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A Regioselectivity Study of Hydrostannylation Reactions on Terminal Alkynes with Oxygen Functionalities in Close Proximity

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A REGIOSELECTIVITY STUDY OF HYDROSTANNYLATION REACTIONS ON TERMINAL ALKYNES WITH OXYGEN FUNCTIONALITIES IN CLOSE PROXIMITY

By

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ABSTRACT

A REGIOSELECTIVITY STUDY OF HYDROSTANNYLATION REACTIONS ON TERMINAL ALKYNES WITH OXYGEN FUNCTIONALITIES IN CLOSE PROXIMITY

By

Michael Burton Rice

Vinyl stannanes hold an important place in organic synthesis. They can be used in a variety of roles and their preparation has been the topic of many studies. One means of preparing a vinyl stannane is to hydrostannate an alkyne. This process can be catalyzed by palladium, as first demonstrated by Oshima and coworkers.[1] A high degree of regioselectivity is almost always desired in these transformations, and this warrants the need for a systematic study on what structural features can influence the regiochemical outcome of the reaction. In this study a variety of terminal alkynes were subjected to Pd(0) mediated hydrostannylation conditions with either a hydroxyl, methoxy, or acetate functional group in close proximity. It was shown here that the oxygen functionalities enhance formation of the internal stannane, either by polarization of the carbon-carbon triple bond[2] or via palladacycle intermediacy.[3] Among the functional groups studied it was observed that the acetate functional group had a greater directing effect then either the hydroxy or methoxy group.

DEDICATION

For my grandfather
who taught me to work hard
and that I could accomplish anything.

ACKNOWLEDGMENTS

I would like to acknowledge my adviser, Dr. Robert E Maleczka Jr., with out his advise and guidance none of this would be possible. By seeing me for who I am and giving me good advice, I was able to make an extremely difficult career choice that has led me in the right direction. I would also like to thank the members of Dr. Maleczka's group for helping me throughout my studies.

I would also like to take this time to thank my family, especially Raymond, who throughout my life has given me inspiration and support in my endeavors.

TABLE OF CONTENTS

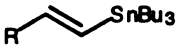
LIST OF FIGURES

LIST OF ABBREVIATION

KF	potassium fluoride
PMHS	polymethylhydrosiloxane
NMR	nuclear magnetic resonance
OAc	acetate
OH	hydroxyl
RB	round bottom
TBAF	tetrabutylammonium fluoride
THF	tetrahydrofuran
THP	tetrahydropyranyl
X	halide

INTRODUCTION

Figure 1. Vinyl Stannane Structure.



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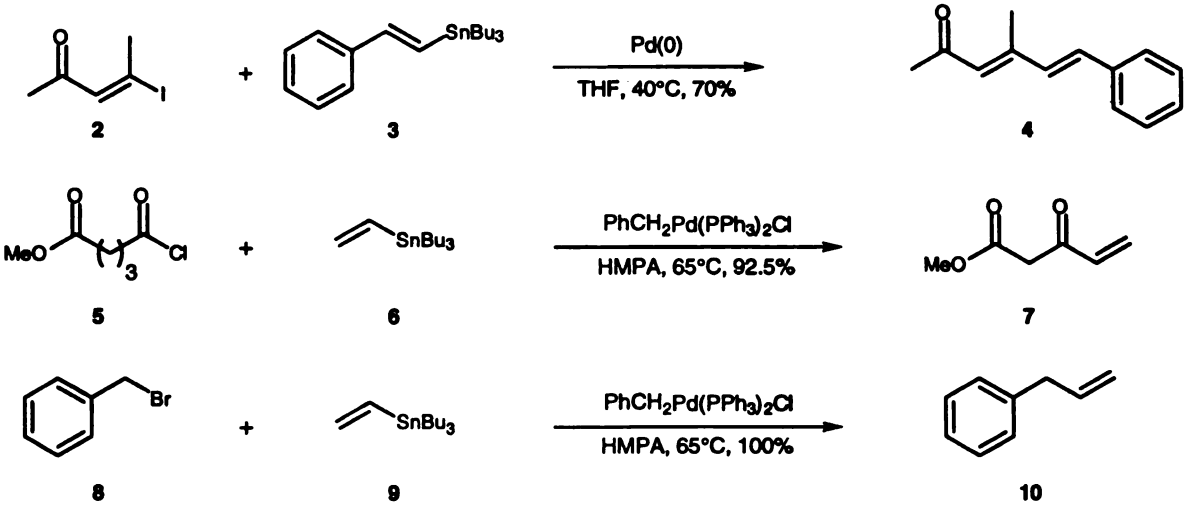
The formation of carbon–carbon bonds is central to the art of organic synthesis. Vinyl stannanes have been widely used for this purpose, a new carbon–carbon bond can be formed by the coupling of a variety of electrophiles with vinyl stannanes. The substrates that can act as electrophiles include carbonyl compounds, enones, acyl chlorides, vinyl, aryl, allyl, and benzyl halides and triflates.[4] Typically these couplings are mediated by catalytic amounts of palladium, as the examples in Figure 2 show. Such conditions are mild and allow for a large array of functional groups to be present in both the

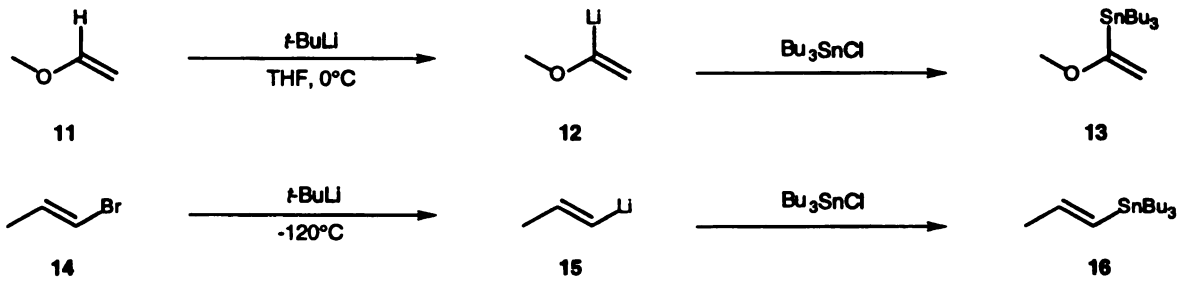
Figure 2. Examples of Pd(0) Cross-Couplings.



2 3 4 5 6 7 8 9 10

electrophilic and nucleophilic substrates. Also the coupled products are often formed in good yields and almost always with retention of the olefin geometry.[19] Due to the synthetic versatility of vinyl stannanes a variety of methods have been developed to prepare them: transmetallation[20] with other vinyl metals; metallometallation[22] of alkynes; hydrostannylation of alkynes, either via metal catalysis[1-11] or under free radical conditions.[12-18]

Figure 3. Formation of Vinyl Stannanes via Transmetallation.

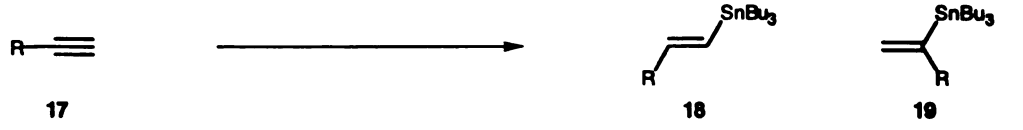


Transmetallation of vinyl metals, in particular lithium, with a tin halide has proven to be a useful method for the preparation of vinyl stannanes (Figure 3). These reactions give good regioselectivity and fairly good yields.[20] However this system only works well if the functional groups present in the system are not sensitive to the basic conditions of the lithiation. The vinyl lithium precursor can be formed either from lithiation of the corresponding alkene or via halogen metal exchange with a vinyl halide. To prepare the vinyl lithium precursor from an alkene, an alkene is reacted with an alkyl lithium reagent. The alkyl lithium reagent is very basic and will abstract a suitably acidic proton from the alkene. Depending on the alkene this may work for or against formation of the desired

product. For the correct regioisomer to be formed the correct hydrogen has to be the most acidic proton available. If the regioselectivity is a concern a vinyl halide of defined geometry could be synthesized prior to halogen metal exchange.[21]

In addition to the transmetallation method a variety of metallometallation techniques have also been developed which take advantage metals which are less electropositive than Li and Na. Metallometallation has the added bonus of providing two synthetic handles on the alkene. Of the bimetallic reagents that have been developed, the Sn–Al, Sn–Si, and Sn–Cu species are the most synthetically useful.[22] These reagents can form vinyl stannanes in good yields and in high regioselectivity (Figure 4). The reaction conditions are fairly mild and insensitive to a variety of functional groups; including OH, OTHP, OAc, and halides. As shown in Figure 4, the two possible isomers are the trans and

Figure 4. Metallometallation of Terminal Alkynes.

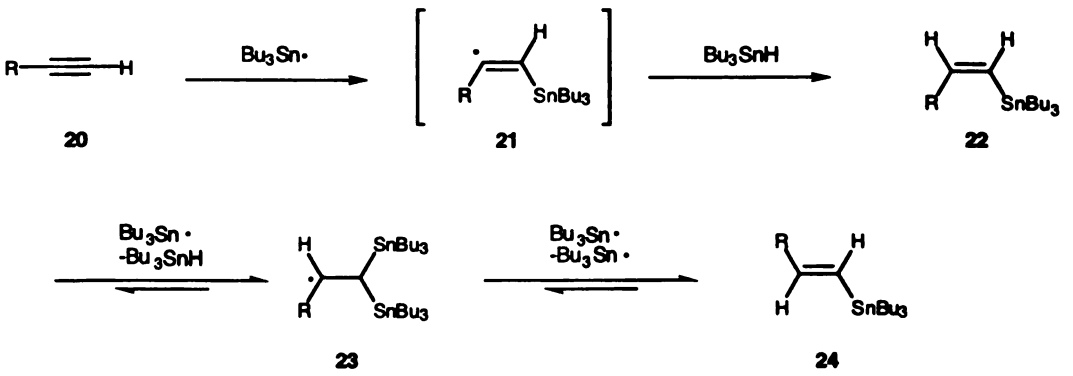


17 18 19

Bimetallic reagent	Conditions	Products Ratio E/Int.
$Bu_3SnSiMe_2Ph$	1. $Pd(Ph_3P)_4$, THF, Δ 2. TBAF, THF/H_2O, r.t.	E only
$Bu_3SnAlEt_2$	1. CuCN, THF, -30°C 2. H^+	91/1
	1. CuCN, HMPA, -30°C 2. H^+	6/94
$Bu_3Sn(R')CuCNLi_2$	1. THF/MeOH, -40 to -30°C 0.5h	

internal vinyl stannanes. This is due to the syn addition of the bimetallic reagent across the carbon–carbon triple bond. One drawback of this methodology is the need for 2 to 3 equivalents of the bimetalic reagents, which can lead to unwanted byproducts. For Sn-Cu and Sn-Al systems, the bimetallic alkene can not be isolated, but in terms of forming vinyl stannanes this is not important. Further more the Sn–Cu and Sn–Al reagents can hydrostannate both internal

Figure 5. Mechanism of Radical Mediated Hydrostannylation.

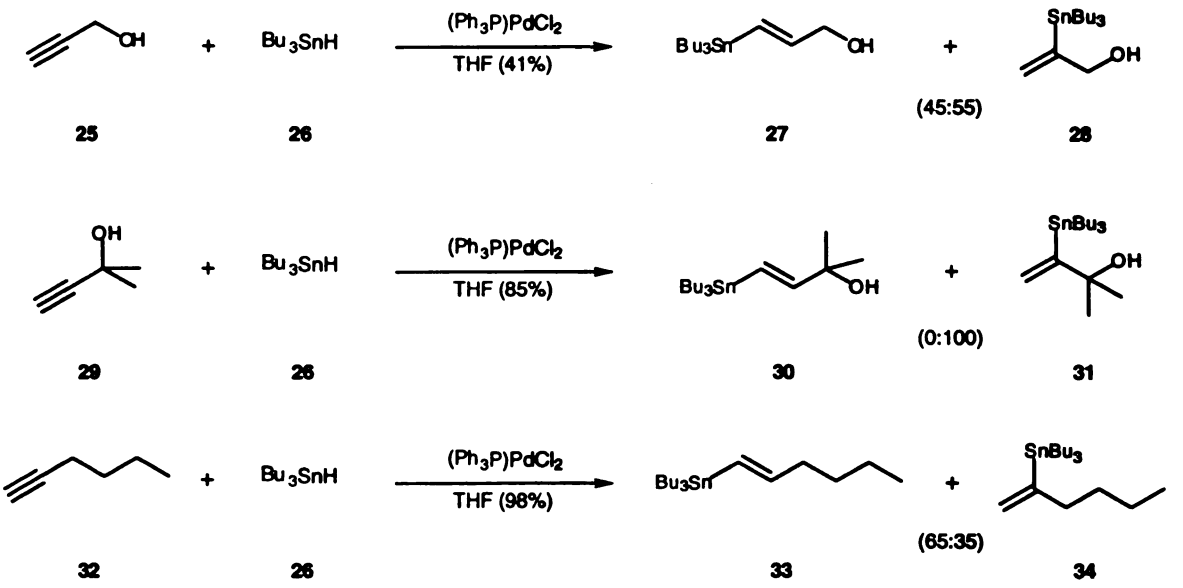


and terminal alkynes. In contrast the Sn–Si reactions are limited to terminal alkynes were the substituents alpha to the carbon–carbon triple bond are not sterically demanding.

Though transmetallation and metallometallation are well established techniques the traditional protocol for forming vinyl stannanes is through the free radical hydrostannylation of alkynes. This method gives predominately the cis and trans isomers (Figure 5).[12-14] The cis vinyl stannane is formed initially as the tin radical attacks the sterically less hindered terminal carbon. The trans isomer is produced as the major isomer, by running the reaction for longer

periods of time and with excess amounts of tin hydride.[12-15] This allows the formation of a second tin radical which under equilibrating conditions can attack the initially formed cis vinyl stannane to form an unstable ditin radical species (**23**). This ditin radical is free to rotate about the carbon–carbon σ-bond, thus elimination of the tributyltin radical will ultimately lead to the formation of the more thermodynamically stable trans stannane.

Figure 6. Examples of Pd(0) Hydrostannylations Reported in the Literature.



Another method to form vinyl stannanes, that is of particular interest to us, is the hydrostannylation of terminal alkynes mediated by catalytic amounts of Pd(0). These conditions are very mild and produce vinyl stannanes in good yields (Figure 6). In the literature there are two mechanisms proposed for palladium mediated hydrostannylations, the first by Oshima[1] in 1987 and the second by Wada in 1988.[5] The only difference between these two mechanisms

Figure 7. Pd(0) Mediated Hydrostannylation Mechanism.

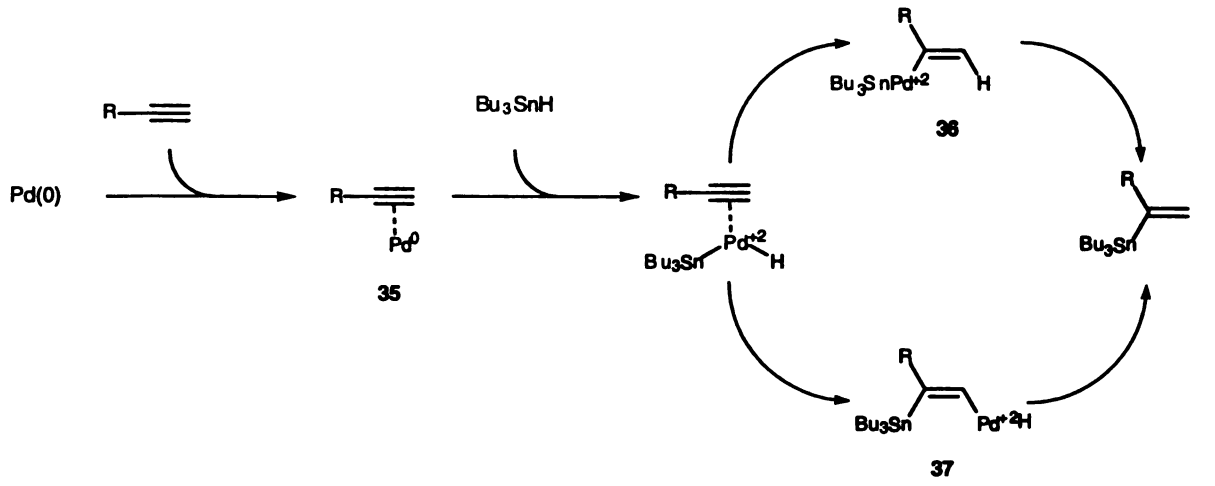
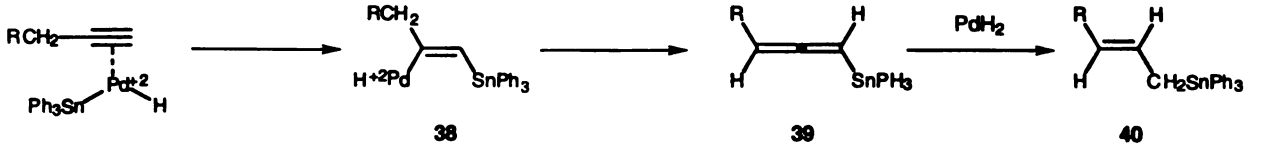


Figure 8. Formation of an Allylic Stannane via an Allene Intermediate.



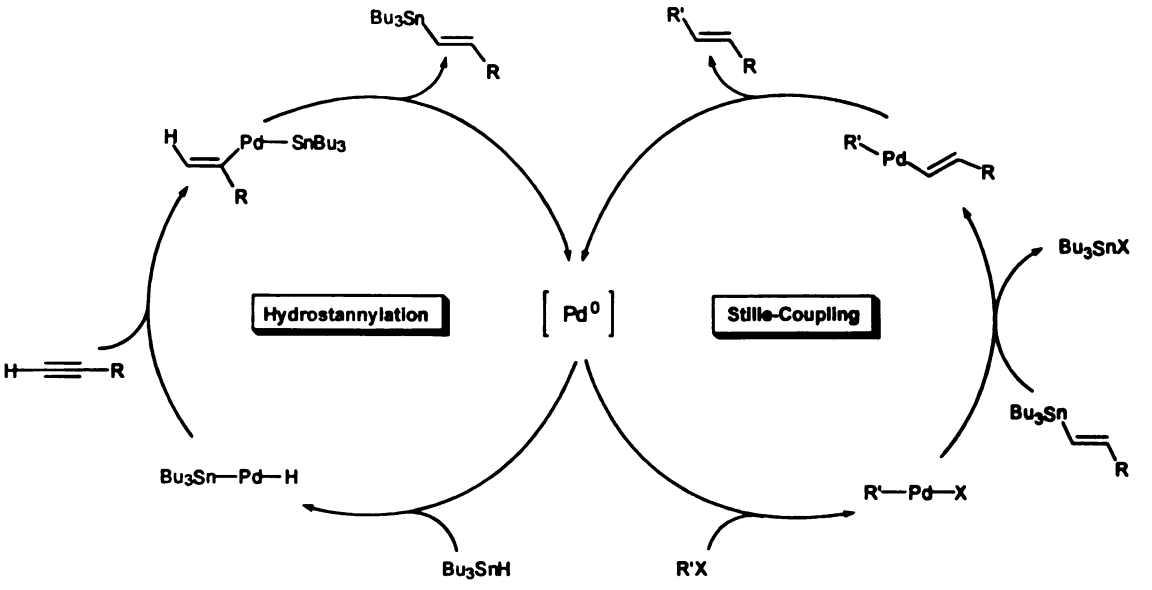
is the order in which the hydrogen and the tin moiety add across the carbon-carbon triple bond (Figure 7). Oshima's work focused on the hydrostannylation of terminal alkynes and he observed mixtures of terminal and internal isomers and on some occasions allylic stannanes. Based on the observed products, Oshima proposed initial addition of the tin moiety to afford intermediate **37**. To further explain the formation of the allylic stannane **40**, Oshima proposed the addition of the tin moiety (Figure 8) can form intermediate **38** where there is the possibility of β-hydride elimination to allow formation of allene **39**. Then the allene could be reduced by PdH_2 to form an allylic stannane. No spectroscopic

experiments were conducted by Oshima to support this proposal and this was the only literature report of the formation of allylic stannanes.

Wada's[5] mechanism follows more traditional transition metal mediated chemistry and he proposed the hydride is added first, to afford intermediate **36**. This proposal was supported by Trost's work[2] on the hydrostannylation of enynes with electron withdrawing group at the alpha position. Trost observed that the proximal isomer predominated when an electron withdrawing substituent was present alpha to the olefin of an internal enyne. Trost states that a reasonable explanation is that the acetylene is polarized by the electron withdrawing group, so the hydrogen will add to the more electron deficient carbon. Of these two proposals the later is more accepted in the literature and will be the one assumed throughout this research. In both mechanistic pathways the addition of the hydride and tin moiety proceeds in a syn fashion, explaining why the trans and internal stannanes are the predominate isomers and very little cis products are ever observed.

Irrespective of the method of formation, vinyl stannanes can be further elaborated via a variety of chemical transformations. As previously mentioned one of the most common applications of vinyl stannanes is in palladium cross-couplings. The Stille cross-coupling of vinyl halides with vinyl stannanes is a mild method for the stereoselective synthesis of 1,3-dienes, a structural unit which is often found in natural products and used as synthetic intermediates.[23-25] In spite of its wide use, this reaction bears some problems. The vinyl halide and

Figure 9. One Pot Hydrostannylation/Stille Cross-Coupling.



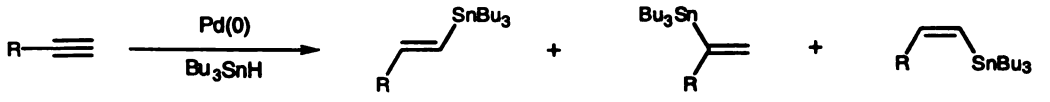
the vinyl tin compound have to be prepared stereoselectively in separate steps, prior to their employment in the coupling reaction. Furthermore, some vinyl tins undergo protodestannylation during chromatographic purification[4,26] and stoichiometric amounts of toxic organotin halides are produced as a byproduct. Therefore, we viewed the development of a one pot protocol for the stereoselective generation of vinyl tins and their subsequent cross-coupling, employing only catalytic amounts of tin, as highly desirable (Figure 9).

Towards this end, Boden *et al.* have shown that upon the complete palladium mediated hydrostannylation of 1-bromo alkynes, the addition of a further quantity of Pd-catalyst and a vinyl bromide could furnish the desired Stille product.[27] This procedure represents a means to obviate the isolation of the vinyl stannane intermediate. However the stepwise nature of the sequence was inconsistent with our own goal of developing a protocol catalytic in tin in

which all reaction components are present at the beginning of the reaction sequence.

