of the disease, the arrest symptoms occurred in the initial year of treatment. Subsequent re-injections are only necessary as a precaution against re-infection. In cases where remission of symptoms is not obtained the first year of treatment, re-injection is necessary on a yearly basis. Furthermore, parts of the tree will be lost to the disease each year, although it is highly unlikely that the entire elm will die if the treatment is continued. However, after a few years the elm will have lost its aesthetic value.

Our experience has been that trunk injections and/or root-flare injections alone, have usually resulted in failure in treatment of diseased elms. In many cases, the diseased tree appeared to respond positively to treatment in the first year. However, in subsequent years the tree declined rapidly, despite repeated yearly trunk and/or root-flare injections. The major drawback to trunk injections has been the persistent "bleeding" from the injection holes resulting from elms with wetwood.

Very poor results have been obtained in treatment of elms which have been diseased for several years prior to injection. It would appear that once the fungus has become firmly established systemically in the tree, no amount of chemical can preserve the aesthetic value of the elm. However, there is a marked delay in the elm's ultimate decline due to DED. It is recommended that such elms not be treated.

IV. INTEGRATION OF CARBENDAZIM H_2PO_4 INJECTIONS INTO EXISTING DUTCH ELM DISEASE CONTROL PROGRAMS

Ideally Carbendazim H_2PO_4 injections should be gradually integrated into existing DED control programs. This ensures minimal disruptions to the existing control program while at the same time assuring a high level of successful injections. To begin with, there are four important precautions which must be adhered to rigidly to ensure that treated diseased elms do not present a hazard to healthy elms in the vicinity.

1) Measures should be taken to ensure that Carbendazim H_2PO_4 injected elms are not root grafted to other elms in locations where root grafts have been shown to be a problem.

2) All injected elms must be properly pruned of all dead and dying branches which can be utilized by the elm bark beetles for breeding purposes. Therefore, injected elms must be monitored throughout the growing season.

3) All cutting tools used on injected elms should be disinfected between cuts.

4) Any injected elm with dead sections or strips along the main tree trunk must be considered a failure and removed immediately.

Step 1: Priority Rating of Elms Within DED Control Area

In order to integrate Carbendazim H_2PO_4 injections into existing DED control programs it is first necessary to rate all elms in the control area into various priority categories, depending on their value. Only elms in the higher categories should be considered as possible candidates for prophylaxis or therapy with chemical injections. High priority elms which cannot be root injected should be automatically placed under an annual root-flare injection program. Two points to consider are that prevention of infection with Carbendazim H_2PO_4 injections is easier than arresting the disease, especially in the case of the larger size elms and that only a realistic number of elms can be injected because of the high cost and time required.

Step 2: Survey of Priority Elms

Bi-weekly surveys of injected elms are necessary so that action can be taken quickly should an elm under protection become infected. Also, priority elms which become infected can be therapeutically treated successfully more frequently when the disease is discovered early. Diseased treated elms require frequent attention so that they can be properly pruned of areas exhibiting disease symptoms and re-injected if necessary. The priority elm survey should be integrated with the overall DED survey for the entire control area.

Step 3: Maintenance of Injected Elms

Elms under an annual injection program should be injected as early as possible each spring. This affords the longest period of protection. These elms should be properly pruned of branches with few or no buds in the early winter. Should a chemically protected elm become infected, the infected part should be immediately removed. It is likely, under such circumstances, that the infection occurred in that part of the elm with little or no chemical, and the infection can be effectively pruned away.

If remission of Dutch elm disease does not occur in the first year of injection of Carbendazim H_2PO_4 treatment in recently infected elms, it is likely that annual injections will be necessary "forever." Furthermore, parts of the elm will be lost to the disease each succeeding year, and, ultimately, the tree will have to be removed because it will have lost its aesthetic value. Such elms require frequent pruning until parts of the main trunk begin to succumb to the disease, at which time the entire elm must be removed. In other words, the tree begins to die in strips, these strips can be utilized by the bark beetles and therefore the entire elm must be removed at this stage.