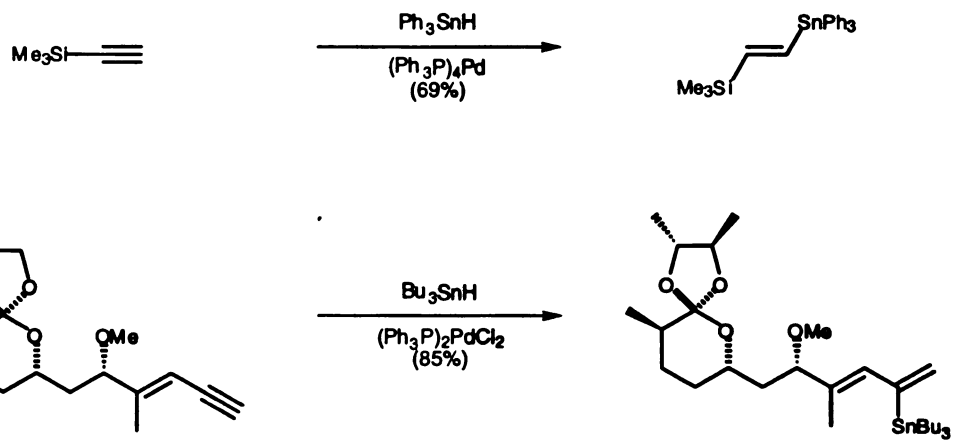
While the Pd-catalyzed hydrostannylation is a well established synthetic tool[1,4,5,28] the feasibility of carrying out Pd-catalyzed hydrostannylations in the presence of a Stille electrophile was by no means assured. We would need to strike a balance between the catalyst requirements for high yielding hydrostannylations (strong σ-donor ligands such as PPh_3) and efficient cross-couplings (weaker σ-donor ligands).[25] Equally important, was the need to minimize side reactions, especially the Pd-mediated Bu_3SnH reduction of vinyl halides.[29,30] Finally, understanding the regiochemical consequence of Pd-catalyzed hydrostannylations remains an important aspect of this methodology.[4,23-25] It is on this last point that this study is focused. We aim to discover the factors that play a role in the regioselectivity of Pd(0) mediated hydrostannylations.

Figure 10. Pd(0) Mediated Hydrostannylation.



Since the addition of the tin moiety can either occur at the terminus or the internal carbon (Figure 10) the possibility of the trans, internal, and the cis isomers are all possible. Literature cases have been reported where the trans vinyl stannane is the predominate product (Figure 11),[1] but there have also

Figure 11. Contrasting Regioselectivity Examples.



been examples where the internal vinyl stannane is formed preferentially.[31] In all cases very little if any of the cis isomer is observed. A systematic study of how oxygen functionalities, in close proximity to the alkyne, affect the regioselectivity during palladium mediated hydrostannylations has not been done. Oxygen functionalities were chosen in order to probe the possibility of coordination of the heteroatom to the Pd center. Coordination to the metal center could enhance formation of the internal stannane, as shown by Guibé and coworkers.[4] In fact while this research was being conducted an example of how an hydroxyl group can direct the tin moiety to the internal carbon via a six member palladacycle was cited by Pancrazi and co-workers.[3] Oxygen functionalities could also alter the polarization of the carbon–carbon triple bond, in keeping with the proposal made by Trost.[2] In conducting such a study we also decided to examine substrates that contained oxygen functionalites which would allow for these situations.

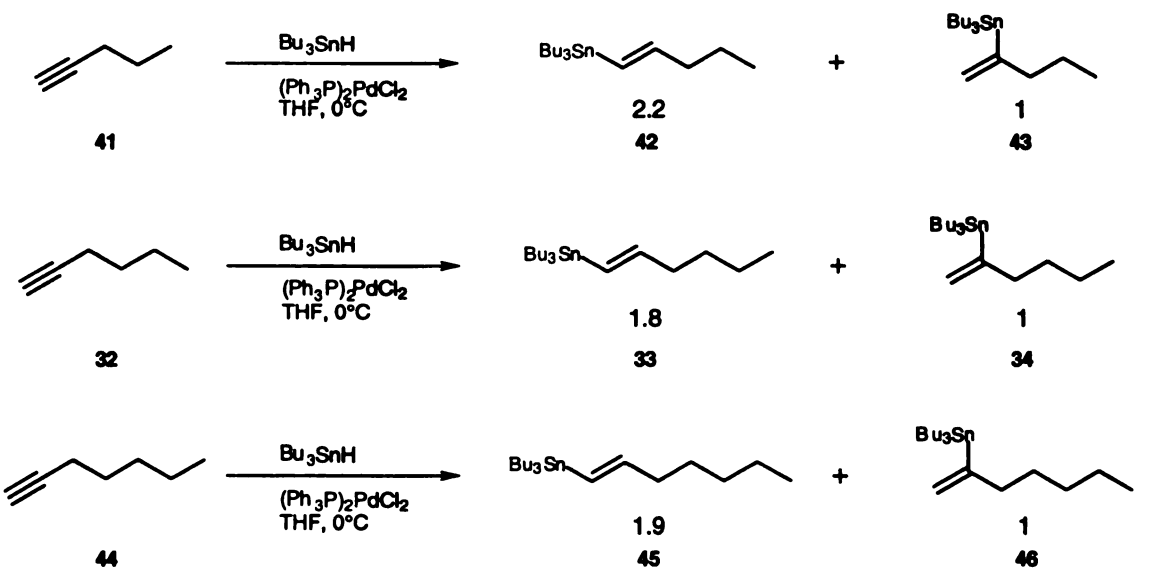
Along with Pd-mediated hydrostannylation, traditional free radical hydrostannylation reactions were also studied. These results allow us to make a direct regiochemical comparison and provide an alternate route to the vinyl stannanes, which would be of assistance in securing their structures.

RESULTS & DISCUSSION

ALIPHATIC SERIES

While our goal was to evaluate the influence of oxygen on regiocontrol, we initially examined a series of aliphatic alkynes to establish for comparison purposes the effects of related non-polarizing and non-coordinating groups. While we wished to initially examine aliphatic alkynes of similar chain length to the oxygenated substrates we would ultimately examine, some allowances for

Figure 12. Hydrostannylations of Aliphatic Alkynes.

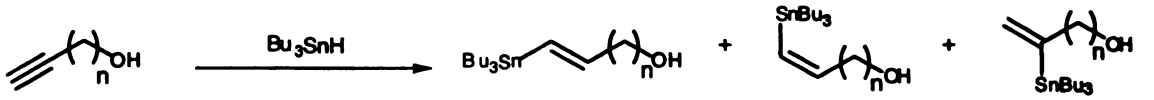


practicality had to be made. For example alkynes with less then 4 carbons in the skeletal chain were too volatile to study. Experimentally, the alkyne was added to a solution of THF, then catalytic amounts of palladium and an equivalent of tin hydride were added. The reactions were usually complete after 45 min., at which time the solvent was removed. The product ratios were determined by ^1H NMR taken of the crude mixture, specifically through the intergration of the vinylic protons. As the data in Figure 7 shows, a 2:1 ratio of trans to internal vinyl stannane isomers would appear to be the inherent bias for these reactions.

ALCOHOL SERIES

With the suggestion of oxygen coordinating to the palladium center, as proposed by Guibé,[4] it was decided that studying a series of alcohols would further probe this hypothesis and provide a greater understanding of these

Figure 13. Oxygen Directed Hydrostannylations.



		Yield	Product Ratios and Structure Number					
n = 1	25	Free Radical: 60%	9	47	2	48	1	49
		Pd(0) Mediated: 52%	1	27	0	50	1.3	28
n = 2	51	Free Radical: >99%	80	52	19	53	1	54
		Pd(0) Mediated: 69%	1.6	55	0	56	1	57
n = 3	58	Free Radical: 70%	9	59	1	60	0	61
		Pd(0) Mediated: 56%	2.5	62	0	63	1	64
n = 4	65	Free Radical: 64%	5.4	66	1	67	0	68
		Pd(0) Mediated: 95%	3	69	0	70	1	71

types of hydrostannylations. The variable within this series would be the relative position of the carbon–carbon triple bond and the hydroxyl function. As with the aliphatic substrates, Pd(0) mediated hydrostannylations were performed. For propargyl alcohol (**25**) a 1:1.3 ratio (Figure 13) of trans to the internal isomer was observed. Similar results for the hydrostannylation of propargyl alcohol were reported by Guibé[4] and co-workers, thus establishing that our techniques were consistent with known procedures. As substrates with more methylene spacers between the acetylene and the hydroxyl group were examined, the apparent directing of the tin moiety to the internal position decreased. Comparing the n = 1 (**25**) and n = 4 (**65**) cases the ratio of trans to internal went from 1:1.3 to 3:1. To explain this trend, it is useful to consider the work of Pancrazi's[3] and coworkers, who have examined the hydrostannylations of enynes. After subjecting an enyne, such as **72** (shown in Figure 14), to standard Pd(0) hydrostannylation conditions a 1:7.3 ratio of terminal to internal vinyl stannanes was observed. This lead Pancrazi to suggest a six member palladacycle (**73**) as an intermediate. The existence of palladacycles can also be applied to the alcohol series. Possible palladacycles for propargyl alcohol

Figure 14. Pancrazi's Proposed Palladacycle Intermediate.

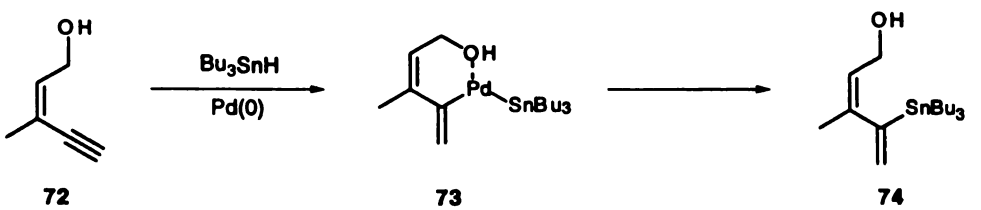
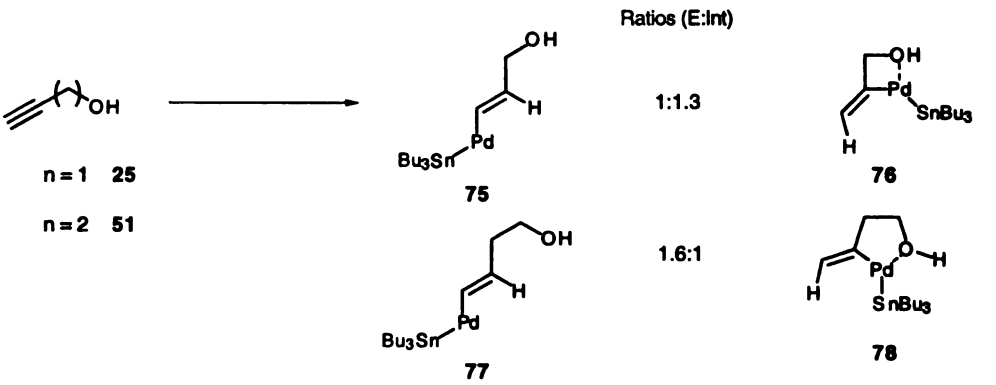


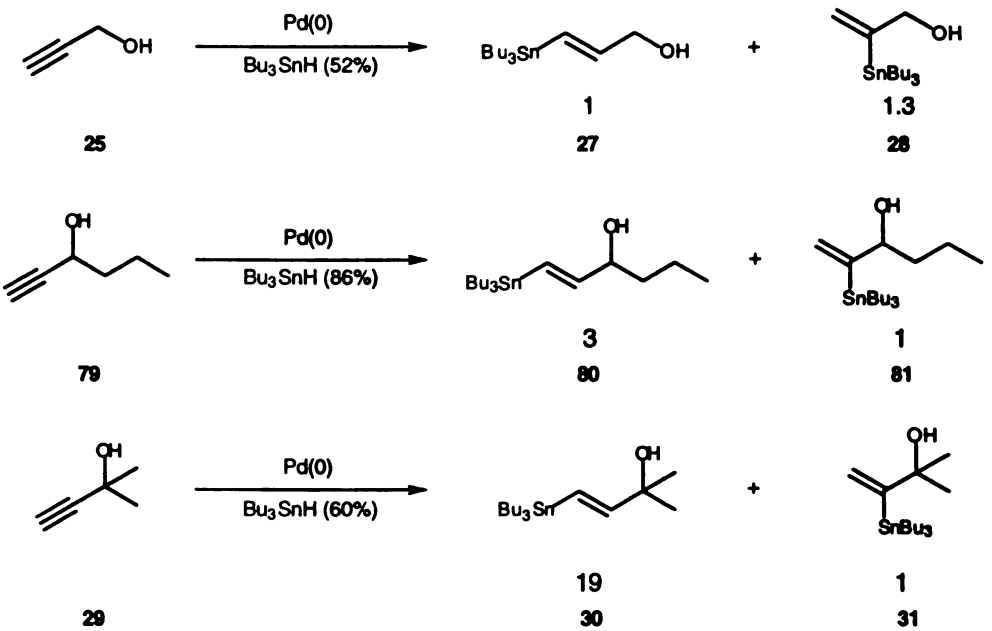
Figure 15. Possible Palladacycles for Terminal Alkynols.



(**25**) and 3-butyn-1-ol (**51**) are shown in Figure 15. These cyclic intermediates may explain why the internal isomer is formed in greater yields when the number of the methylene spacers are small. When n = 1, 2, and 3 the cyclic intermediates are 4, 5, and 6 membered rings respectively. Work done by Dieter[35] and coworkers suggest that palladcycles that are 4 member rings are not favored, but 5 and 6 membered rings are. It would then be reasonable to expect the 5 and 6 membered ring intermediates to give the lowest ratio of trans to internal stannane, but this is not what is observed. To explain why the ratio of trans to internal stannane is lowest for the n = 1 case, the electronics of the system must also be considered. It has already been shown that the presence of an electron withdrawing group alpha to the carbon–carbon triple bond leads to selective internal isomer production. This is explained by the polarization of the triple bond. Once polarized, the terminal carbon will be partially positive which will enhance the addition of the hydride to that position.

With regards to the free radical conditions, the trans isomer is always the dominant isomer and in the 4-pentyn-1-ol (**58**) and 5-hexyn-1-ol (**65**) examples

Figure 16. Hydrostannylation of α-Substituted Alkynes.



no internal isomer is observed. In comparing the two methods, they seem complementary with regards to the trans isomer being predominate under radical conditions and the internal isomer being available in decent yields via the Pd(0) conditions.

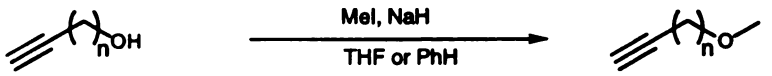
To get an idea of the strength of the directing effect compared to steric hindrance, a series of experiments was designed to examine these potentially competing features (Figure 16). With only one substituent alpha to the carbon–carbon triple bond, the trans isomer predominates but significant amounts of the internal stannane are produced. For the disubstituted propargyl alcohol the trans isomer is formed in a large excess, 19:1. These results agree with the general consensus in the literature,[3,4] that large steric hindrance at the alpha

position can overwhelm any directing effects by neighboring oxygen functionalities.

METHYL ETHER SERIES

The next question was whether the observed directing effect is unique to hydroxyl oxygens, or can other oxygen containing functionalities such as ethers or esters influence the regioselectivity. To answer this question, the alcohols studied previously were converted to the corresponding methyl ethers[32] and then subjected to both free radical and Pd(0) catalyzed hydrostannylation conditions. To form the methyl ethers, the corresponding alcohols were reacted with sodium hydride and then exposed to methyl iodide (Figure 17). The isolation of these compounds were not as trivial as one may suspect, due to their boiling points being similar to those of the solvents, a prep-GC was used to

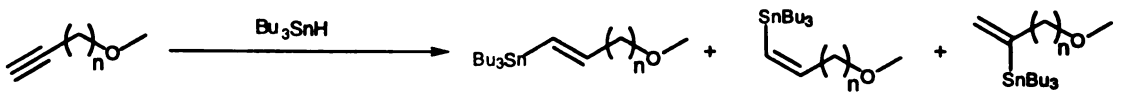
Figure 17. Preparation of the Methyl Ether Series.



n = 2, 3, 4

purify the methyl ethers. The prep-GC did prove adequate to purify small amounts of the methyl ethers, but due to time only enough of the material was isolated to be carried on to the hydrostannylation step. As indicated by the results shown in Figure 18, the ether series did indeed promote the addition of the tin moiety to the internal carbon. In fact, there was a greater directing effect

Figure 18. Methoxy Ether Oxygen Directed Hydrostannylations.



	Yeilds	Product Ratios and Structure Numbers		
n = 1 **82**	Free Radical: 82%	7.8 **83**	1.8 **84**	1 **85**
	Pd(0) Mediated: 81%	5.7 **86**	1 **87**	16.7 **88**
n = 2 **89**	Free Radical: 50%	19 **90**	1 **91**	0 **92**
	Pd(0) Mediated: 77%	6.5 **93**	1 **94**	6.6 **95**
n = 3 **96**	Free Radical: 46%	20 **97**	1 **98**	2 **99**
	Pd(0) Mediated: 81%	1.4 **100**	0 **101**	1 **101**
n = 4 **102**	Free Radical: 48%	16 **103**	1 **104**	1 **105**
	Pd(0) Mediated: 73%	3.5 **106**	1 **107**	1.3 **108**

for the methoxy propargyl substrate than for propargyl alcohol. This may be a reflection of the availability of the oxygen to coordinate to the Pd center in a palladacycle intermediate. The hydroxyl functional group will be hindered for coordination due to hydrogen bonding with the solvent (THF), but this will not be the case for the methyl ether group. The hindrance caused by hydrogen bonding will be amplified for the n = 1 case. In this situation the formation of a 4 membered palladacycle intermediate is highly strained, and the hindrance of any solvation of oxygen will be even more sterically demanding. The ratio of trans to internal slowly goes to 3:1 as the methoxy group position is extended by 4 methylene spacers (**102**). The methoxy function did not effect the ratio under the free radical conditions. The trans isomer is always formed in a fairly high excess and in ratios similar to the hydroxyl substrates.

ACETATE SERIES

Next a new series with acetate functional groups were examined. Acetates should be able to coordinate to the Pd metal center better than the hydroxyls or the methoxy ethers already studied. The acetates were synthesized from the corresponding alcohols by reacting the alkynol with acetic anhydride and pyridine (Figure 19).[32] The acetates also showed a directing effect, which was larger than that observed for either the hydroxyl groups or the methyl ethers (Figure 20). Even when there were four methylene spacers (**128**) between the acetylene and acetate functionality the ratio of trans to internal stannane was 1.3:1, where as for the corresponding alcohol (**65**) it was 3:1 and

Figure 19. Preparation of Acetate Series.

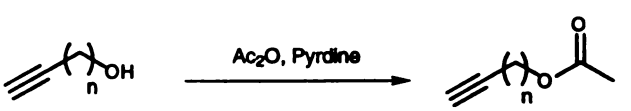
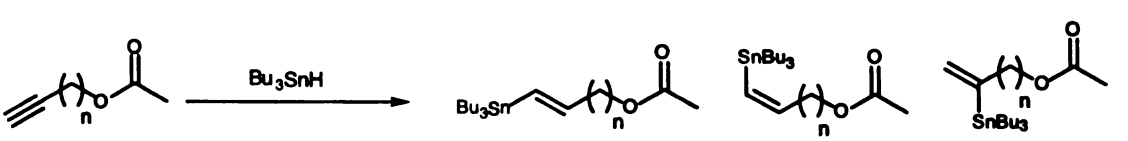


Figure 20. Acetate Oxygen Directed Hydrostannylations.



	Yeilds	Product Ratios and Structure Numbers		
n =2 **109**	Free Radical: 69%	9.7 **110**	1 **111**	0 **112**
	Pd(0) Mediated: 94%	1 **113**	0 **114**	1.3 **115**
n = 3 **116**	Free Radical: 75%	18.6 **117**	1.5 **118**	1 **119**
	Pd(0) Mediated: 60%	1.4 **120**	0 **121**	1 **122**
n = 4 **123**	Free Radical: 61%	4 **124**	1 **125**	0 **126**
	Pd(0) Mediated: 99%	1.3 **127**	0 **128**	1 **129**

the for methyl ether (**102**) 2.7:1 ratio was observed. Thus the acetate exhibited 3 times the directing effect than the hydroxyl and methyl ether substrates. This result may be due to the increased basicity at the carbonyl oxygen. Unfortunately direct comparison in the propargyl were impossible due to the fact that during hydrostannylation under Pd(0) conditions the acetate functionality would serve as a leaving group and no vinyl stannane could be formed.[28]

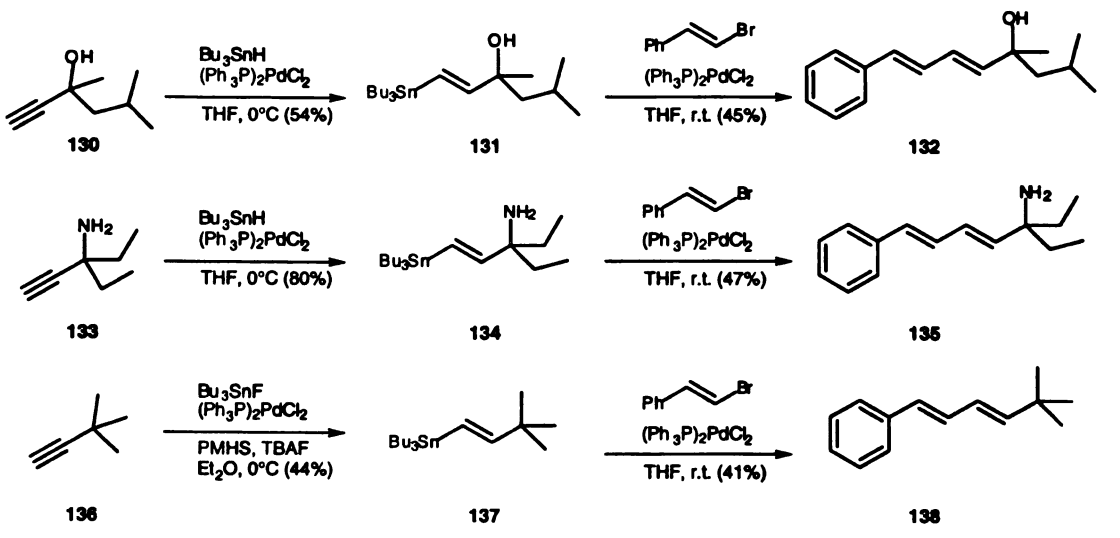
The results of the reactions under the free radical conditions followed the trend that had been observed in the previous series. The formation of the trans isomer was always dominates. Hydrostannylation of the propargyl acetate under free radical did not produce a vinyl stannane as decomposition of starting material occurred.

ONE POT HYDROSTANNYLATION/STILLE-CROSS COUPLING

Development of our one pot hydrostannylation/Stille-Cross coupling methodology ran concurrent with this project. The initial results of steric vs. oxygen directed hydrostannylations helped identify the alkynes to be used for the one pot study. As the focus of our study was the combination of the hydrostannylation and cross-coupling reactions, we wished to minimize complications which could arise from the hydrostannylation step being non-regioselective. Therefore we chose α-trisubstituted alkynes as our substrates since they are highly biased towards (*E*)-vinylstannanes upon Pd-catalyzed hydrostannylation.[3,4,34]

Thus it was observed by others within the group that the reaction of Bu_3SnH with a variety of alkynes in the presence of 1.1 equivalents of β-

Figure 21. Two Step Hydrostannylation/Stille-Cross Coupling.



bromostyrene and 0.3 mol% $(PPh_3)_2PdCl_2$ resulted in formation of the anticipated 1,3-dienes in yields that were comparable or superior to that of the stepwise variant. Control reactions were also completed using the traditional two step method with 3,3-dimethyl-1-butyne (**136**), 3,5-dimethyl-1-hexyn-3-ol (**130**), and 3,3-diethylpropargylamine (**133**) as shown in Figure 21. As expected, the high steric hindrance at the alpha position, lead to the trans stannane being formed as the sole product during the hydrostannylation. The vinyl tin products from these reactions were then subjected to Stille cross-couplings (Figure 21).