Step 4: Tagging of Injected Elms

In order to fully integrate Carbendazim H_2PO_4 injections into the Dutch elm disease program, it is necessary to tag with pertinent information each treated elm. This will prevent accidental removal of treated diseased elms when they really do not present a hazard to other elms. The field identification of treated elms also aids in re-injection and in follow-up maintenance of treated elms.

The identification and tagging of injected elms should include privately treated elms. This is very important because elms under chemical protection with Carbendazim H_2PO_4 do not have to be removed when they become lightly infected. (Note: if injection was properly undertaken infection is always very light if it occurs at all. More likely the elm will not become infected.) It is only necessary to immediately prune away the lightly infected area. The infection, if it occurs, will probably be on a suppressed branch which received no chemical because it is a suppressed branch.

Step 5: Accurate Injection and Elm Data

It is important to keep accurate injection data for future reference. Both successes and failures in treatment should be analyzed employing the past injection data. Usually failures in treatment can be related to injection problems which have been noted accurately on injection data sheets at the time injection was undertaken. However, instances will occur when failure or success of treatment cannot be fully explained. To supplement the injection data an accurate record of the elm condition at time of treatment will be helpful. (See Section VI - Treatment Records.)

V. DISEASE INDEXING

In the section on "Scope and Limitation of MBC-P Injection for DED" it was stated that elms exhibiting a Disease Index of over 50 should not be treated therapeutically. This recommendation is based on field experience obtained over a 6-year period. The Disease Index was developed in an effort to remove as much of the subjectivity in assessing the so-called "percent infection" for a given elm to determine whether it can be therapeutically treated. Refer to GLFRC publication O-X-201 "An Index for Rating Trees with Dutch Elm Disease" for the method and criteria of indexing a diseased elm. With field practice, individuals can be trained to obtain similar disease indices.

VI. TREATMENT RECORDS AND POST-INJECTION TREE CONDITION CLASSIFICATION

Maintaining accurate and up-tö-date treatment records is essential to any successful operation. Accurate records such as those shown in Figure 5 allow follow-up and if problems arise can be used to assist in analysis of the problem in an intelligent manner. Review of the successful treatment can aid in future treatment and analysis of failures can show obvious pitfalls to avoid in future treatment. Above all, accurate records can be analyzed by researchers to improve success rates for that part of the country. It is obvious that conditions are not uniform across North America and therefore differences in results can be expected. We have tried to anticipate as many of the problems as possible. However, in the final analysis only accurate records and review of the records will result in higher and higher success rates in treatment of elms whether healthy or diseased.

Assessment of the tree condition after treatment should be undertaken on a uniform basis. This facilitates comparison of the tree condition from month to month or even year to year, after treatment. It is suggested that the post-injection tree condition classification system in Table 4 be employed uniformly by everyone employing MBC-P for control of DED. Unfortunately the classification system is largely subjective. However, close adherence to the crown description for each class should result in fairly uniform assessments.

VII. TROUBLE SHOOTING

In the event of major problems concerning treatment of elms or if treated elms continue to decline, please contact:

Figure 5. Example of an injection field data sheet

INJECTION FIELD DATA SHEET

1. Organization Name: ______________________ Tree No. ____________
2. Tree Data: DBH ______________(cm) Height ________________(m)
   Species ____
   Tree location and site description
   ____
   ____
   ____
   ____
   ____
   ____

Map

3. Injection Data: Protection [ ] Therapy [ ] Reinjection [ ]

   Healthy [ ] Date: ____________
   Description ____________
   ____
   ____
   ____

   Diseased [ ] Date: ____________
   Tree Condition Class: ____________
   Proportion of crown affected: ____________
   Disease Index: ____________

   (If re-injection) Post-Injection Tree Condition Class: ____________
   Weather: ____

   No. of injection points: Flare [ ] Root [ ] Trunk [ ]
   Chemical name: ____
   Chemical concentration: ______________________________(ppm)
   Estimated injection volume: ______________________________(litres)
   Injection date: Start: ______________________________
   Injection time: Start: ____________ End: ____________
   Total time to complete injection: ______________________(hrs)
   Total chemical uptake: ______________________________(litres)

4. Comments: ____
   ____
   ____
   ______________________(add additional comments on back of page)

5. Data collected by: ______________________________(full name)

Table 4. Post injection tree condition classes

Class	Crown Description
A	Excellent condition and form - no visual symptoms of DED - crown full - leaves normal size
B	Good condition and form - no new DED symptoms - majority of leaves normal size - crown full to somewhat thin - few dead twigs
C	Fair condition and form - obvious new symptoms but only a slight spread of DED in crown - both normal and small leaf sizes throughout crown - some dead branches and twigs
D	Poor condition and form - aesthetic value of tree is question-able - obvious spread of DED - crown extremely sparse and leaves small - many dead branches and twigs
E	Tree "aesthetically lost" - majority of crown dying or dead - DED symptoms throughout elm

E. S. Kondo
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
Sault Ste. Marie, Ontario, P6A 5M7

Phone: 705-949-9461

If sampling is required

1. Bioassay Samples

   - are samples of twigs about 30 cm long with leaves, if available, taken from the tips of major branches throughout the crown of the treated elm. A minimum of 12 sample stations are required.
   - these samples are used in the laboratory to determine distribution of the chemical injected into the tree.

2. Dutch Elm Disease Determination Samples

   - are samples of branches approximately 1.5 cm in diameter and 15 cm long taken from branches showing wilting, yellowing or browning of leaves.
   - care must be taken to sample the live portion of the branches showing active symptoms of disease.

Shipment of Samples

1. Bioassay Samples

   - samples are labeled and placed in plastic bags
   - keep samples from individual sample stations in separate bags
   - it is important that samples be retained in a refrigerator until shipment

- under no circumstances, allow samples to sit in direct sunlight once they are placed in plastic bags
- all samples should be packed in a corrugated box and shipped via the fastest mode of transportation

2. Dutch Elm Disease Determination Samples
   - wrap samples in wax paper before packaging in a box or wrapping paper in a normal manner for shipment by parcel post

Storage of MBC-P

1. The chemical is quite acidic in concentrate form and therefore should not be stored in metal containers other than stainless steel. Fibreglass or plastic containers should be employed for storage.
2. Store the chemical only at room temperature or higher. Do not allow the chemical concentrate to be exposed to near freezing temperatures.
3. The concentrate should always be a clear amber colour or almost colourless. Do not use MBC-P concentrate if cloudy or with any precipitates.
4. The chemical can also be stored in a diluted form without degradation.

Water Quality

When the quality (suitability) of water to be used for mixing with the chemical concentrate is questionable, it is advisable to take the following precautions:

1. Test for particulates in the water

   (a) Pour the water into a clear four-litre bottle and observe for particulates or obvious cloudiness.

   (b) Water showing obvious particulates or cloudiness should not be employed for formulation of injection solution.

2. Test for alkalinity of the water

   (a) Add one part by volume of chemical concentrate and 27 parts by volume of the water to be tested into a clear four-litre bottle. Place the bottle into the refrigerator for approximately 2-4 hours and look for any residue at the bottom of the bottle.

   (b) Any residue at the bottom of the bottle shows that the water is unsuitable for formulation of injection solution.

   If more suitable water cannot be obtained the water can be filtered and de-ionized with portable cartridges. It is recommended that chemical not be added to unsuitable water to maintain water solubility of MBC-P.

Phytotoxicity Symptoms

Extensive experiments have been undertaken to establish phytotoxicity levels of MBC-P and therefore no toxicity should occur, if the recommended dosages are employed. In the event of an error in excessive dosage, toxicity due to the chemical may be exhibited by the elm in the following manner:

1. External Phytotoxicity Symptoms

   (a) Light Toxicity Symptoms: Leaf margins will show a loss of green pigments and will, with time, become yellowish. Later brownish blotches will become evident. All this should occur within 2-3 weeks after injection.