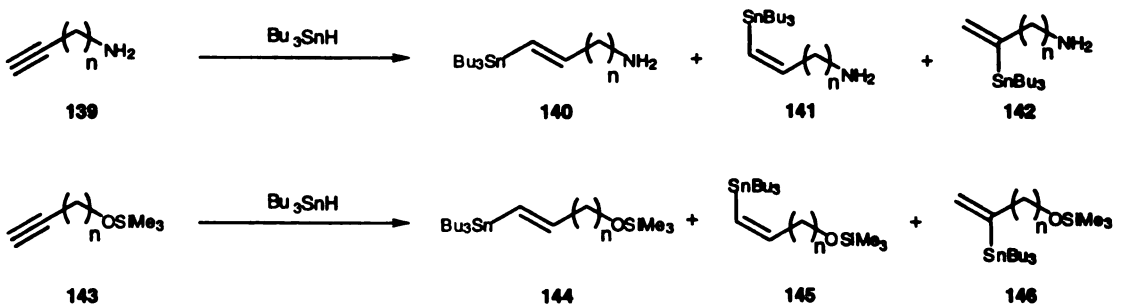
One problem that plagues Pd(0) mediated hydrostannylations is the separation of the vinyl stannane from any hexabutylditin byproduct. Since the polarity of the hexabutylditin and many alkyl vinyl stannanes is very similar their elution times on a silica gel column is often identical. To avoid this problem a

modification to the hydrostannylation conditions were discovered by a coworker within the group.[36] By using slight excess of Bu_3SnCl, aqueous KF, and PMHS to effect the in situ generation of Bu_3SnH, the formation of the tin dimer can be minimized.

FUTURE WORK

To date we have demonstrated that there is a directing effect from oxygen functionalities which can enhance the formation of internal vinyl stannanes. To further explore this topic, a series of experiments with functional groups that could coordinate either better or worse to the palladium metal center need to be developed. By comparing these extreme cases to the functional groups already studied, a better handle on the factors that influences internal stannane

Figure 22. Future Series.



formation would be attained. For example, it is known that amino groups bind to palladium better than do oxygen. If our proposal is correct, using the amino functionality in a series should show an increased trend in formation of the internal stannane. Silylethers would be expected to decrease the coordination due to the steric hindrance around the oxygen atom, resulting in a smaller

amount of internal stannane produced. The electronics of the silylethers would be similar to that of the methyl ethers so the effect of polariztion would not be a factor when comparing the two sets of data. Once these two series are studied a clearer picture into the question of coordination to the palladium center and the possibility of palladacycles will be available.

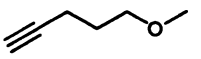
SUMMARY AND CONCLUSIONS

To conclude, it has been shown that oxygen functionalities can influence the regioselectivity of hydrostannylation reactions, with a bias in the direction of the internal isomer. The degree of this influence does decrease as the oxygen functionality is moved away from the alkyne and there is a high degree of steric hindrance at the α position. This directing effect maybe the result of polarization of the triple bond and/or the formation of palladacycle intermediates. The notion of polarization of the triple bond explains the large amount of internal vinyl stannane being formed when the oxygen is alpha to the alkyne. Once the oxygen functionality is further removed, palladacycle intermediates provide reasonable explanations for the formation of the internal isomer. It was also observed that the acetates exhibited 3 times the directing effect as the hydroxyl or methyl ether functional groups. This information will prove useful in predicting the expected ratios of Pd(0) mediated hydrostannylations, and may also assist in the decision as to which methodology to employ when forming vinyl stannanes.

EXPERIMENTAL

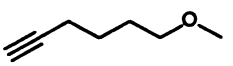
Reactions were carried out in oven-dried glassware under nitrogen atmosphere, unless otherwise noted. All commercial reagents were used without purification. All solvents were reagent grade. THF was freshly distilled from sodium/benzophenone from under nitrogen. Benzene was freshly distilled from calcium hydride under nitrogen. Except as otherwise indicated, all reactions were magnetically stirred and monitored by thin layer chromatography with 0.25-mm precoated silica gel plates. Flash chromatography was performed with silica gel 60 Å (particle size 230-400 Mesh ASTM) supplied by Whatman Inc. The column used in the preparatory gas chromatography was packed with 20% SE-30 on Chromosorb W-AW-DMCS. Yields refer to chromatographically and spectroscopically pure compounds, unless otherwise stated. Infrared spectra were recorded on a Nicolet IR/42 spectrometer. Proton and carbon NMR spectra were recorded on a Varian Gemini-300 spectrometer. Chemical shifts are reported relative to the residue peaks of solvent chloroform (δ 7.24 for ^{1}H and δ 77.0 for ^{13}C). High-resolution mass spectra were obtained at either the Michigan State University Mass Spectrometry Service Center with a JEOL-AX505 mass spectrometer (resolution 7000) or at the Mass Spectrometry Laboratory of the University of South Carolina, Department of Chemistry & Biochemistry with a Micromass VG-70S mass spectrometer. GC/MS were performed with either a HP-5890 GC/MS fitted with a SPB-20 fused silica column or a Finnigan 4500 fitted with a Restek Rtx-5 column (30 meter by 0.25 mm ID).

Preparation of 5-methoxy-1-pentyne (mbr1-68):



To a 100 mL RB containing a solution of MeI (8.90 g, 63 mmol) and THF (50 mL) was added NaH (2.40 g, 55 mmol, 55% dispersion in oil).[12] The reaction was then placed in an oil bath that was preheated to 65 °C. 4-pentyn-1-ol (3.40 g, 40 mmol) was added dropwise to the reaction mixture. Upon complete addition the reaction was allowed to stir for 1 hr. At this time a few milliliters of water were added to destroy any remaining NaH. Then the mixture was extracted with diethyl ether (3x) and dried over $MgSO_4$. The ether layer was filtered and then distilled until the distalant was no longer pure ether (~ 30 mL). The remaining mixture was then subjected to preparatory gas chromoatography. The desired product, a yellowish liquid, had a retention time of 6 min. when the prep-GC was set at 80°C, ~100 mg was collected. ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.76 (m, 2 H), 1.92 (t, J = 2.5 Hz, 1 H), 2.26 (dt, J = 2.7 Hz, 7.1 Hz, 2 H), 3.32 (s, 3 H), 3.45 (t, J = 6.3 Hz, 2 H). The spectroscopic data was consistent with those previously reported in the literature: Jackson, R.; Perlmutter P.; Smallridge A. *Aust. J. Chem.* **1988**, *41*, 251.

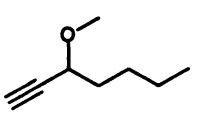
Formation of 6-methoxy-1-hexyne (mbr1-26):



To a 100 mL RB containing a solution of MeI (8.57 g, 61 mmol) and THF (40 mL) was added NaH (2.40 g, 55 mmol, 55% dispersion in oil).[12] The reaction was then placed in an oil bath that was preheated to 65 °C. 5-hexyn-1-ol (3.90 g, 40 mmol) was added dropwise to the reaction mixture. Upon

complete addition the reaction was allowed to stir for 1.5 hr. At this time a few milliliters of water were added to destroy any remaining NaH. Then the mixture was extracted with diethyl ether (3x) and dried over $MgSO_4$. The ether layer was filtered and then distilled until the distalant was no longer pure ether (~ 30 mL). The remaining mixture was then subjected to preparatory gas chromoatography. The desired product, a yellowish liquid, had a retention time of 6 min. when the prep-GC was set at 80 °C, ~130 mg was collected. ^1H NMR (300 MHz, $CDCl_3$) δ 1.60 (m, 4 H), 1.90 (t, J = 2.8 Hz, 1 H), 2.18 (dt, J = 2.7 Hz, 6.8 Hz, 2 H), 3.28 (s, 3 H), 3.35 (t, J = 6 Hz, 2 H). The spectroscopic data was consistent with those previously reported in the literature: Jackson, R.; Perlmutter P.; Smallridge A. *Aust. J. Chem.* **1988**, *41*, 251.

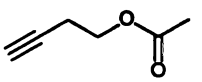
Formation of 3-methoxy-1-hexyne (mbr1-28):



To a 100 mL RB containing a solution of MeI (4.25 g, 30 mmol) and THF (20 mL) was added NaH (4.01 g, 97 mmol, 55% dispersion in oil).[12] The reaction was then placed in an oil bath that was preheated to 65 °C. 1-hexyn-3-ol (1.98 g, 40 mmol) was added dropwise to the reaction mixture. Upon complete addition the reaction was allowed to stir for 1.5 hr. At this time a few milliliters of water were added to destroy any remaining NaH. Then the mixture was extracted with diethyl ether (3x) and dried over $MgSO_4$. The ether layer was filtered and then distilled until the distillate was no longer pure ether (~ 30

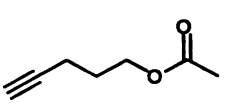
mL). The remaining mixture was then subjected to preparatory gas chromoatography. The desired product, a yellowish liquid, had a retention time of 6 min. when the prep-GC was set at 80 °C, ~100 mg was collected. ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.91 (t, J = 7.2 Hz, 3 H), 1.47 (m, 2 H), 1.67 (m 2 H), 2.41 (d, J = 2.2 Hz, 1 H), 3.39 (s, 3 H), 3.92 (dt, J = 2.2 Hz, 6.4 Hz, 1 H).

Formation of 4-aceto-1-butyne (mbr1-43):



To a 50 mL RB containing a solution of pyridine (5.45 g, 69 mmol) and 3-butyn-1-ol (4.84 g, 69 mmol) was added acetic anhydride (6.92 g, 68 mmol). Upon complete addition the reaction was allowed to stir for 6 hrs. The reaction mixture was extracted with diethyl ether and $CuSO_4$ (3x) and dried over $MgSO_4$. The organic layer was filtered and then concentrated on a rotavap. The desired product, a clear liquid, was isolated in a 65 % yield. ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.96 (t, J = 3.8 Hz, 1 H), 2.04 (s, 3 H), 2.48 (dt, J = 2.8 Hz, 6.8 Hz, 2 H), 4.13 (t, J = 6.8 Hz, 2 H). Preperation of 4-aceto-1-butyne was done similiar as reported in the literature: Jones, E.; Shen T.; Whiting M. *Chem. Soc.* **1950**, 230.

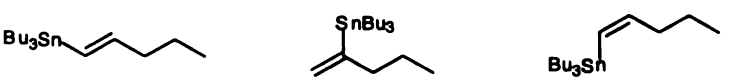
Formation of 5-aceto-1-pentyne (mbr1-63):



To a 50 mL RB containing a solution of pyridine (5.45 g, 69 mmol) and 4-petyn-1-ol (5.80 g, 69 mmol) was added acetic anhydride (6.99 g, 68 mmol).

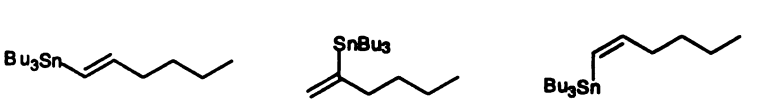
Upon complete addition the reaction was allowed to stir for 6 hrs. The reaction mixture was extracted with diethyl ether and $CuSO_4$ (3x) and dried over $MgSO_4$. The organic layer was filtered and then concentrated on a rotavap. The desired product, a clear liquid, was isolated in a 72 % yield (6.28 g). ^1H NMR (300 MHz, $CDCl_3$) δ 1.82 (m, 2 H), 1.93 (t. J = 2.8 Hz, 1 H), 2.01 (s, 3 H), 2.25 (dt, J = 2.7 Hz, 7.0 Hz 2 H), 4.13 (t, J = 6.3 Hz, 2 H). The spectroscopic data was consistent with those previously reported in the literature: White J.; Kim T.; Nambu M. *J. Am. Chem. Soc.* **1997**, *119*, 103.

Hydrostannylation of 1-pentyne (Pd(0), mbr1-86):



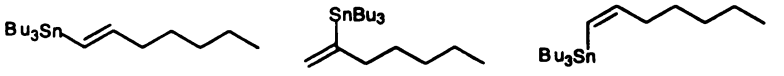
In a 25 mL RB 5 mL THF, 8 mg $(Ph_3P)_2PdCl_2$ (8 μmol), and 68 mg of 1-pentyne (1 mmol) were added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 0.4 mL Bu_3SnH (1.5 mmol) was added slowly. After 45 min. a crude NMR was taken to establish the ratio of regioisomers, E/Int/Z 2.2/1/0. ^1H NMR (300 MHz, $CDCl_3$) for E; δ 0.87 (m, 20 H), 1.28 (m, 6 H), 1.45 (m, 6 H), 2.08 (m, 2 H), 5.89 (m, 2 H). ^1H NMR (300 MHz, $CDCl_3$) for Int.; δ 0.87 (m, 20 H), 1.28 (m, 6 H), 1.45 (m, 6 H), 2.19 (t, J = 7.1 Hz, 2 H), 5.07 (m, 1 H), 5.63 (m, 1 H).

Hydrostannylation of 1-hexyne (Pd(0), mbr1-69):



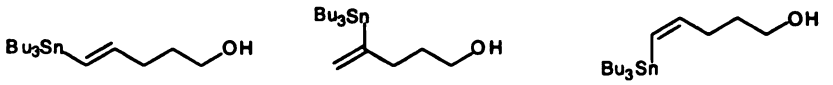
In a 25 mL RB 5 mL THF, 5.4 mg $(Ph_3P)_2PdCl_2$ (8 μmol), and 90 mg of 1-hexyne (1 mmol) were added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 0.4 mL Bu_3SnH (1.5 mmol) was added slowly. After 1 hr a crude NMR was taken to establish the ratio of regioisomers, E/Int/Z 1.8/1/0. ^1H NMR (300 MHz, $CDCl_3$) for E; δ 0.87 (m, 20 H), 1.28 (m, 8 H), 1.45 (m, 8 H), 2.11 (q, 2 H), 5.88 (m, 2 H). ^1H NMR (300 MHz, $CDCl_3$) for Int.; δ 0.86 (m, 20 H), 1.28 (m, 8 H), 1.45 (m, 6 H), 2.21 (t, 2 H), 5.06 (m, 1 H), 5.63 (m, 1 H).

Hydrostannylation of 1-heptyne (Pd(0), mbr1-87):



In a 25 mL RB 5 mL THF, 5 mg $(Ph_3P)_2PdCl_2$ (8 μmol), and 96 mg of 1-heptyne (1 mmol) were added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 0.4 mL Bu_3SnH (1.5 mmol) was added slowly. After 45 min. a crude NMR was taken to establish the ratio of regioisomers, E/Int/Z 1.9/1/0. ^1H NMR (300 MHz, $CDCl_3$) for E; δ 0.86 (m, 20 H), 1.28 (m, 8 H), 1.45 (m, 8 H), 2.10 (dq, J = 1.1 Hz, J = 6.9 Hz, 2 H), 5.89 (m, 2 H). ^1H NMR (300 MHz, $CDCl_3$) for Int.; δ 0.86 (m, 20 H), 1.28 (m, 8 H), 1.45 (m, 8 H), 2.20 (t, J = 7.4 Hz, 2 H), 5.06 (m, J_{Sn} = 66 Hz, 1 H), 5.63 (m, J_{Sn} = 142 Hz, 1 H). The spectroscopic data was consistent with those previously reported in the literature: Cliff M.; Pyne S. *Tetrahedron* **1996**, *52*, 13703-13712.

Hydrostannylation of 4-pentyn-1-ol (Pd(0), mbr1-62):



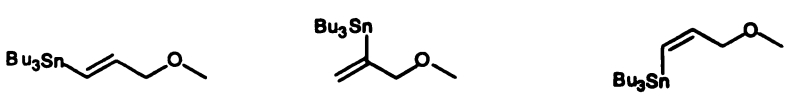
In a 25 mL flask 5 mL THF, 5.9 mg (8 μmol) $(Ph_3P)_2PdCl_2$ and 0.095 mL (1 mmol) 4-pentyn-1-ol was added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 0.4 mL (1.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 45 min. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 2.5:1:0. The mixture was passed through a silica column using 95.5:0.5 petroleum ether/ethyl acetate, R_f = 0.25. The isolated yield was 56% (210 mg mixture of the E and internal isomer). IR (neat) 3330, 2960, 2920, 2880, 2860, 1450, 1410, 1380, 1070 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) for E: δ 0.86 (m, 15 H), 1.29 (m, 6 H), 1.43 (m, 6 H), 1.66 (m, 2 H), 2.21 (m, 2 H), 3.63 (m, 2 H), 5.92 (m, 2 H) for Internal: δ 0.86 (m, 15 H), 1.29 (m, 6 H), 1.43 (m, 6 H), 1.66 (m, 2 H), 2.30 (t, *J* = 7.4 Hz, 2 H), 3.63 (m, 2 H), 5.11 (m, J_{Sn} = 30.5 Hz, 1 H), 5.69 (m, J_{Sn} = 68.4 Hz, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 148.6, 128.1, 62.4, 34.1, 31.7, 29.1, 27.2, 13.7, 9.3 for internal: δ 154.7, 125.2, 62.4, 37.4, 32.3, 29.1, 27.3, 13.6, 9.5; HRMS (EI) *m/z* 319.1082 [(M^+-Bu); calcd. for $C_{13}H_{27}OSn$ 319.1086].

(radical, mbr1-64)

In a 25 mL flask 5 mL benzene, 9.9 mg (0.08 mmol) AIBN and 0.094 mL (1 mmol) 4-pentyn-1ol was added. A preheated oil bath was used to maintain the temperature of the reaction at 80 °C. Then 0.4 mL (1.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 3.25 hrs. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Int./Z 9:0:1. The

mixture was passed through a silica column using 95.5:0.5 petroleum ether/ethyl acetate, R_f = 0.20. The isolated yield was 70% (91 mg of the E isomer and 170 mg mixture of the E and Z isomer). IR (neat) 3310, 2960, 2920, 2870, 2850, 1450, 1390, 1070 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) for E; δ 0.87 (m, 15 H), 1.29 (m, 6 H), 1.44 (m, 6 H), 1.66 (m, 2 H), 2.20 (dt, *J* = 4.4 Hz, 7.1 Hz 2 H), 3.64 (t, *J* = 6.3 Hz, 2 H), 5.92 (m, 2 H) for Z; δ 0.87 (m, 15 H), 1.29 (m, 6 H), 1.44 (m, 6 H), 1.66 (m, 2 H), 2.10 (ddt, *J* = 0.8 Hz, 7.2 Hz, 6.5 Hz, 2 H), 3.64 (t, *J* = 6.3 Hz, 2 H), 5.80 (dt, *J* = 12.4 Hz, 1.1 Hz, 1 H), 6.51 (dt, *J* = 12.4 Hz, 7.2 Hz, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) for E; δ 9.3, 13.7, 27.2, 29.1, 31.7, 34.1, 62.5, 128.2, 148.6 for Z; δ 148.6, 128.2, 62.5, 33.3, 32.8, 29.1, 27.3, 13.7, 10.2; HRMS (EI) *m/z* 319.1090 [(M^+-Bu); calcd. for $C_{13}H_{27}OSn$ 319.1086]. The spectroscopic data was consistent with those previously reported in the literature: Dussault P.; Eary T. *J. Am. Chem. Soc.* **1998**, *120*, 7133-7134 .

Hydrostannylation of 3-methoxy-1-propyne (Pd(0), mbr1-32):



In a 25 mL flask 5 mL THF, 5.4 mg (8 μmol) $(Ph_3P)_2PdCl_2$ and 0.084 mL (1 mmol) 3-methoxy-1-propyne was added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 0.4 mL (1.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 45 min. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 2.6:8.1:1. The mixture was passed through a silica column using 99.5:0.5 petroleum ether/ethyl acetate, R_f = 0.18. The isolated yield was 49% (72.1 mg of the E

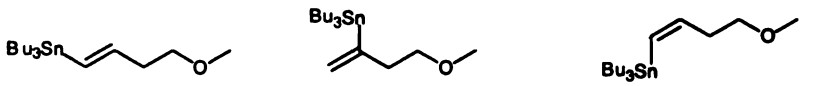
isomer and 104.3 mg mixture of the Z and internal isomer). IR (neat) 2930, 2910, 2830, 2810, 1405, 1050. ^{1}H NMR (300 MHz, $CDCl_3$) for E: δ 0.87 (m, 15 H), 1.27 (m, 12 H), 1.44 (m, 12 H), 3.32 (s, 3 H), 3.93 (dd, *J* = 1.4 Hz, 4.9 Hz, 1 H), 6.02 (dt,*J* = 19.2 Hz, 5.0 Hz, 2 H), 6.20 (dt, *J* = 18.9 Hz, 1.1 Hz, 1 H) for Internal: δ 0.87 (m, 15 H), 1.27 (m, 12 H), 1.44 (m, 12 H), 3.32 (s, 3 H), 4.00 (t, *J* = 1.6 Hz), 5.24 (m, J_{Sn} = 64.9 Hz, 1 H), 5.83 (m, J_{Sn} = 116.7 Hz, 1 H) for Z: δ 0.87 (m, 15 H), 1.27 (m, 12 H), 1.44 (m, 12 H), 3.27 (s, 3 H), 3.89 (dd, *J* = 5.5 Hz, 1.4 Hz, 2 H), 6.06 (d, *J* = 13.2 Hz, 1 H), 6.60 (dt, *J* = 12.9 Hz, 5.5 Hz, 1 H); ^{13}C NMR 75 MHz, $CDCl_3$) for E: δ 144.4, 131.3, 76.3, 57.8, 29.1, 27.3, 13.7, 9.4 for Internal: δ 153.0, 124.6, 79.7, 57.7, 29.1, 27.4, 13.7, 9.5 for Z: δ 143.9, 131.8, 75.1, 57.7, 29.1, 27.4, 13.7, 9.5; HRMS (EI) *m/z* 305.0933 [(M^+-Bu); calcd. for $C_{12}H_{25}OSn$ 305.0929].

(radical, mbr1-60)

In a 25 mL flask 10 mL benzene, 11 mg (0.09 mmol) AIBN and .09 mL (1 mmol) 3-methoxy-1-propyne was added. A preheated oil bath was used to maintain the temperature of the reaction at 80 °C. Then 0.27 mL (1 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 3 hrs. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 7.8:1:1.8. The mixture was passed through a silica column using 95:5 petroleum ether/ethyl acetate, R_f = 0.41. The isolated yield was 82% (48.4 mg of the E isomer and 248.9 mg mixture of the E, Z, and internal isomer). IR (neat) 2950, 2920, 2870, 2840, 2810, 1450, 1380, 1110, 1100, 1000 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) for E: δ 0.86 (m, 15 H), 1.29 (m, 6 H), 1.45 (m, 6 H), 3.31 (s, 3

H), 3.92 (dd, J = 1.3 Hz, 5.0 Hz, 2 H), 6.05 (m, 2 H) for Internal: δ 0.86 (m, 15 H), 1.29 (m, 6 H), 1.45 (m, 6 H), 3.27 (s, 3 H), 4.00 (t, J = 1.5 Hz, 2 H), 5.24 (m, J_{Sn} = 62.4 Hz, 1 H), 5.83 (m, J_{Sn} = 128.2 Hz, 1 H) for Z: δ 0.86 (m, 15 H), 1.29 (m, 12 H), 1.45 (m, 12 H), 3.31 (s, 3 H), 3.87 (dd, J = 1.3 Hz, 5.2 Hz, 2 H), 6.06 (dt, J = 13.2 Hz, 1.4 Hz, 1 H), 6.59 (dt, J = 13.2 Hz, J = 5.5 Hz, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 144.4, 131.3, 76.6, 57.8, 29.1, 27.3, 13.7 for Internal: δ 153.0, 124.6, 79.7, 58.0, 29.1, 27.4, 13.7, 9.5 for Z: δ 143.9, 131.8, 75.1, 58.0, 29.1, 27.4, 13.7, 9.5; HRMS (EI) *m/z* 305.0936 [(M^+-Bu); calcd. for $C_{12}H_{25}OSn$ 305.0929]. The spectroscopic data was consistent with those previously reported in the literature: Verlhac J.; Pereyre M. *Tetrahedron* **1990**, *46*, 6399-6412.

Hydrostannylation of 4-methoxy-1-butyne (Pd(0), mbr1-53):



In a 25 mL flask 5 mL THF, 5.9 mg (8 μmol) $(Ph_3P)_2PdCl_2$ and 79 mg (1 mmol) 4-methoxy-1-butyne was added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 0.4 mL (1.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 50 min. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 6.5:6.6:1. The mixture was passed through a silica column using 99.5:0.5 petroleum ether/ethyl acetate, R_f = 0.11. The isolated yield was 77% (285.3 mg mixture of the E, Z, and internal isomer). IR (neat) 2960, 2920, 2860, 2850, 1450, 1360, 1110 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) for E: δ 0.86 (m, 15 H), 1.28 (m, 12 H),

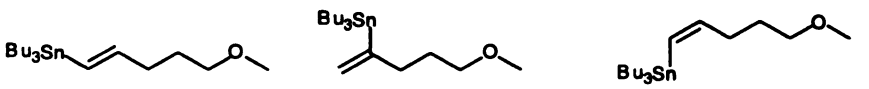
1.45 (m, 12 H), 2.40 (m, 2 H), 3.30 (s, 3 H), 3.41 (t, J=6.9 Hz, 2 H), 5.93 (m, 2 H) for Internal: δ 0.86 (m, 15 H), 1.28 (m, 12 H), 1.45 (m, 12 H), 2.49 (t, J = 6.6 Hz, 2 H), 3.30 (s, 3 H), 3.37 (t, J = 6.9 Hz, 2 H), 5.16 (m, J_{Sn} = 60 Hz, 1 H), 5.72 (m, J_{Sn} = 136 Hz, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 145.1, 129.8, 72.6, 41.3, 29.1, 27.4, 13.7, 9.7 for Internal: δ 151.6, 126.6, 72.2, 58.5, 29.3, 27.3, 13.7, 9.5; HRMS (EI) *m/z* 319.1088 [(M^+-Bu); calcd. for $C_{13}H_{27}OSn$ 319.1086].

Preparation/hydrostannylation of 4-methoxy-1-butyne (mbr1-90)

To a 50 mL RB containing a solution of MeI (709 mg, 5 mmol) and benzene (25 mL) was added NaH (117 mg, 5.1 mmol). A preheated oil bath was used to maintain the temperature of the reaction at 80 °C. 3-butyn-1-ol (350 mg, 5 mmol) was added dropwise to the reaction mixture. After the reaction had stirred for 3 hr, catalytic amount of AIBN (40 mg) was added. Then Bu_3SnH (2.5 mL, 5.5 mmol) was added drop wise. The reaction was stopped after stirring for an additional 3.5 hours. The reaction mixture was concentrated and a crude NMR was taken to establish the ratio of the regioisomers, E/Internal/Z 15/0/1. Then the reaction was purified by flash column chromotography using 9:1 hexanes/ethyl acetate, R_f = 0.57. The observation was made that a large portion of the original alcohol was not converted to the methyl ether (~1.2 g), so there was a substantial amount of alkynol vinyl stannane formed. 0.94 g of the trans isomer was isolated (50 % yield) with trace amounts of the cis isomer being present. IR (neat) 2950, 2910, 2870, 2850, 1420, 1100 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) for E: δ 0.86 (m, 15 H), 1.28 (m, 6 H), 1.45 (m, 6 H), 2.39 (m, 2 H), 3.31 (s, 3 H), 3.41 (t, J = 7.0 Hz, 2 H), 5.95 (m, 2

H). ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 144.7, 131.9, 61.5, 41.2, 29.1, 27.3, 13.7, 9.5; HRMS (EI) *m/z* 319.1097 [(M^+-Bu); calcd. for $C_{13}H_{27}OSn$ 319.1086].

Hydrostannylation of 5-methoxy-1-pentyne (Pd(0), mbr1-73):

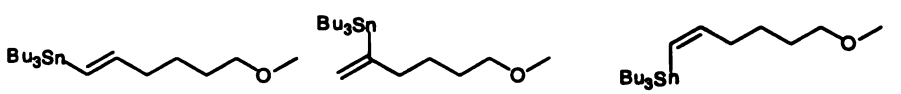


In a 25 mL flask 5 mL THF, 7.1 mg (0.1 mmol) $(Ph_3P)_2PdCl_2$ and 120 mg (1.2 mmol) 4-methoxy-1-butyne was added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 0.6 mL (2.2 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 45 min. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 1.4:1:0. The mixture was passed through a silica column using 95:5 petroleum ether/ethyl acetate, R_f = 0.75. The isolated yield was 81% (316.3 mg mixture of the E and internal isomer). IR (neat) 2960, 2920, 2870, 2850, 1450, 1110 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) for E: δ 0.86 (m, 15 H), 1.28 (m, 12 H), 1.44 (m, 12 H) 1.65 (m, 2 H), 2.16 (dt, *J* = 4.6 Hz, 7.7 Hz, 2 H), 3.30 (s, 3 H), 3.35 (t, *J* = 6.6 Hz, 2 H), 5.89 (m, 2 H) for Internal: δ 0.86 (m, 15 H), 1.28 (m, 12 H), 1.44 (m, 12 H) 1.65 (m, 2 H), 2.26 (t, *J* =7.5 Hz, 2 H), 3.30 (s, 3 H), 3.35 (t, *J* = 6.6 Hz, 2 H), 5.09 (m, J_{Sn} = 62.0 Hz, 1 H), 5.66 (m, J_{Sn} = 138.6 Hz, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 148.6, 127.8, 72.2, 58.5, 34.1, 29.1, 27.2, 13.7, 9.3 for Internal: δ 154.6, 125.0, 72.3, 58.5, 37.4, 29.1, 27.3, 13.7, 9.5; HRMS (EI) *m/z* 333.1246 [(M^+-Bu); calcd. for $C_{14}H_{29}OSn$ 333.1243].

(radical, mbr1-71):

In a 25 mL flask 5 mL benzene, 9 mg (0.078 mmol) AIBN and 100 mg (1 mmol) 5-methoxy-1-pentyne was added. A preheated oil bath was used to maintain the temperature of the reaction at 80 °C. Then 0.4 mL (1.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 3 hrs. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Int./Z 10:1:1. The mixture was passed through a silica column using 95:5 petroleum ether/ethyl acetate, R_f = 0.40. The isolated yield was 46% (69 mg of the E isomer and 110 mg mixture of the E, Z, and internal isomer). IR (neat) 2960, 2920, 2870, 2850, 1460, 1110 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) for E: δ 0.86 (m, 15 H), 1.29 (m, 12 H), 1.45 (m, 12 H) 1.66 (m, 2 H), 2.16 (m, 2 H), 3.30 (s, 3 H), 3.35 (t, J = 6.6 Hz, 2 H), 5.90 (m, 2 H) for Internal: δ 0.86 (m, 15 H), 1.29 (m, 12 H), 1.45 (m, 12 H) 1.66 (m, 2 H), 2.06 (m, 2 H), 3.30 (s, 3 H), 3.35 (t, J = 6.6 Hz, 2 H), 5.10 (m, J_{Sn} = 61.0 Hz), 5.66 (m, J_{Sn} = 144.2 Hz) for Z: δ 0.86 (m, 15 H), 1.29 (m, 12 H), 1.45 (m, 12 H) 1.66 (m, 2 H), 2.27 (m, 2 H), 3.30 (s, 3 H), 3.35 (t, J = 6.6 Hz, 2 H), 5.780 (dt, 12.4 Hz, 1.1 Hz, 1 H), 6.48 (dt, J = 12.4 Hz, 7.2 Hz, 2 H). ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 148.6, 127.8, 72.2, 58.5, 34.2, 29.1, 28.8, 27.3, 13.7, 9.4 for Z: δ 148.3, 128.3, 72.2, 58.5, 34.2, 29.1, 27.3, 13.7, 9.4; HRMS (EI) *m/z* 333.1249 [(M-Bu); calcd. for $C_{14}H_{29}OSn$ 333.1243].

Hydrostannylation of 6-methoxy-1-hexyne (Pd(0), mbr1-27):



In a 25 mL flask 5 mL THF, 4.1 mg (5 μmol) $(Ph_3P)_2PdCl_2$ and 113 mg (1 mmol) 6-methoxy-1-hexyne was added. An ice bath was used to maintain the

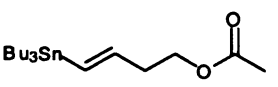
temperature of the reaction at 0 °C. Then 0.54 mL (1.9 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 35 min. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 6.2:3:1. The mixture was passed through a silica column using 99:1 petroleum ether/ethyl acetate, R_f = 0.10. The isolated yield was 73% (294.8 mg mixture of the E, Z, and internal isomer). IR (neat) 2980, 2960, 2930, 2920, 1210, 1150; ^1H NMR (300 MHz, $CDCl_3$) for E: δ (m, 15 H), 1.28 (m, 12 H), 1.43 (m, 12 H), 1.56 (m, 4 H), 2.12 (dt, J = 4.9 Hz, 7.1 Hz, 2 H), 3.30 (s, 3 H), 3.35 (t, J = 6.5 Hz, 2 H), 5.87 (m, 2 H) for Internal: δ (m, 15 H), 1.28 (m, 12 H), 1.43 (m, 12 H), 1.56 (m, 4 H), 2.33 (t, J = 7.4 Hz, 2 H), 3.30 (s, 3 H), 3.34 (t, J = 6.6 Hz, 2 H), 5.08 (m, J_{Sn} = 62 Hz, 1 H), 5.64 (m, J_{Sn} = 140.2 Hz, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 149.0, 127.3, 72.7, 41.0, 29.1, 27.3, 13.8, 9.4 for Internal: δ 155.0, 124.8, 72.6, 58.5, 29.2, 27.4, 13.8, 9.6; HRMS (EI) *m/z* 347.1397 [(M^+-Bu); calcd. $C_{15}H_{31}OSn$ 347.1400].

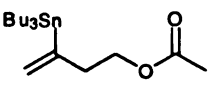
(radical, mbr1-22):

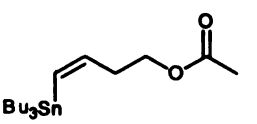
In a 50 mL flask 16 mL benzene, 8.2 mg (0.07 mmol) AIBN and 100 mg (1 mmol) 6-methoxy-1-hexyne was added. A preheated oil bath was used to maintain the temperature of the reaction at 80 °C. Then 0.4 mL (1.5 mmol) Bu_3SnH was added dropwise. After 3 hrs 8 mg (0.07 mmol) AIBN and 0.05 mL (0.1 μmol) Bu_3SnH was added, and the reaction was stopped 1.5 hrs later. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Int./Z 10:0:1. The mixture was passed through a silica column using 99:1 petroleum ether/ethyl acetate, R_f = 0.10. The isolated yield was 48% (87.4 mg mixture of

the E and Z isomer). IR (neat) 2980, 2970, 2930, 2920, 1210, 1050; ^{1}H NMR (300 MHz, $CDCl_3$) for E; δ 0.86 (m, 15 H), 1.28 (m, 12 H), 1.43 (m, 12 H), 1.56 (m, 2 H), 2.13 (dt, 4.7 Hz, 7.1 Hz, 2 H), 3.31 (s, 3 H), 3.35 (t, J = 6.6 Hz, 2 H), 5.87 (m, 2 H) for Z; δ 0.86 (m, 15 H), 1.28 (m, 12H), 1.43 (m, 12 H), 1.56 (m, 2 H), 2.03 (dt, 7.3 Hz, 7.2 Hz, 2 H), 3.31 (s, 3 H), 3.35 (t, J = 6.6 Hz, 2H), 5.87 (d, 12.4 Hz, 1 H), 6.47 (dt, J = 12.4 Hz, 7.2 Hz, 1 H).

Hydrostannylation of 4-aceto-1-butyne (Pd(0), mbr1-55):







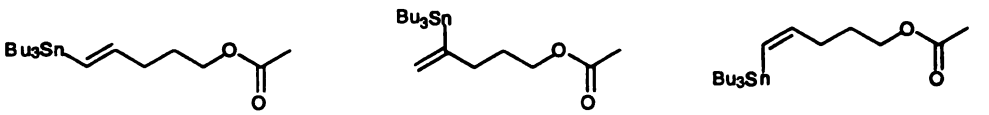
In a 25 mL flask 5 mL THF, 5.5 mg (7.8 μmol) $(Ph_3P)_2PdCl_2$ and 112 mg (1 mmol) 4-aceto-1-butyne was added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 0.4 mL (1.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 45 min. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 1:1.4:0. The mixture was passed through a silica column using 99.5:0.5 petroleum ether/ethyl acetate, R_f = 0.06. The isolated yield was 94% (380.6 mg mixture of the E and internal isomer). IR (neat) 2960, 2920, 2880, 2850, 1730, 1450, 1380, 1350, 1220, 1020 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) for E: δ .086 (m, 15 H), 1.28 (m, 12 H), 1.44 (m, 12 H), 2.01 (s, 3 H) 2.43 (ddt, J = 0.8 Hz, 5.8 Hz, 6.9 Hz, 2 H), 4.06 (t, J = 6.8 Hz, 2 H), 5.91 (m, 2 H) for Internal: δ .086 (m, 15 H), 1.28 (m, 12 H), 1.44 (m, 12 H), 2.01 (s, 3 H), 2.52 (t, J = 6.8 Hz, 2 H), 4.09 (t, J = 6.9 Hz, 2 H), 5.19 (m, J_{Sn} = 60.4 Hz, 1 H), 5.73 (m, J_{Sn} = 133.4 Hz, 1 H); ^{13}C NMR (75 MHz

$CDCl_3$) for E: δ 171.0, 143.8, 131.3, 63.5, 36.8, 29.0, 13.7, 9.3 for Internal: δ 171.0, 150.3, 127.7, 64.0, 39.7, 27.3, 21.0, 13.7, 9.5; HRMS (EI) *m/z* 347.1032 [(M^+-bu); calcd. for $C_{14}H_{27}O_2Sn$ 347.1036].

(radical, mbr1-57):

In a 50 mL flask 15 mL benzene, 12 mg (0.1 mmol) AIBN and 112 mg (1 mmol) 4-aceto-1-butyne was added. A preheated oil bath was used to maintain the temperature of the reaction at 80 °C. Then 0.27 mL (1 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 3 hrs. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 9.7:0:1. The mixture was passed through a silica column using 95:5 petroleum ether/ethyl acetate, R_f = 0.62. The isolated yield was 69% (280 mg mixture of the E and Z isomer). IR (neat) 2950, 2920, 2870, 2840, 1740, 1450, 1380, 1350, 1210, 1020 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) for E: δ 0.85 (m, 15 H), 1.28 (m, 12 H), 1.44 (m, 12 H), 2.01 (s, 3 H), 2.42 (ddt, *J* = 0.8 Hz, 6.0 Hz, 6.9 Hz, 2 H), 4.09 (t, *J* = 6.8 Hz, 2 H), 5.95 (m, 2 H) for Z: δ 0.85 (m, 15 H), 1.28 (m, 12 H), 1.44 (m, 12 H), 2.01 (s, 3 H), 2.33 (ddt, *J* = 1.1 Hz, 6.8 Hz, 6.9 Hz, 2 H), 4.07 (t, *J* = 6.8 Hz, 2 H), 5.92 (dt, *J* =12.7 Hz, 1.1 Hz, 1 H), 6.44 (dt, *J* = 12.7 Hz, 6.9 Hz, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 171.1, 143.8, 131.3, 63.6, 36.8, 29.0, 27.2, 20.9, 13.7, 9.3 for Z: δ 171.0, 143.7, 131.8, 63.8, 36.0, 29.0, 27.2, 20.9, 13.7, 9.3; HRMS (EI) *m/z* 347.1036 [(M^+-bu); calcd. for $C_{14}H_{27}O_2Sn$ 347.1036].

Hydrostannylation of 5-aceto-1-pentyne (Pd(0), mbr1-66):



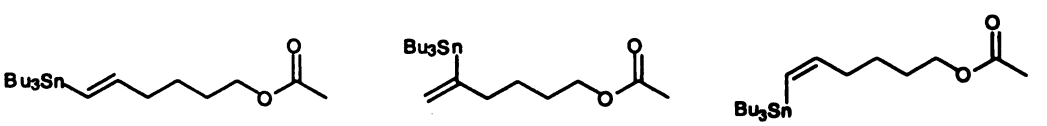
In a 25 mL flask 5 mL THF, 8 mg (11 μmol) $(Ph_3P)_2PdCl_2$ and 129 mg (1 mmol) 5-aceto-1-pentyne was added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 0.4 mL (1.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 50 min. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 1.4:1:0. The mixture was passed through a silica column using 99.5:0.5 petroleum ether/ethyl acetate, R_f = 0.12. The isolated yield was 60% (250 mg mixture of the E and internal isomer). IR (neat) 2950, 2910, 2890, 2830, 1730, 1450, 1370, 1230, 1050; ^{1}H NMR (300 MHz, $CDCl_3$) for E: δ 0.86 (m, 15 H), 1.29 (m, 12 H), 1.45 (m, 12 H), 1.70 (m, 2 H), 2.03 (s, 3 H), 2.17 (m, 2 H), 4.04 (t, J = 6.6 Hz, 2 H), 5.90 (m, 2 H) for Internal: δ 0.86 (m, 15 H), 1.29 (m, 12 H), 1.45 (m, 12 H), 1.70 (m, 2 H), 2.03 (s, 3 H), 2.27 (t, J = 7.7 Hz, H), 4.02 (t, J = 6.6 Hz, 2 H), 5.12 (m, J_{Sn} = 61.6 Hz, 1 H), 5.66 (m, J_{Sn} = 137.4 Hz, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 171.2, 147.7, 128.5, 64.0, 33.9, 29.2, 29.1, 27.2, 21.0, 13.7, 9.3 for Internal: δ 171.2, 153.9, 125.5, 64.1, 37.2, 29.3, 29.1, 27.4, 20.9, 13.7, 9.5; HRMS (EI) *m/z* 361.1192 [(M^+-Bu); calcd. for $C_{15}H_{29}O_2Sn$ 361.1192].

(radical mediated, mbr1-65):

In a 25 mL flask 6 mL benzene, 12 mg (0.1 mmol) AIBN and 112 mg (0.89 mmol) 5-aceto-1-pentyne was added. A preheated oil bath was used to maintain the temperature of the reaction at 80 °C. Then 0.4 mL (1.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 3 hrs. A crude

NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 18:0:1. The mixture was passed through a silica column using 95:5 petroleum ether/ethyl acetate, R_f = 0.45. The isolated yield was 75 % (326 mg mixture of the E and Z isomer). IR (neat) 2960, 2920, 2870, 2850, 1720, 1470, 1340, 1210, 1030 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) for E: δ 0.85 (m, 15 H), 1.25 (m, 12 H), 1.44 (m, 12 H), 1.70 (m, 2 H), 2.01 (s, 3 H), 2.17 (m, 2 H), 4.03 (t, *J* = 6.6 Hz, 2 H), 5.90 (m, 2 H) for Z: δ 0.85 (m, 15 H), 1.25 (m, 12 H), 1.44 (m, 12 H), 1.70 (m, 2 H), 2.01 (s, 3 H), 2.17 (m, 2 H), 4.03 (t, *J* = 6.6 Hz, 2 H), 5.83 (dt, *J* = 12.4 Hz, 1.1 Hz, 1 H), (dt, *J* = 12.3 Hz, 6.9 Hz, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 171.1, 147.7, 128.5, 64.0, 33.9, 29.2, 29.1, 27.2, 20.9, 13.7, 9.3 for Z: δ 171.1, 147.4, 129.2, 64.0, 33.3, 29.2, 29.1, 27.2, 20.9, 13.7, 9.3; HRMS (EI) *m/z* 361.1194 [(M^+-Bu); calcd. for $C_{15}H_{29}O_2Sn$ 361.1192].

Hydrostannylation of 6-aceto-1-hexyne (Pd(0), mbr1-52)



In a 25 mL flask 5 mL THF, 5.6 mg (7.9 μmol) $(Ph_3P)_2$ $PdCl_2$ and 140 mg (1 mmol) 6-aceto-1-hexyne was added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 0.4 mL (1.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 50 min. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 1.2:1:0. The mixture was passed through a silica column using 95:5 petroleum ether/ethyl acetate, R_f = 0.30. The isolated yield was 99% (412 mg mixture of the E and

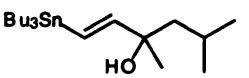
internal isomer). IR (neat) 2950, 2910, 2870, 2820, 1770,1210; ^{1}H NMR (300 MHz, $CDCl_3$) for E: δ 0.86 (m, 15 H), 1.28 (m, 12 H), 1.44 (m, 12 H), 1.58 (m, 4 H).2.02 (s, 3 H), 2.12 (dt, *J* = 4.4 Hz, 7.4 Hz, 2H), 4.03 (t, *J* = 6.6 Hz, 2 H), 5.87 (m, 2 H) for Internal: δ 0.86 (m, 15 H), 1.28 (m, 12 H), 1.44 (m, 12 H), 1.58 (m, 4 H), 2.02 (s, 3 H), 2.24 (t, *J* = 7.5 Hz, 2 H), 4.03 (t, *J* = 6.6 Hz, 2 H), 5.09 (m, 1 H), 5.64 (m, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 171.1, 148.5, 127.7, 64.3, 37.2, 29.1, 28.0, 27.2, 25.1, 13.6, 9.3 for Internal: δ 171.1, 154.4, 125.0, 65.7, 37.3, 29.2, 28.1, 27.3, 25.8, 13.6, 9.5; HRMS (EI) *m/z* 375.1347 [(M^+-Bu); calcd. for $C_{16}H_{31}O_2Sn$ 375.1349]. The spectroscopic data was consistent with those previously reported in the literature: Sharma S.; Oehlschlager A. *J. Org. Chem.* **1989**, *54*, 5064-5073.

(radical mediated, mbr1-36):

In a 25 mL flask 15 mL benzene, 18 mg (0.15 mmol) AIBN and 139 mg (1 mmol) 6-aceto-1-hexyne was added. A preheated oil bath was used to maintain the temperature of the reaction at 80 °C. Then 0.27 mL Bu_3SnH was added dropwise. The reaction was stopped after 2 hrs. A crude NMR was taken to establish the ratio of the regioisomers formed, E/Internal/Z 3.2:0:1. The mixture was passed through a silica column using 99:1 petroleum ether/ethyl acetate, R_f = 0.50. The isolated yield was 61% (263 mg mixture of the E and Z isomer). ^{1}H NMR (300 MHz, $CDCl_3$) for E: δ 0.86 (m, 15 H), 1.29 (m, 12 H), 1.46 (m, 12 H), 1.59 (m, 4 H), 2.01 (s, 3 H), 2.13 (dt, *J* = 4.4 Hz, 7.4 Hz, 2 H), 4.03 (t, *J* = 6.6 Hz, 2 H), 5.88 (m, 2 H) for Z: δ 0.86 (m, 15 H), 1.29 (m, 12 H), 1.46 (m, 12 H), 1.59 (m, 4 H), 2.01 (s, 3 H), 2.13 (dt, *J* = 4.4 Hz, 7.4 Hz, 2H), 4.03 (t, *J* = 6.6

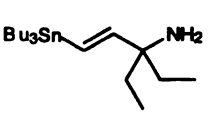
Hz, 2H), 5.88 (dt, J = 12.4 Hz, 1.1 Hz, 1H), 6.46 (dt, J = 6.8 Hz, 12.4 Hz, 1H, Z); ^{13}C NMR (75 MHz, $CDCl_3$) for E: δ 171.1, 148.7, 127.8, 64.4, 37.3, 29.1, 28.0, 27.3, 25.2, 13.8, 9.4 for Z: δ 171.1, 148.3, 128.2, 64.4, 37.3, 29.2, 28.0, 27.4, 21.1, 13.8, 9.4; HRMS (EI) *m/z* 375.1346 [(M^+-Bu); calcd. for $C_{16}H_{31}O_2Sn$ 375.1349].