(b) Severe Toxicity Symptoms: Within a few days after injection much of the leaves will show distinct brown blotches and the leaves will show an obvious wilted appearance. The leaves will begin to fall from the tree within 1 week from the time of injection.

NOTE: The above toxicity symptoms should not be confused with normal fall colour.

2. Internal Phytotoxicity Symptoms

(a) Light Toxicity Symptoms: Light internal toxicity symptoms will be evident in elms showing little or no foliar toxicity. A cross section of the elm in the immediate area of injection will show discoloration of the xylem tissue. Unlike discoloration related to only mechanical wounding, chemical toxicity discoloration does not have a sharp demarcation between the healthy and "dead" affected tissue. Also, the extent or border of the discoloration will change with time as the elm attempts to clearly establish a reaction zone. This is part of the natural defensive mechanism of the elm, before it can develop effective new tissue as part of the "healing" process. "Healing" chemical injury takes much longer than a mechanical wound alone in that it takes a period of trial and error before the tree can clearly delineate the chemical injury area and take effective action.

(b) Severe Toxicity Symptoms: Severe internal toxicity symptoms will always be evident in elms showing external foliar toxicity. A cross section of the elm either above or below the injection site will show deep and dark discoloration of the xylem tissue. As with light internal toxicity, the elm will have great difficulty in "healing" the damage. However, unlike light toxicity, cambial cells will be killed and therefore the injection wound will not close for several years. Cutting back of the old injection will reveal dead tissue and no callous tissue will be evident at least for a few years.

Precipitation of MBC-P During Injection

1. Periodically check all sections of transparent hoses for deposits. The deposit is probably MBC which has precipitated out due to hard or alkaline water.
2. Check cut surfaces of injected root for any deposits. (Any deposit indicates precipitation of the chemical.)
3. Check root-flare or trunk injection holes for any deposits. (Any deposit indicates precipitation of the chemical.)

If precipitation is severe, it is likely that the treated elm did not receive sufficient chemical. The tree must be re-injected. The severed roots must be recut and new flare injection holes drilled before re-injection.

Injection During the "Blind" Period

Problems may be encountered in prophylactically injecting an elm in the spring during the so-called "blind" period, when although an elm may be systemically infected, no disease symptoms are visible. It must be remembered that elms do not exhibit DED symptoms even though they are infected until a certain period in the spring when they are physiologically able to express disease symptoms.

An operator injecting elms during this period is basically working during a blind period in that the elm appears healthy, but may be severely infected internally. A few days or weeks later, when the elm is physiologically able to express disease symptoms, the tree will express external symptoms of DED as if it had never been injected with Carbendazim H_2PO_4. To the owner of the tree it will appear as if the chemical and injection was totally responsible for expressed symptoms or that the treatment was ineffective.

Since the chemical merely acts as a fungicide, it cannot remove the *C. ulmi* toxic metabolites produced prior to the injection and the elm will inevitably react to the presence of the metabolites when it is physiologically able. All the chemical does is prevent further sporulation and hence further production of toxic metabolites.

The only precaution one can take to avoid such a consequence is to thoroughly sample and culture for the presence of *C. ulmi* if one suspects the elm of being infected, prior to injection.

Injection Wounds

Any wound created on any living elm presents a potential problem to the tree. The elm must heal over the wound quickly and effectively. Within the white elm species different trees possess differing abilities to heal wounds. This is probably both genetically and environmentally controlled to a great degree between individuals of the same species. There are two aspects in the healing process. First, when a hole is drilled into the sapwood of a live elm, a host reaction begins almost immediately which is similar to heartwood formation and can be termed protection wood formation. Second, the tree begins to close the hole, externally, through formation of callous tissue. A responsive elm, which is growing rapidly will normally completely heal over an injection wound of 1 cm diameter in one growing season. However, there are individuals which require much more time, usually they are slow growers or have wetwood problems. Although one cannot always be positive how a given elm will react to injection wounds, there are certain precautions which tend to minimize the injection hole closure problems. The following rules should be adhered to rigidly.