Hydrostannylation of 3,5-dimethyl-1-hexyn-3-ol (mbr1-75)



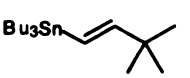
In a 100 mL flask 50 mL THF, 23 mg (0.03 mmol) $(Ph_3P)_2PdCl_2$ and 757 mg (6 mmol) 3,5-dimethyl-1-hexyn-3-ol was added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 1.84 mL (6.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 60 min. The mixture was passed through a silica column using 9:1 hexanes/petroleum ether, R_f = 0.25. The isolated yield was 54% (1.94 g). ^1H NMR (300 MHz, $CDCl_3$) for E; δ 0.86-0.95 (m, 21 H), 1.22-1.37 (m, 9 H), 1.42-1.55 (m, 8 H), 1.60-1.72 (m, 1 H), 6.01 (d, J = 19.3 Hz, 1 H), 6.08 (d, J = 19.3 Hz, 1 H). The spectroscopic data was consistent with those previously reported in the literature: Maleczka, Jr. R.; Terstiege, I *J. Org. Chem.* **1998**, *63*, 9622-9623.

Hydrostannylation of 3-amino-3-ethyl-1-pentyne (mbr1-76)



In a 100 mL flask 50 mL THF, 23 mg (.03 mmol) $(Ph_3P)_2$ $PdCl_2$ and 667 mg (6 mmol) 3-amino-3-ethyl-1-pentyne was added. An ice bath was used to maintain the temperature of the reaction at 0 °C. Then 1.84 mL (6.5 mmol) Bu_3SnH was added dropwise. The reaction was stopped after 60 min. The mixture was passed through a silica column using 9:1 hexanes/petroleum ether, R_f = 0.1. The isolated yield was 80% (1.90 g). ^1H NMR (300 MHz, $CDCl_3$) for E; δ 0.79 (t, *J* = 7.6 Hz, 6 H), 0.87 (m, 15 H), 1.29 (m, 6 H), 1.43 (q, *J* = 7.5 Hz, 4 H), 1.46 (m, 6 H), 5.96 (m, 2 H). ^{13}C NMR (75 Mhz, $CDCl_3$) δ 3.4, 4.9, 9.1, 22.7, 24.5, 29.1,4 29.1, 53.8, 118.7, 150.9. The spectroscopic data was consistent with those previously reported in the literature: Maleczka, Jr. R.; Terstiege, I *J. Org. Chem.* **1998**, *63*, 9622-9623.

Hydrostannylation of 3,3-dimethyl-1-butyne (mbr1-83)

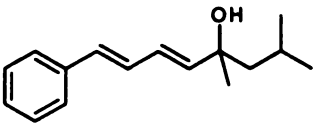


In a 50 mL flask 25 mL THF, 22 mg $(Ph_3P)_2PdCl_2$ (0.03 mmol), 0.37 mL PMHS, 1.89 g Bu_3SnF (6.1 mmol), and 492 mg 6-aceto-1-hexyne (6 mmol) was added. Then a catalytic amount of TBAF was added. The reaction was stopped after 60 min. The mixture was passed through a silica column using pentane, R_f = 0.77. The isolated yield was 44% (0.97 g). ^1H NMR (300 MHz, $CDCl_3$) for E; δ 0.87 (m, 15 H), 0.98 (s, 9 H), 1.26-1.35 (m, 6 H), 1.43 - 1.53 (m, 6 H), 5.76 (d, *J* = 19.3 Hz, 1 H), 5.96 (d, *J* = 19.3 Hz, 1 H); ^{13}C NMR (75 Mhz, $CDCl_3$) δ 9.4, 13.7, 27.2, 29.1,4 29.2, 35.9, 119.7, 160.0. The spectroscopic data was consistent

with those previously reported in the literature: Maleczka, Jr. R.; Terstiege, I *J. Org. Chem.* **1998**, *63*, 9622-9623.

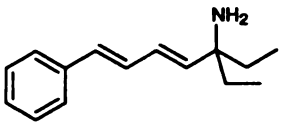
Coupling of bromostyrene with:

3,5-dimethyl-1-(tributylstannyl)-1(E)-buten-3-ol (mbr1-77)



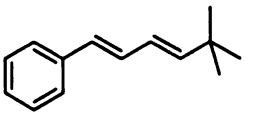
In a 50 mL flask 2 mL THF, 9 mg $(Ph_3P)_2PdCl_2$ (0.01 mmol), 0.62 g bromostyrene (3.3 mmol) was added. Then 1.30 g 3,5-dimethyl-1-(tributylstannyl)-1(E)-buten-3-ol (3 mmol) was added to the reaction. After a few days of stirring at room temperature starting material was still present according to TLC. At this point the reaction was brought to reflux and a small amount of catalyst was added. After two days the reaction was stopped and the mixture was passed through a silica column using 9:1 hexanes/ethyl acetate, R_f = 0.14. The isolated yield was 45% (306 mg). ^1H NMR (300 MHz, $CDCl_3$); δ 0.92 (d, *J* = 4.7 Hz, 3 H), 0.94 (d, *J* = 4.4 Hz, 3 H), 1.33 (s, 3 H), 1.50 (d, *J* = 6.0 Hz, 2 H), 1.76 (m, 1 H), 5.88 (d, *J* = 15.4 Hz, 1 H), 6.39 (dd, *J* = 15.4 Hz, 10.4 Hz, 1 H), 6.53 (d, *J* = 15.7 Hz, 1 H), 6.76 (dd, *J* = 15.7 Hz, 10.4 Hz, 1 H), 7.22-7.39 (m, 5 H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 24.4, 24.6, 29.1, 51.4, 73.6, 126.2, 127.2, 127.3, 128.5, 128.6, 131.8, 137.3, 141.6. The spectroscopic data was consistent with those previously reported in the literature: Maleczka, Jr. R.; Terstiege, I *J. Org. Chem.* **1998**, *63*, 9622-9623.

3-amino-3-ethyl-1-(tributylstannyl)-1(E)-pentene (mbr1-78)



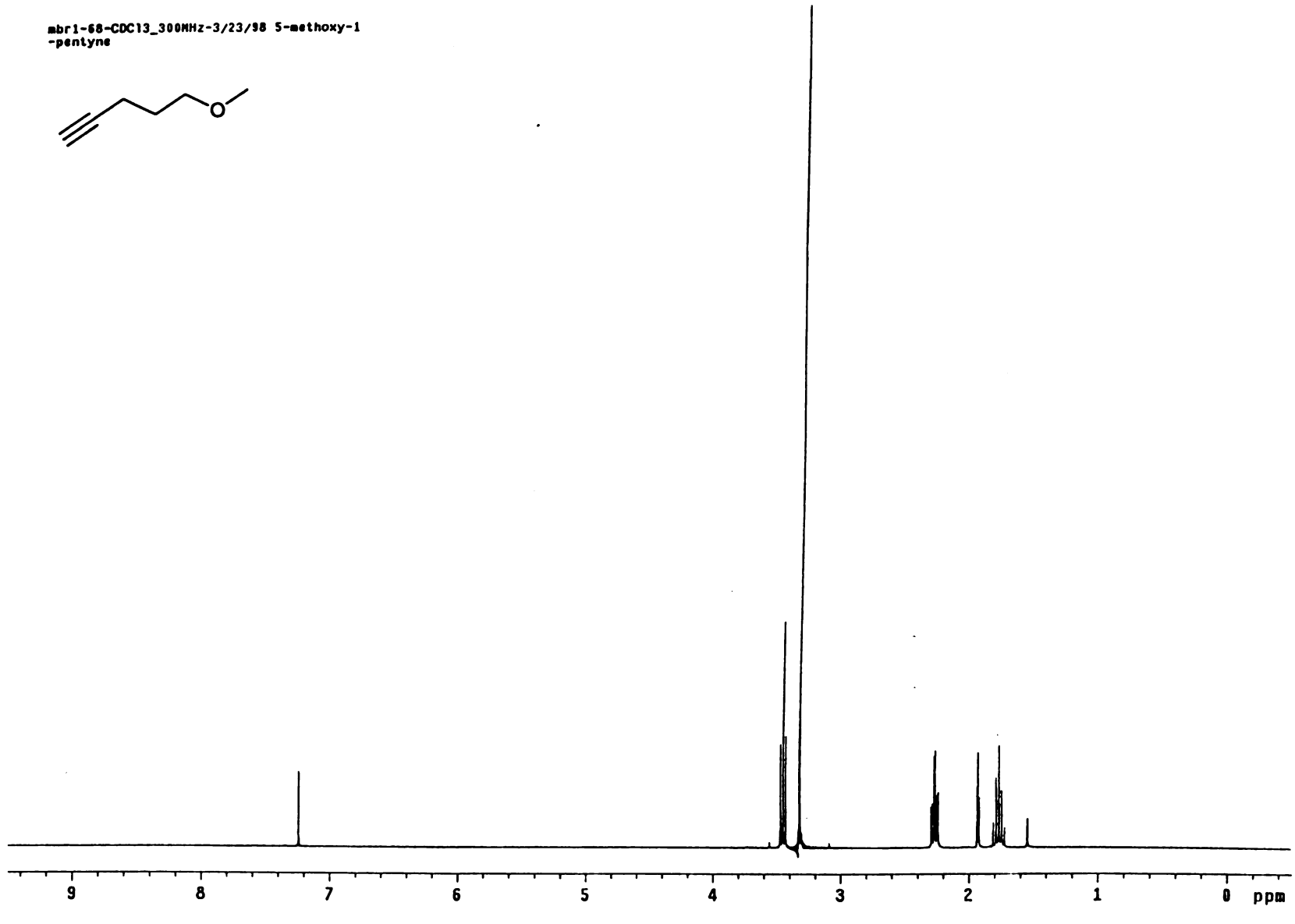
In a 25 mL flask 2 mL THF, 9 mg $(Ph_3P)_2PdCl_2$ (0.01 mmol), 0.60 g bromostyrene (3.3 mmol) was added. Then 1.30 g 3-amino-3-ethyl-1-(tributylstannyl)-1(E)-pentene (3 mmol) was added to the reaction. After a few days of stirring at room temperature starting material was still present according to TLC. At this point the reaction was brought to reflux and a small amount of catalyst was added. After four days the reaction was stopped, to separate the product to the hexabutyl tin byproduct the mixture was added to a solution of KF and stirred overnight. After extracting with diethyl ether (3x), dried over $MgSO_4$, and concentrated down via rotovap. The resulting oil was passed through a silica column using 9:1 hexanes/ethyl acetate, R_f = 0.15. The isolated yield was 47% (306 mg). ^{1}H NMR (300 MHz, $CDCl_3$); δ 0.84 (t, *J* = 7.4 Hz, 6 H), 1.33 (br, 2 H), 1.48 (q, *J* = 7.4 Hz, 4 H), 5.74 (d, *J* = 15.4 Hz, 1 H), 6.28 (dd, *J* = 15.4 Hz, 10.4 Hz, 1 H), 6.49 (d, *J* = 15.7 Hz, 1 H), 6.78 (dd, *J* = 15.7 Hz, 15.4 Hz, 10.4 Hz, 10.2 Hz, 1 H), 7.15-7.38 (m, 5 H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 8.1, 34.0, 56.3, 126.1, 127.1, 128.1, 128.6, 129.1, 130.9, 137.5, 142.4. The spectroscopic data was consistent with those previously reported in the literature: Maleczka, Jr. R.; Terstiege, I *J. Org. Chem.* **1998**, *63*, 9622-9623.

3,3-dimethyl -1-(tributylstannyl)-1(E)-butene (mbr1-84)



In a 25 mL flask 5 mL THF, 7 mg $(Ph_3P)_2PdCl_2$ (0.01 mmol), 530 mg bromostyrene (2.9 mmol) was added. Then 980 mg 3,3-dimethyl-1-(tributylstannyl)-1(E)-butene (2.6 mmol) was added to the reaction. The reaction was refluxed for 2.5 days. The mixture was passed through a silica column using pentane, $R_f = 0.10$. Trace amount of Bu_3SnBr were still present so the resulting oil was stirred in a KF aq. The aqueous layer was extracted with diethyl ether (3x) and then the organic layer was dried over $MgSO_4$ and concentrated. The isolated yield was 41% (197 mg). ^1H NMR (300 MHz, $CDCl_3$) δ 1.09 (s, 9 H), 5.87 (d, *J* = 15.4 Hz, 1 H), 6.16 (dd, *J* = 15.4 Hz, 10.2 Hz, 1 H), 6.48 (d, *J* = 15.7 Hz, 1 H), 6.76 (dd, *J* = 15.7 Hz, 10.2 Hz, 1 H), 7.20-7.42 (m, 5 H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 29.6, 33.4, 125.4, 126.1, 127.0, 128.6, 129.9, 130.2, 137.7, 146.8. The spectroscopic data was consistent with those previously reported in the literature: Maleczka, Jr. R.; Terstiege, I *J. Org. Chem.* **1998**, *63*, 9622-9623.

SPECTRA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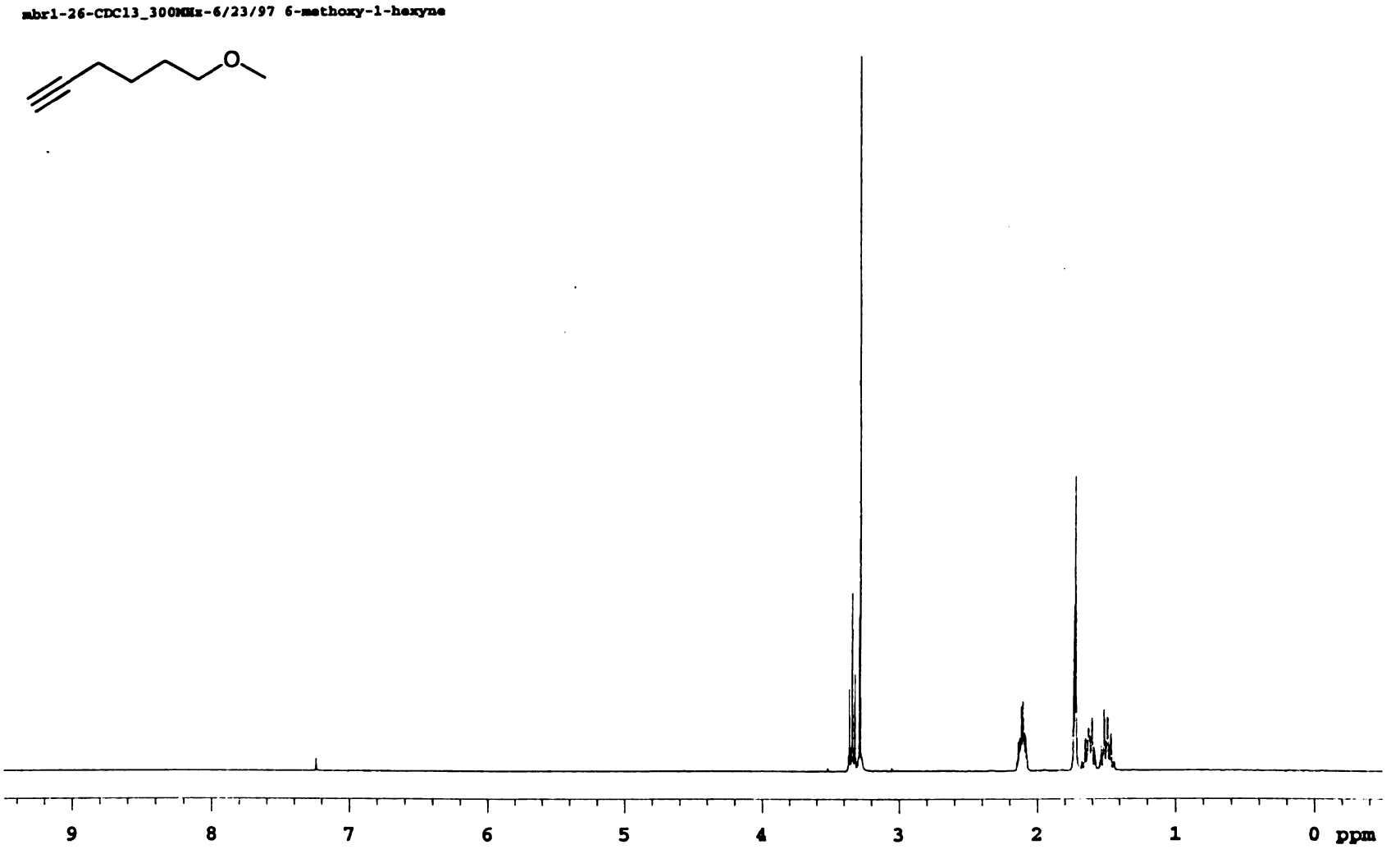
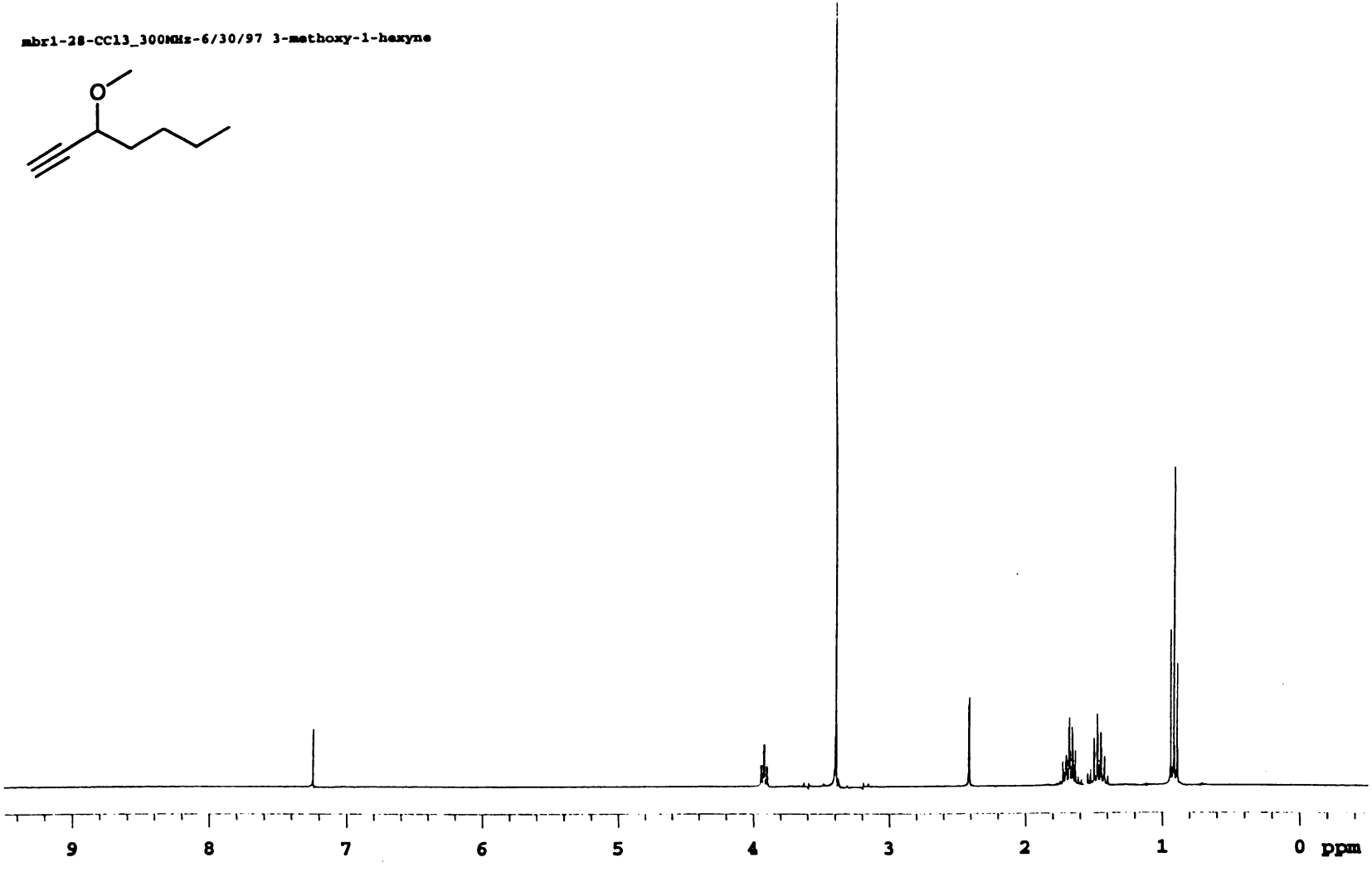
-pentyne
O
9
8
7
6
5
4
3
2
1
0
ppm


mbr1-26-CDC13_300MHz-6/23/97 6-methoxy-1-hexyne
O
9
8
7
6
5
4
3
2
1
0
ppm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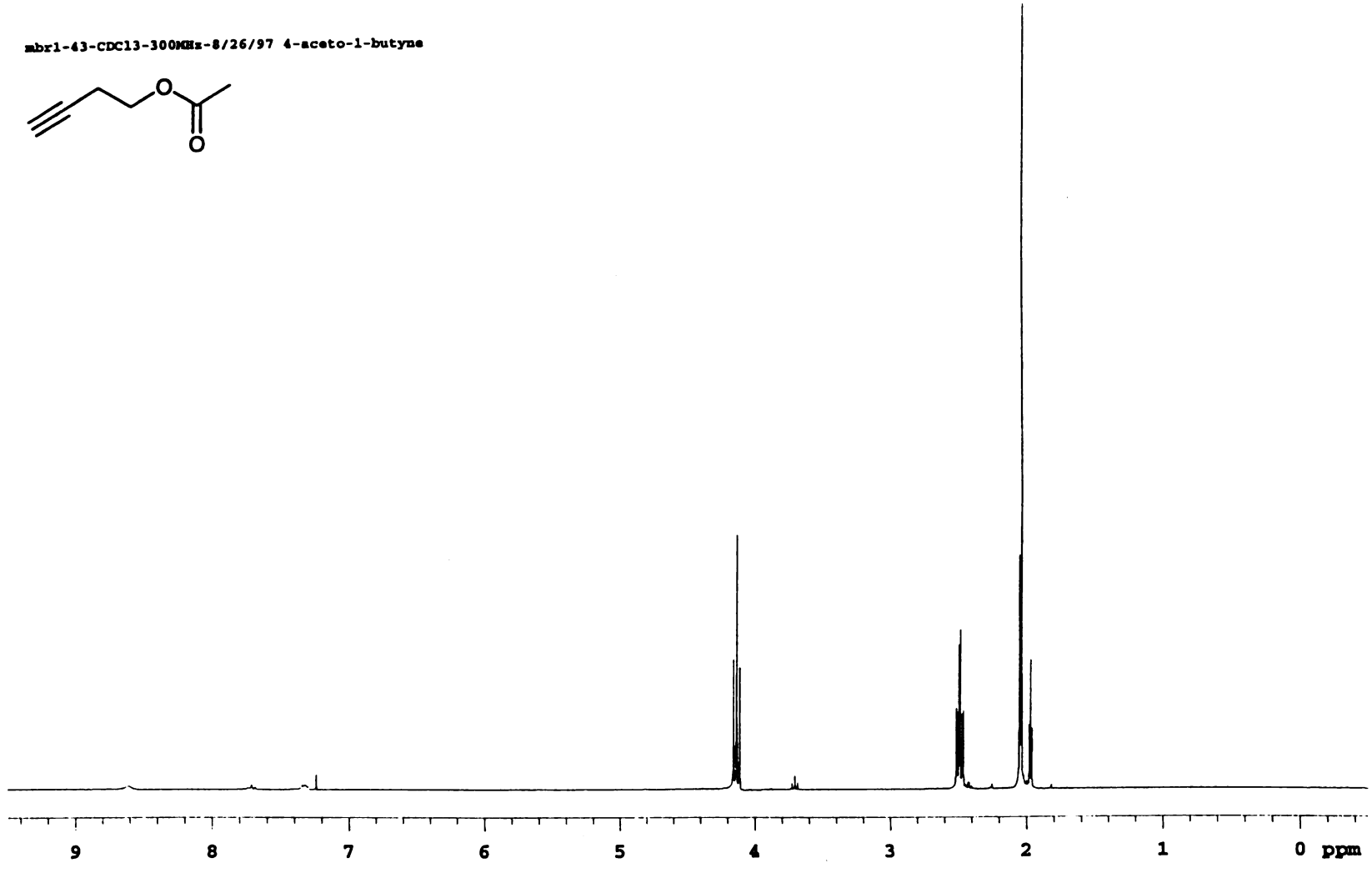
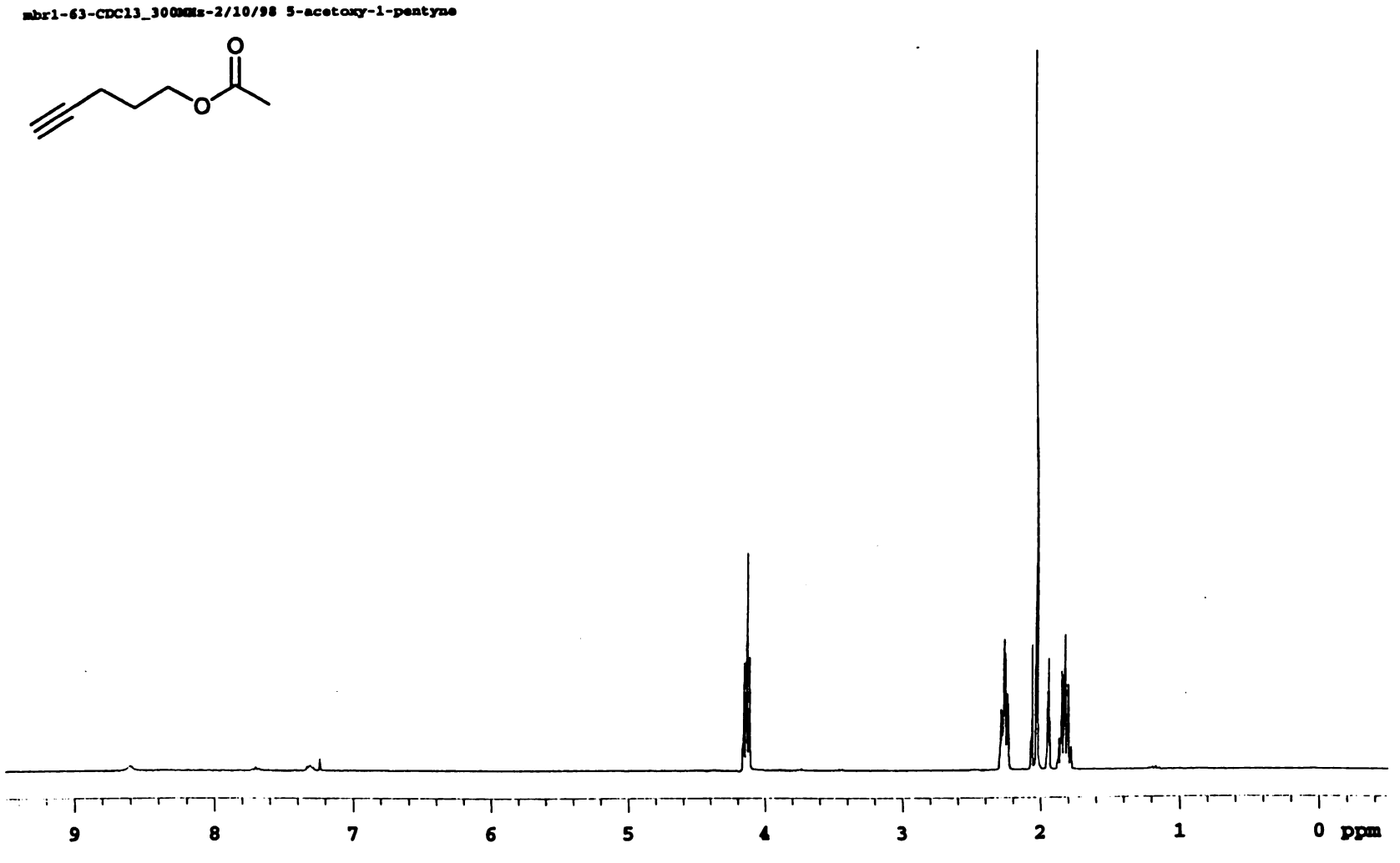
O
9
8
7
6
5
4
3
2
1
0
ppm

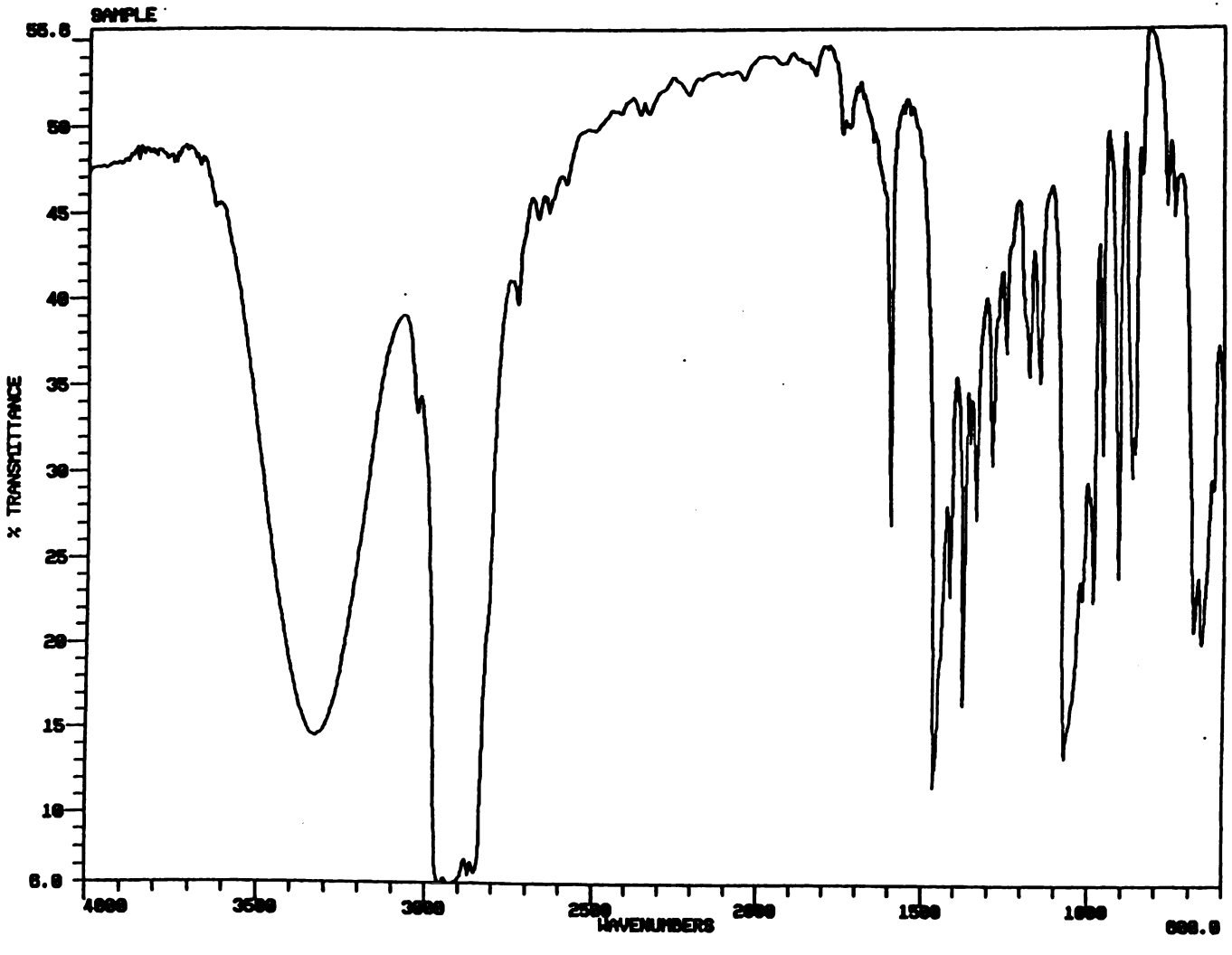

mbr1-43-CDCl3-300MHz-8/26/97 4-aceto-1-butyne
O
O
9
8
7
6
5
4
3
2
1
0 ppm


mbr1-63-CDCl3_300MHz-2/10/98 5-acetoxy-1-pentyne
O
O
9
8
7
6
5
4
3
2
1
0 ppm

mbc1-86-CDCl3_300MHz-9/3/98 crude
Bu3Sn
SnBu3
9
8
7
6
5
4
3
2
1
0 ppm

mkz1-69-CDCl3_300MHz-1/27/98 cmsb
Bu3Sn
SnBu3
9
8
7
6
5
4
3
2
1
0 ppm

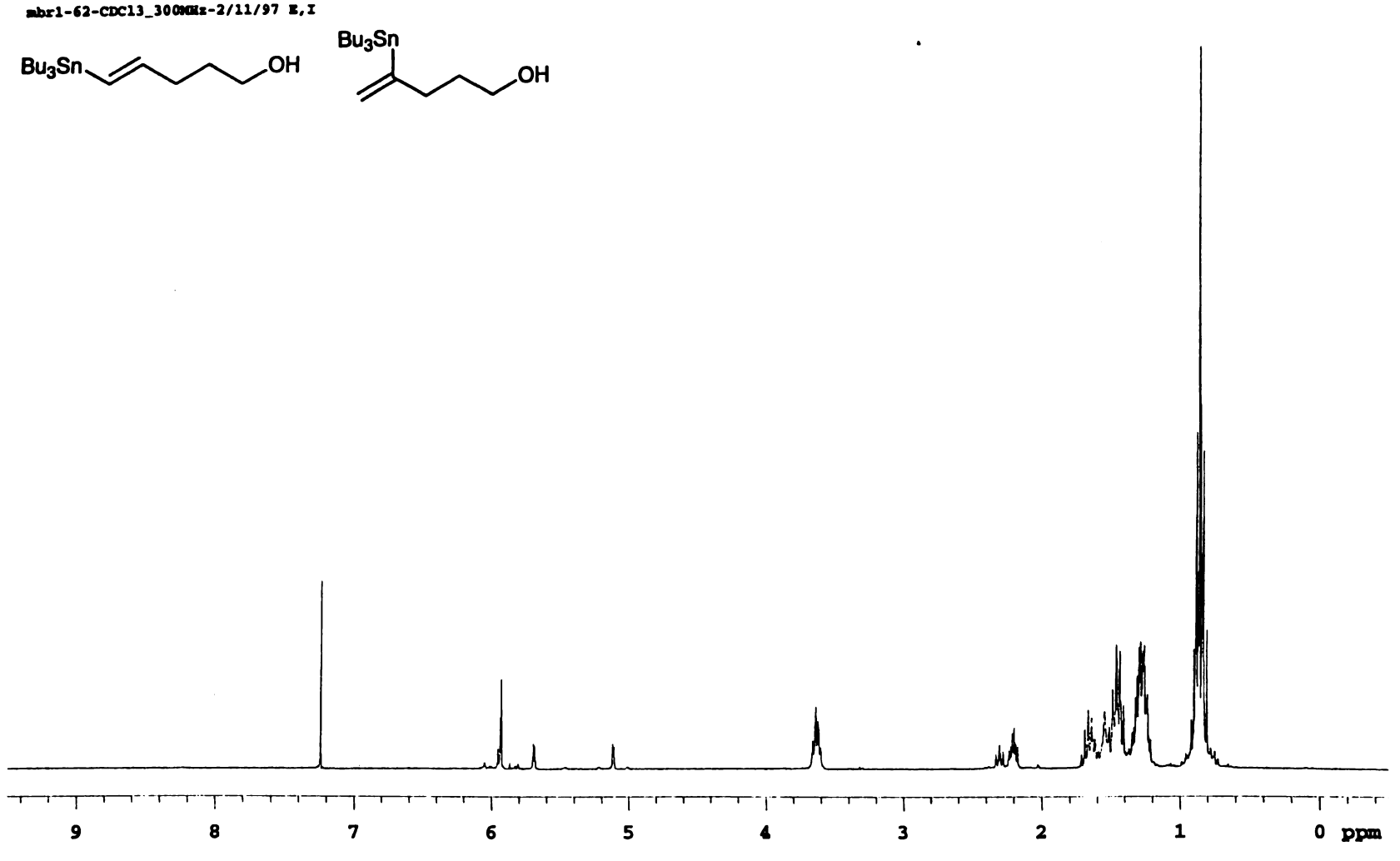
mbz1-87-CDCl3_300MHz-8/4/98 crude
Bu3Sn
SnBu3
9
8
7
6
5
4
3
2
1
0
ppm