1. Avoid drilling holes into the main trunk of the elm. If you must, keep the holes as low to the flare area as possible.
2. Use injector heads that result in small holes or that require only a small drill hole (1 cm diameter or less).
3. Only sharp drill bits should be used to obtain a sharp, clean cut.
4. Avoid drilling deep holes. It is not necessary to drill beyond the fifth annual growth ring.
5. Close injection holes only with grafting wax (or nothing). Do not use wooden plugs.
6. Allow proper aeration of the wound.
7. Avoid high pressures to inject chemical solutions into

elms (0.7 kg/cm^2 is sufficient).

8. Avoid high concentrations of chemical solution (1000 ppm or greater) to insure minimal chemical toxicity at the injection point.
9. Do not flare-inject in the flare valley areas.
10. Stagger successive years' injection holes and keep them at least 25 cm apart.

VIII. INDEX OF SUPPORTING PUBLICATIONS

1972. Kondo, E.S. A method for introducing water-soluble chemicals into mature elms. Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-171.

1972. Takai, S. and E.S. Kondo. Seasonal changes in susceptibility of white elm trees to Dutch elm disease in central Ontario. Proc. Canadian Phytopathology Society. 39:42.

1973. Kondo, E.S., D.N. Roy and E. Jorgensen. Salts of methyl-2-benzimidazole carbamate and assessment of their potential in Dutch elm disease control. Canadian Journal of Forest Research 3(4):548-555.

1973. Kondo, E.S. and G.D. Huntley. Root-injection field trials of MBC-phosphate in 1972 for Dutch elm disease control. Can. For. Serv., Sault Ste. Marie, Ontario. Report O-X-182.

1974. Kondo, E.S. and G.D. Huntley. An index for rating trees with Dutch elm disease. Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-201. 7 p.

1974. Kondo, E.S. and G.D. Huntley. A large-capacity injection system for chemical solutions in Dutch elm disease control. Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-192. 7 p.

1975. Kondo, E.S. and G.D. Huntley. Calculation of injection periods and dosages of MBC-Phosphate for flexibility in Dutch elm disease control. Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-237. 8 p.

1975. Kondo, E.S. and G.D. Huntley. A disposable trunk and root-flare injector head for low-pressure injection of chemical solutions into trees. Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-235. 5 p.

1976. Kondo, E.S. Summary of 1976 elm injection results. Proc. of XXXI Annual Conference on Dutch elm disease, Waltham, Mass.

1977. Kondo, E.S. A six-year summary of four years of field experiments with MBC-P solutions to control Dutch elm disease. Bi-monthly Research Notes, Vol. 33, No. 3.

1977. Euale, L., L.M. Gardiner, G.D. Huntley, E.S. Kondo and L.G. Jago. An integrated Dutch elm disease control program for Sault Ste. Marie. Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-268. 31 p.

1977. Kondo, E.S. Integration of Carbendazim H_2PO_4 injections into Dutch elm disease control programs. The current state-of-the-art of Dutch elm disease control. National Arborist Association Symposium No. 1. p. 36-41.

1978. Kondo, E.S. Scope and limitations of Carbendazim H_2PO_4 injection in Dutch elm disease control. Journal of Arboriculture 4(4):80-86.

1978. Euale, L.R., L.M. Gardiner, G.D. Huntley, L.G. Jago and E.S. Kondo. An integrated Dutch elm disease control program for Sault Ste. Marie: Part II. Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-283. 29 p.

1979. Kondo, E.S. Root flare and root injection techniques. Proc. of Symp. on Systemic Chemical Treatments in Tree Culture. E. Lansing, Michigan State University.