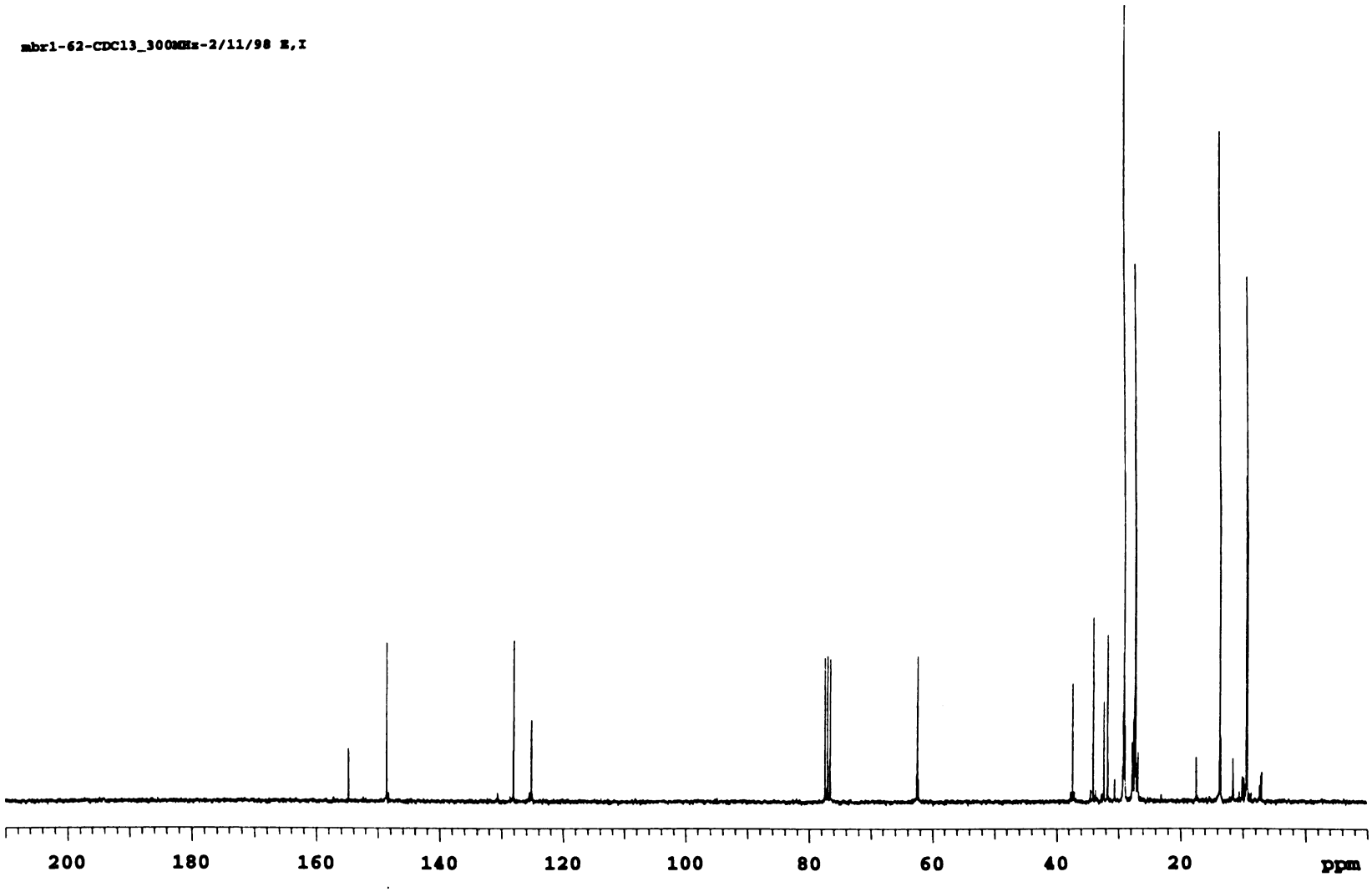


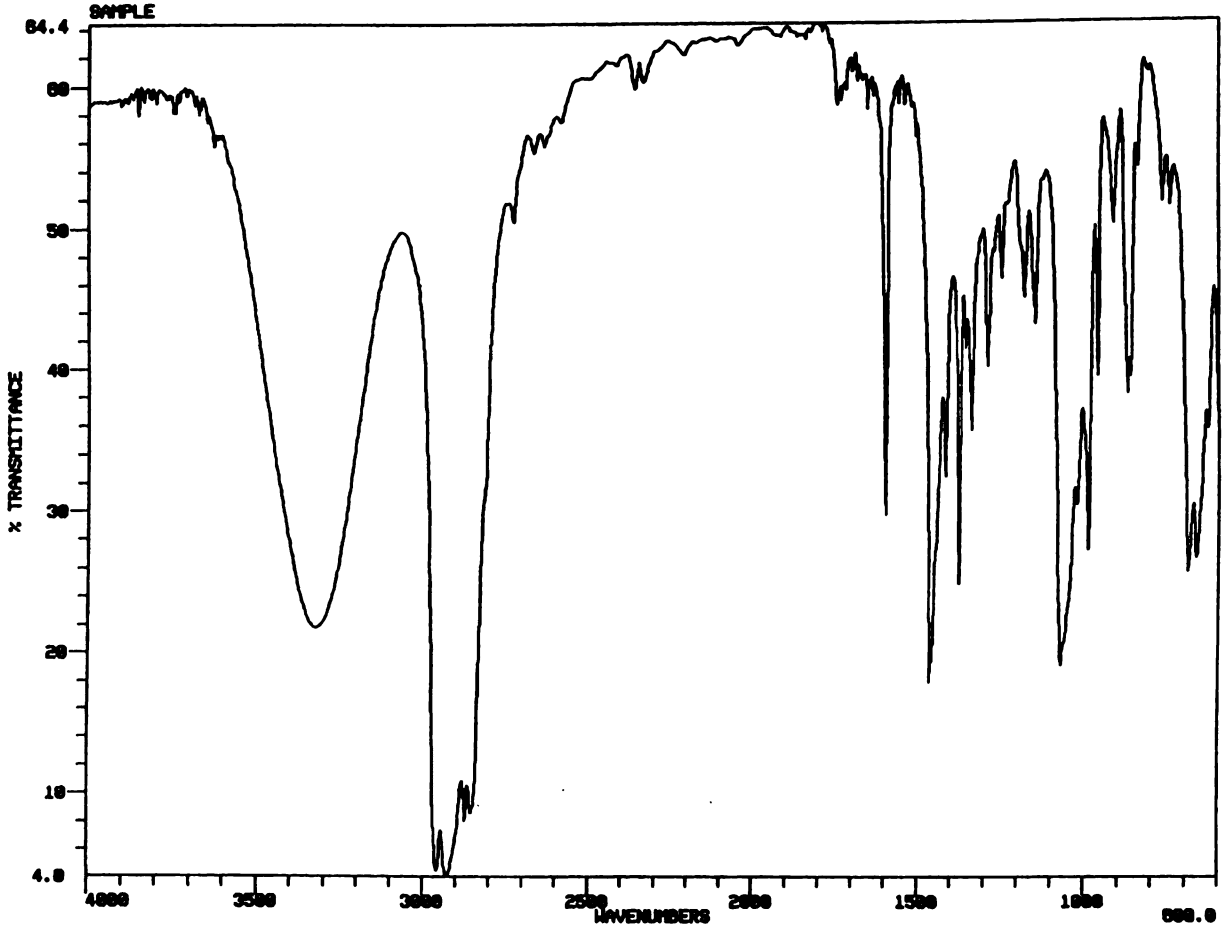
Nicolet Instrument Corporation

mbr1-02

SCANS: 32 RES: 4.0 TIME: 05/09/99 19:12:28


mbr1-62-CDCl3_300MHz-2/11/97 E,I
Bu3Sn
OH
Bu3Sn
OH
9
8
7
6
5
4
3
2
1
0 ppm

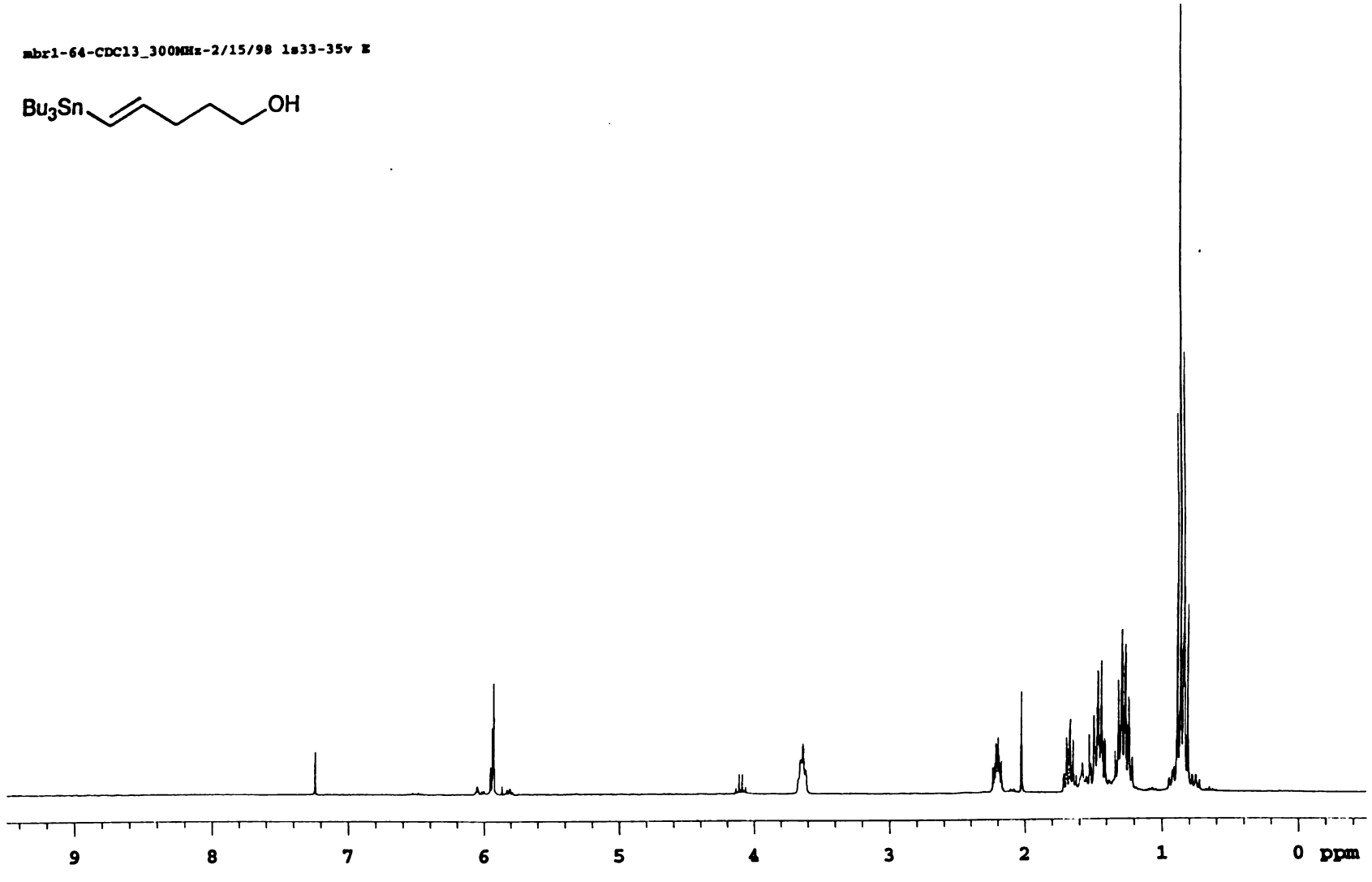

mbr1-62-CDCl3_300MHz-2/11/98 E,I
200
180
160
140
120
100
80
60
40
20
ppm

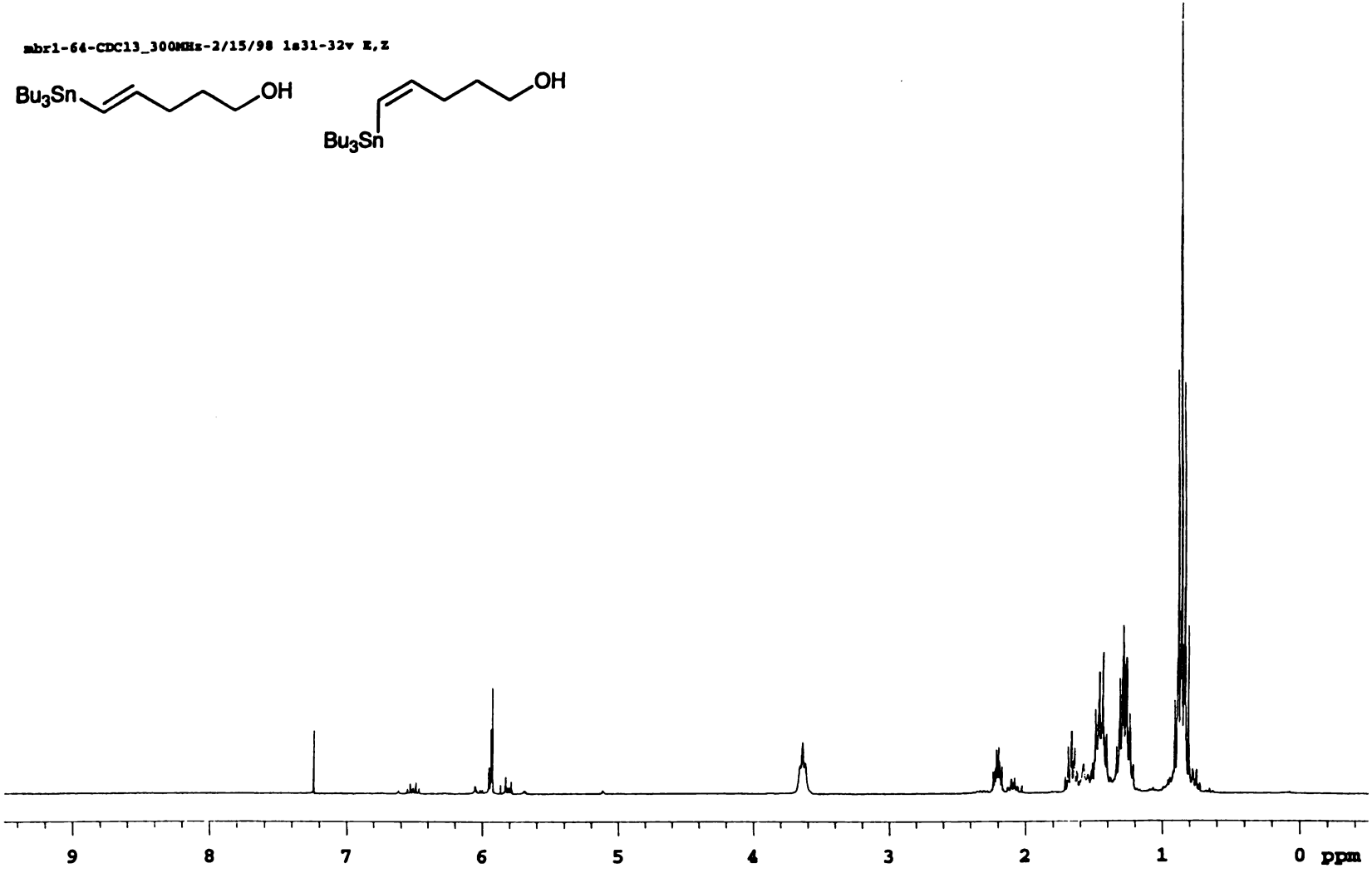


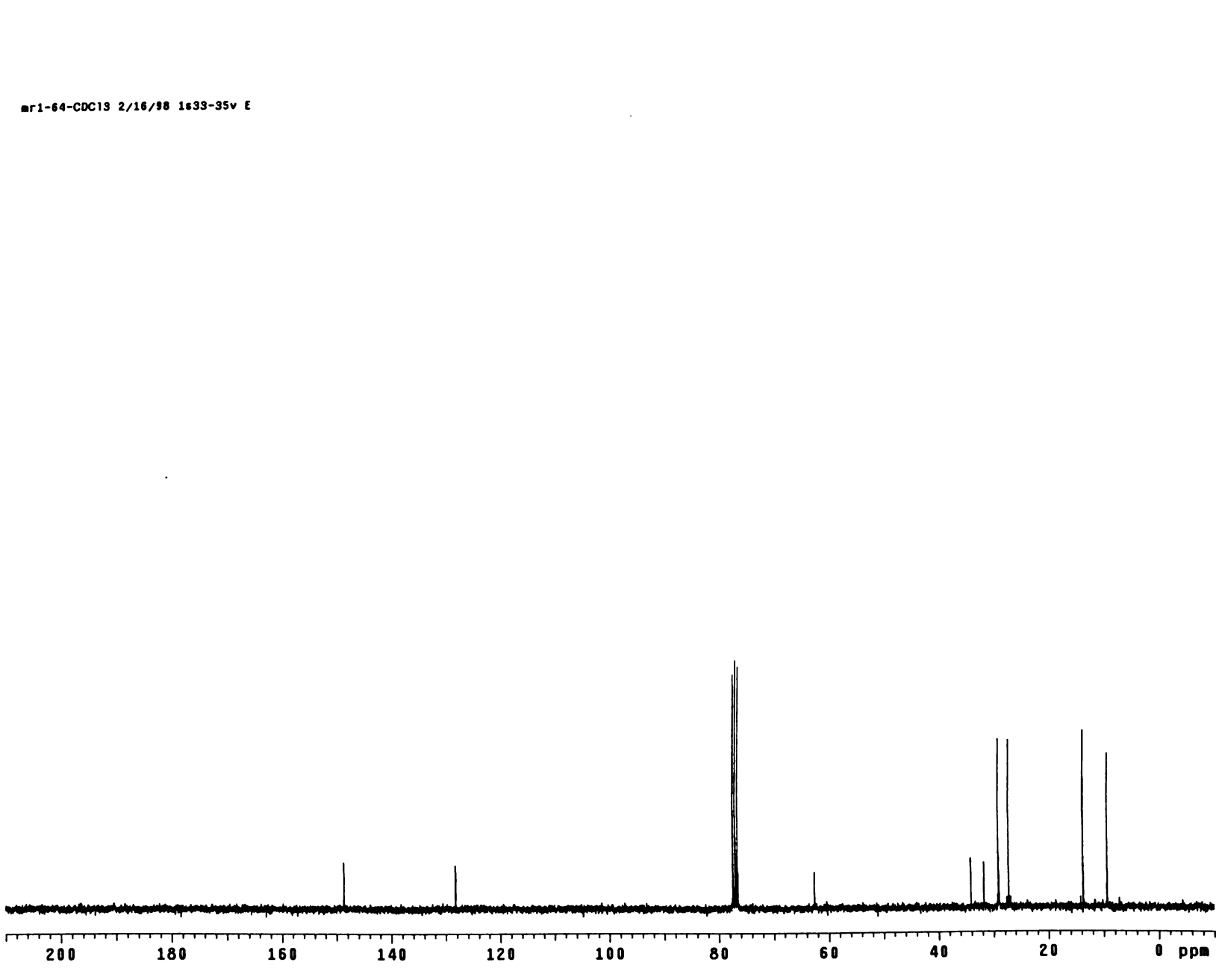
Nicolet Instrument Corporation

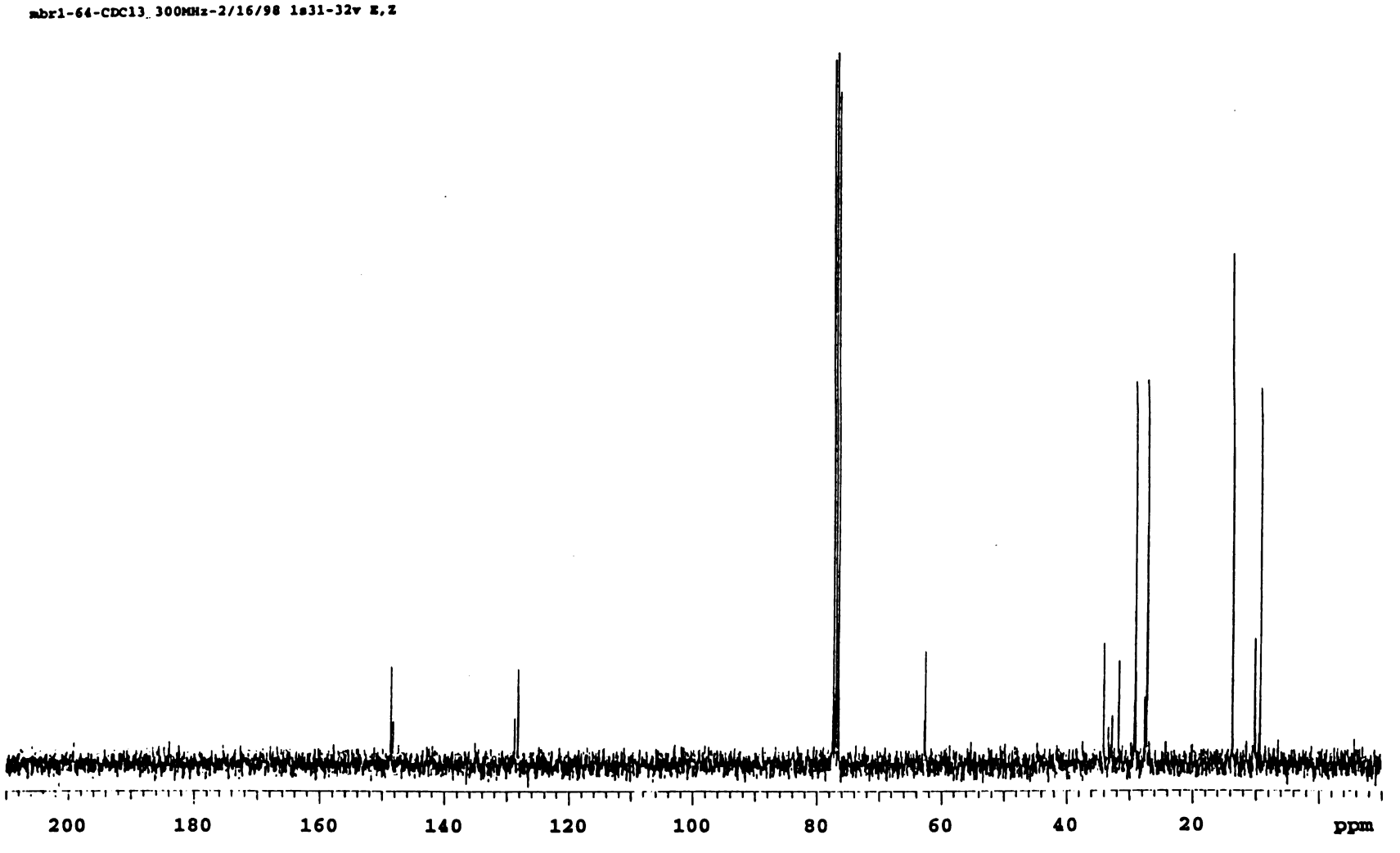
mbr1-64

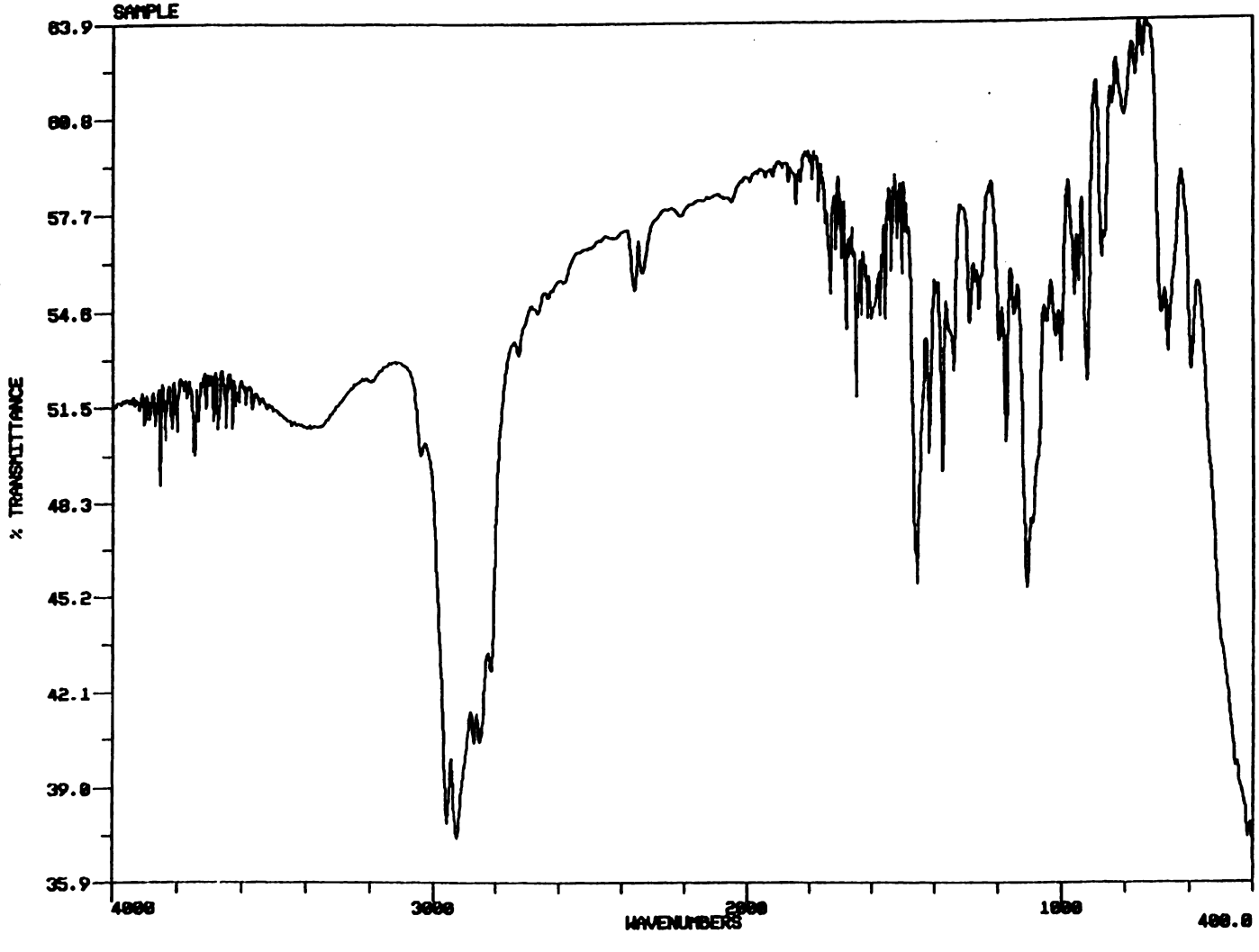
SCANS: 32 RES: 4.0 TIME: 05/09/99 19:20:13


mbr1-64-CDCl3_300MHz-2/15/98 1s33-35v E
Bu3Sn
OH
9
8
7
6
5
4
3
2
1
0 ppm


mbr1-64-CDCl3_300MHz-2/15/98 1s31-32v E,Z
Bu3Sn
OH
Bu3Sn
OH
9
8
7
6
5
4
3
2
1
0
ppm


mr1-64-CDCl3 2/16/98 1s33-35v E
200
180
160
140
120
100
80
60
40
20
0 ppm

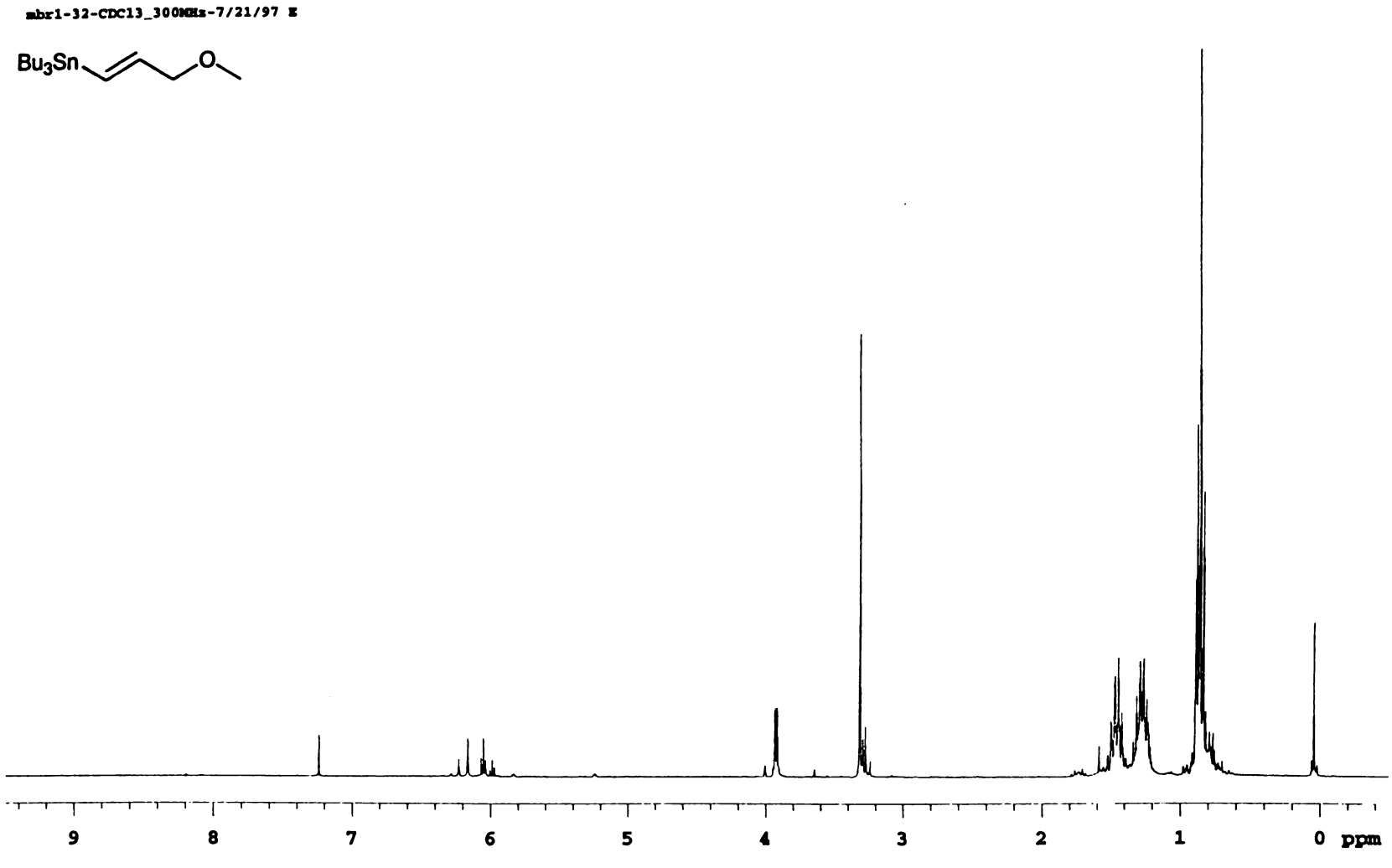

mbr1-64-CDC13 300MHz-2/16/98 1s31-32v E,Z
200
180
160
140
120
100
80
60
40
20
ppm

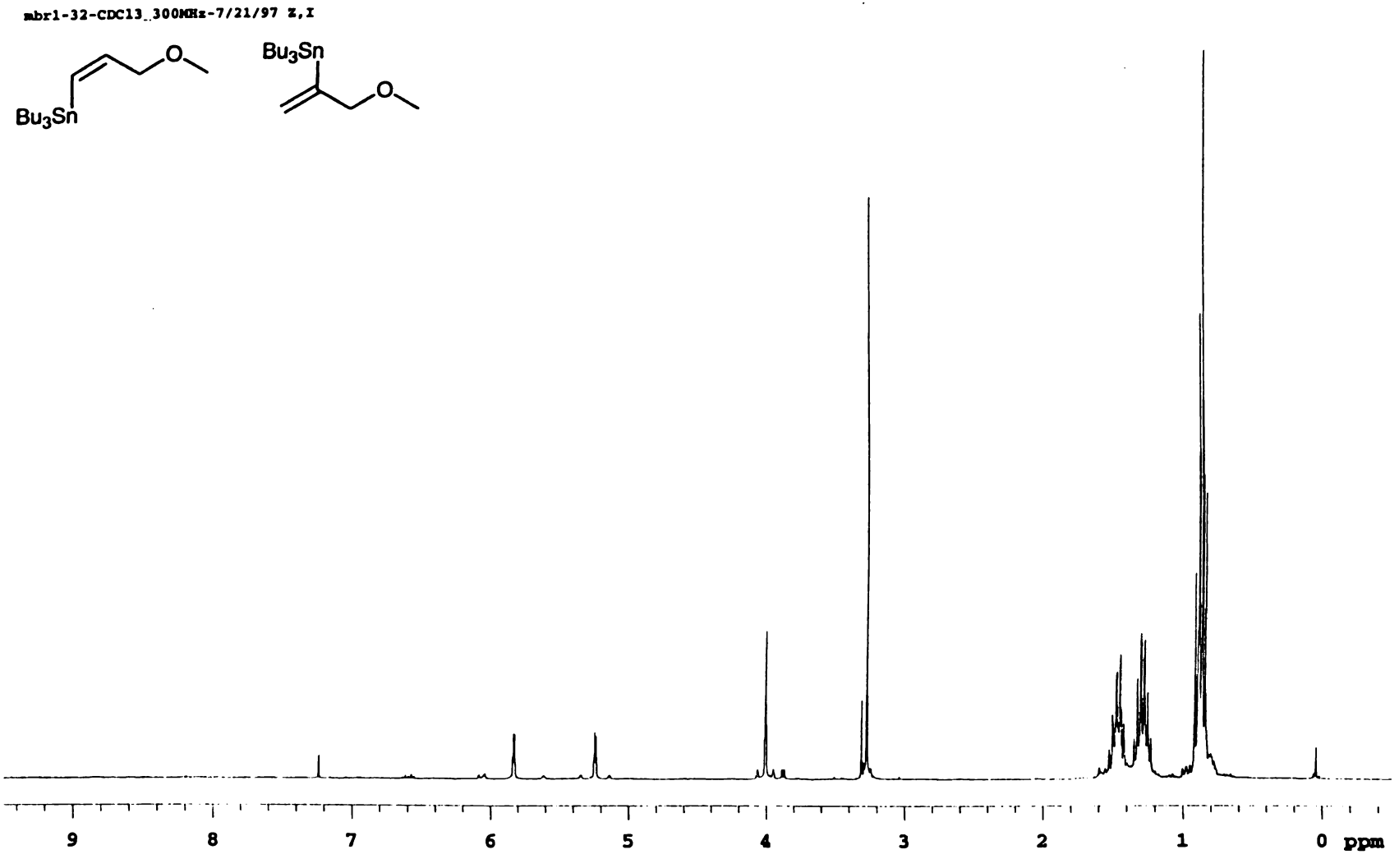


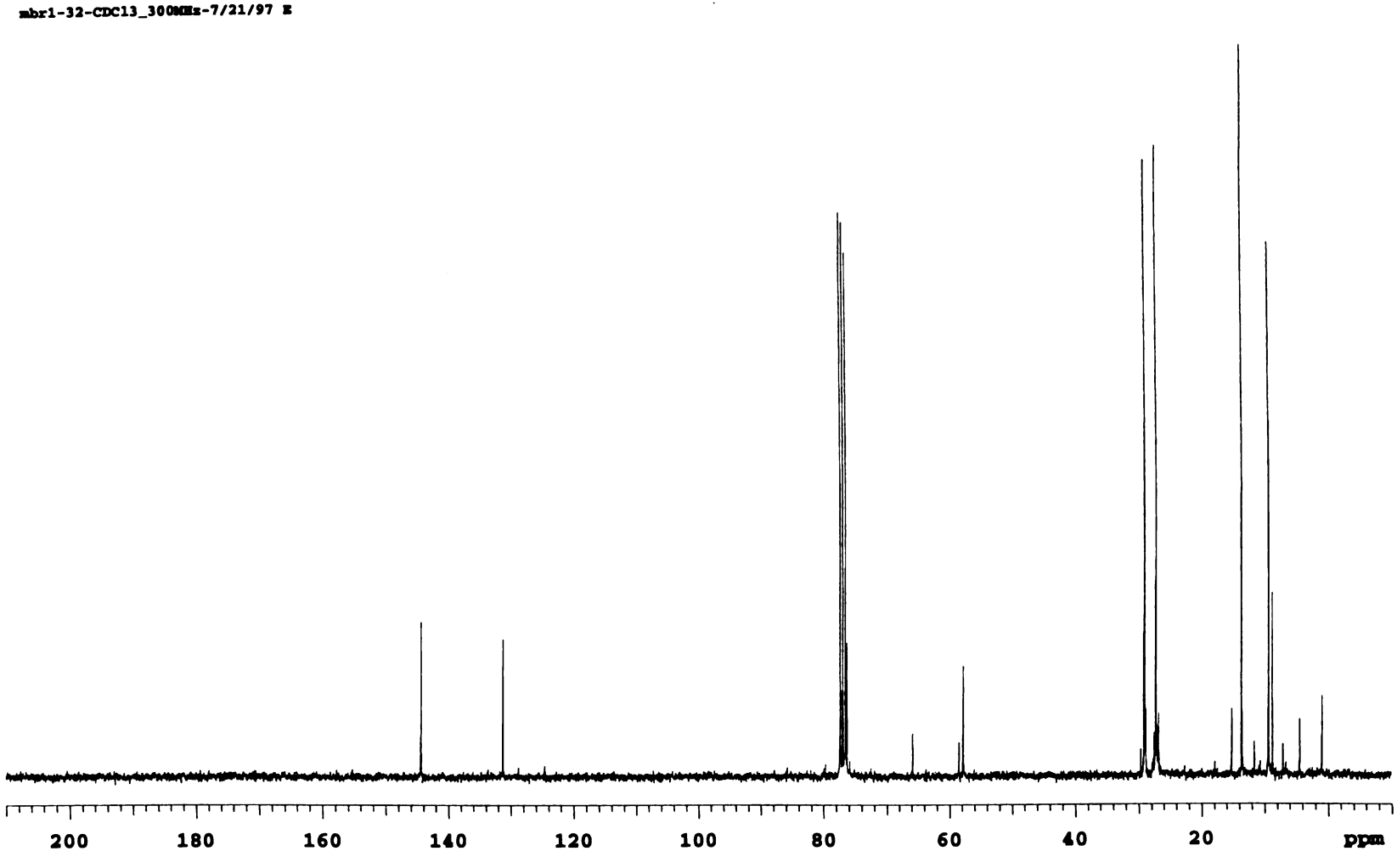
Nicolet Instrument Corporation

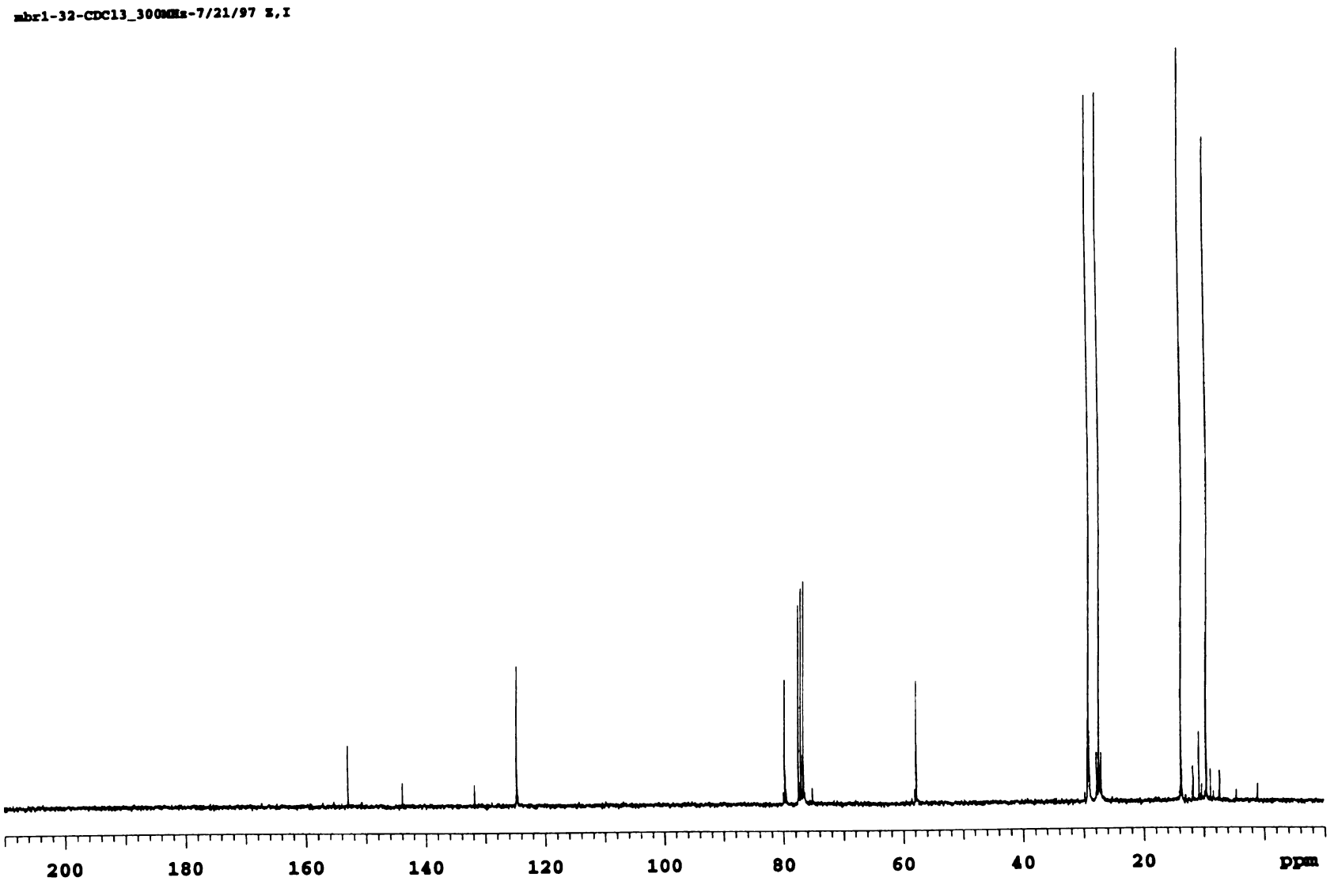
mbr1-32

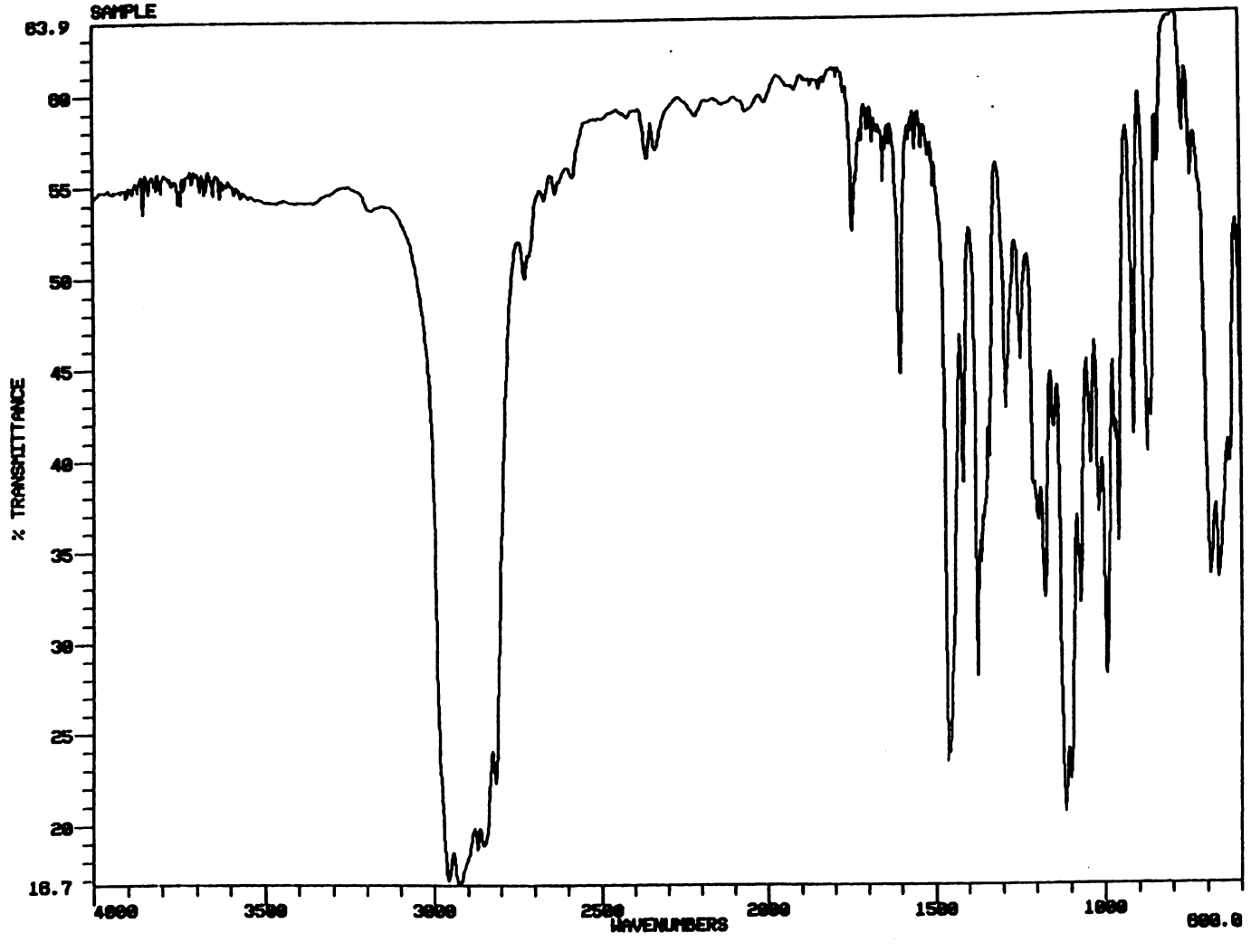
SCANS: 32 RES: 4.0 TIME: 05/31/99 19:16:56


mbr1-32-CDCl3_300MHz-7/21/97 E
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0
ppm


mbr1-32-CDCl3_300MHz-7/21/97 E,I
Bu3Sn
O
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0 ppm


mbr1-32-CDCl3_300MHz-7/21/97 E
200
180
160
140
120
100
80
60
40
20
ppm


mbr1-32-CDCl3_300MHz-7/21/97 E,I
200
180
160
140
120
100
80
60
40
20
ppm



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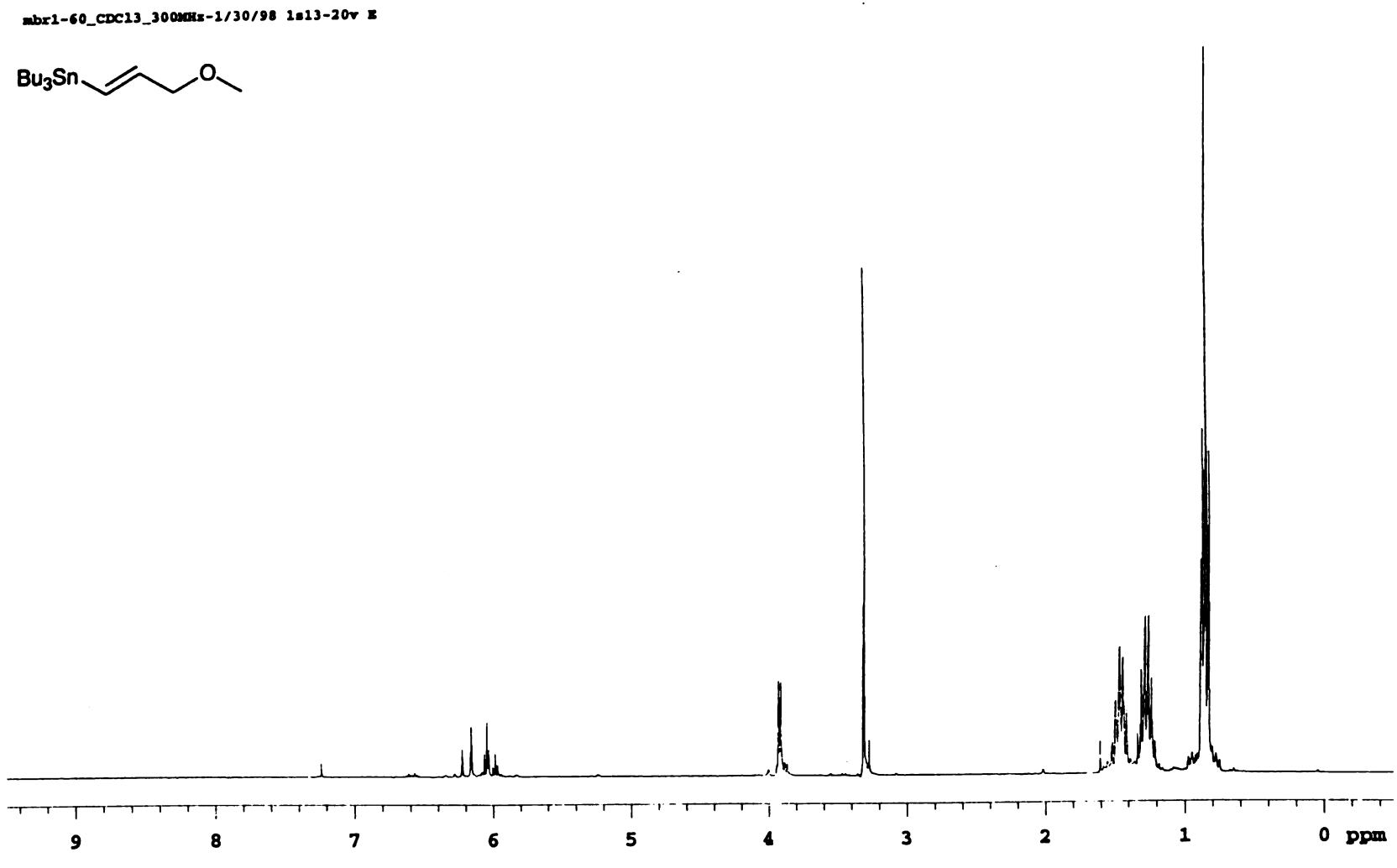
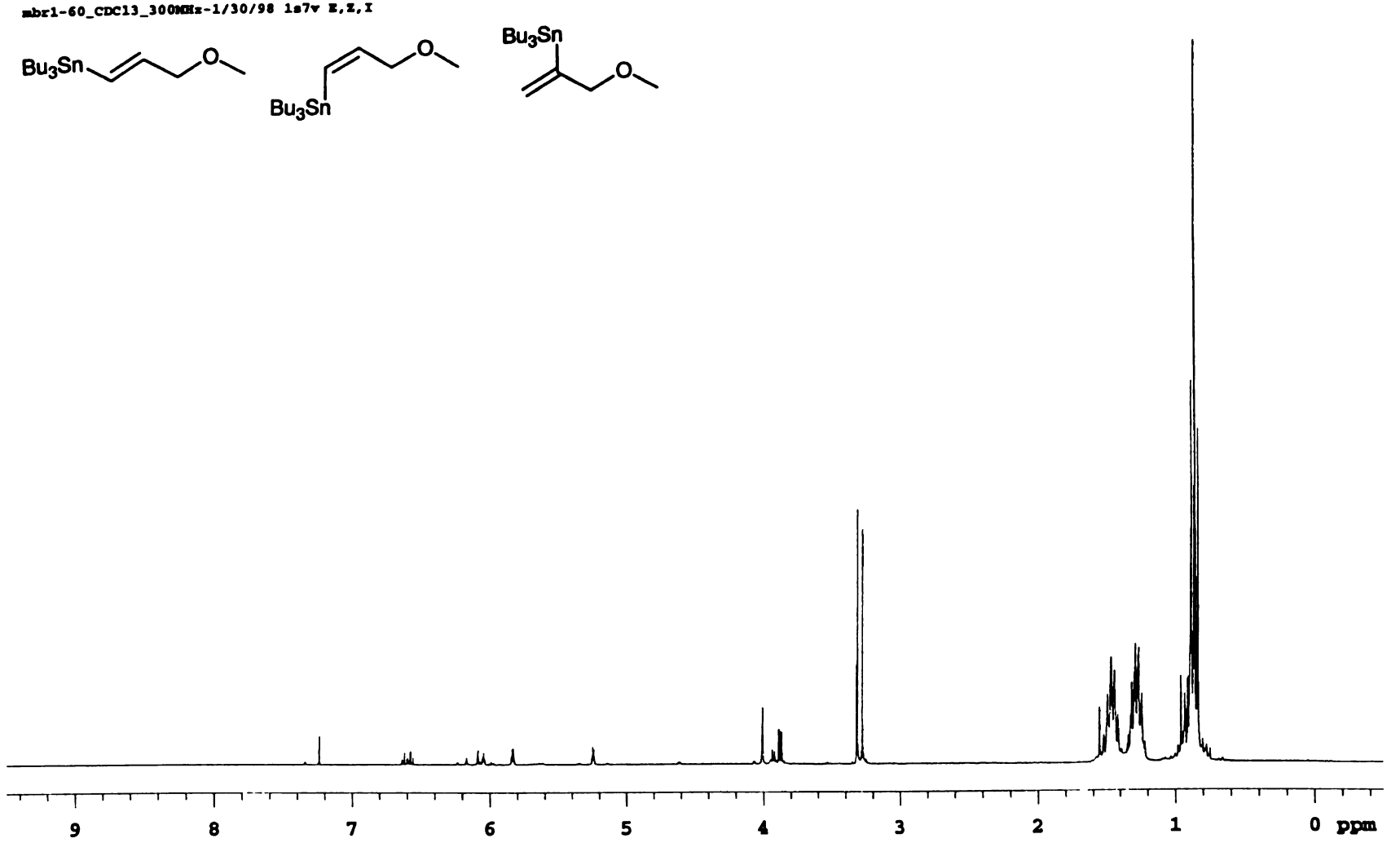
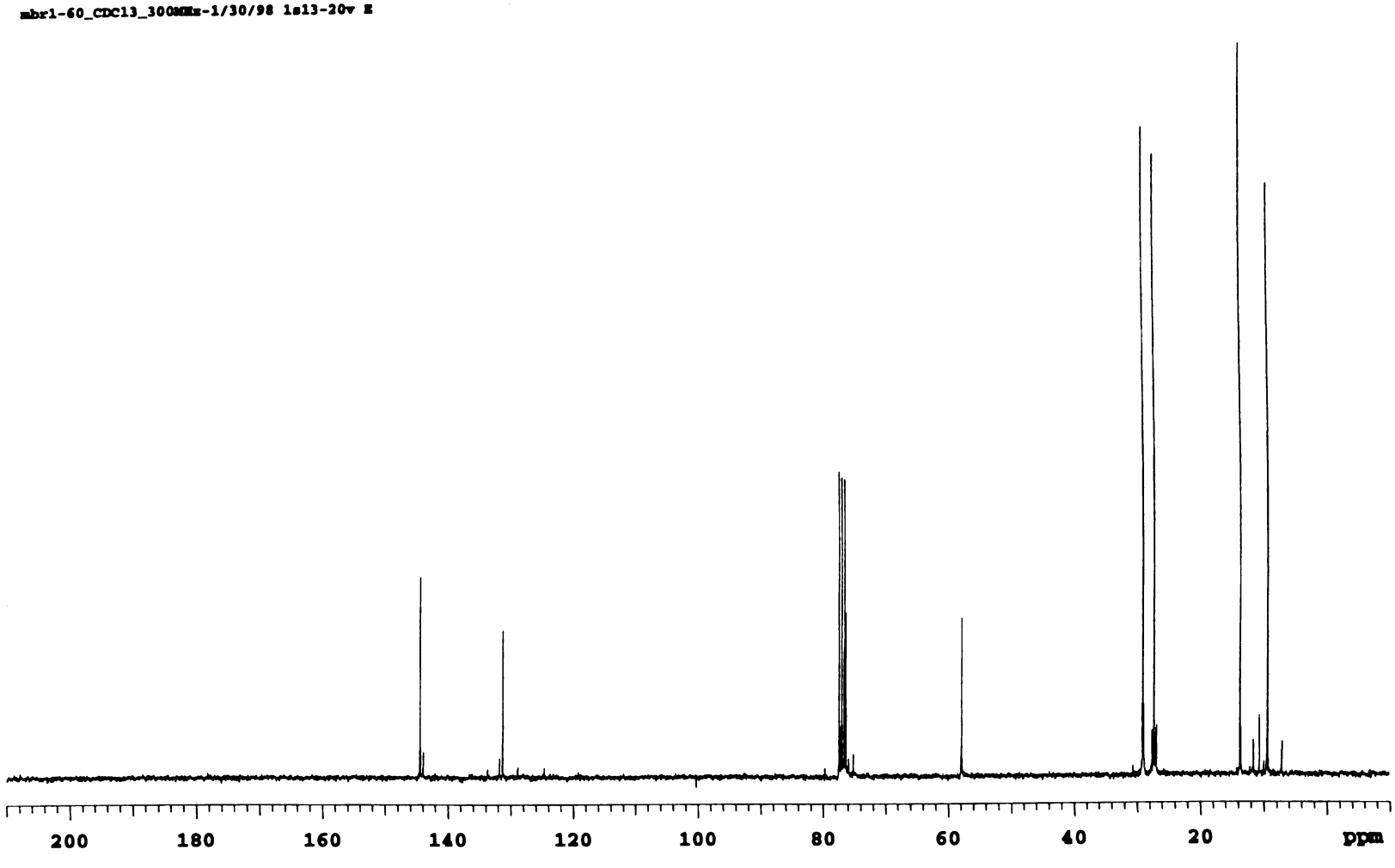
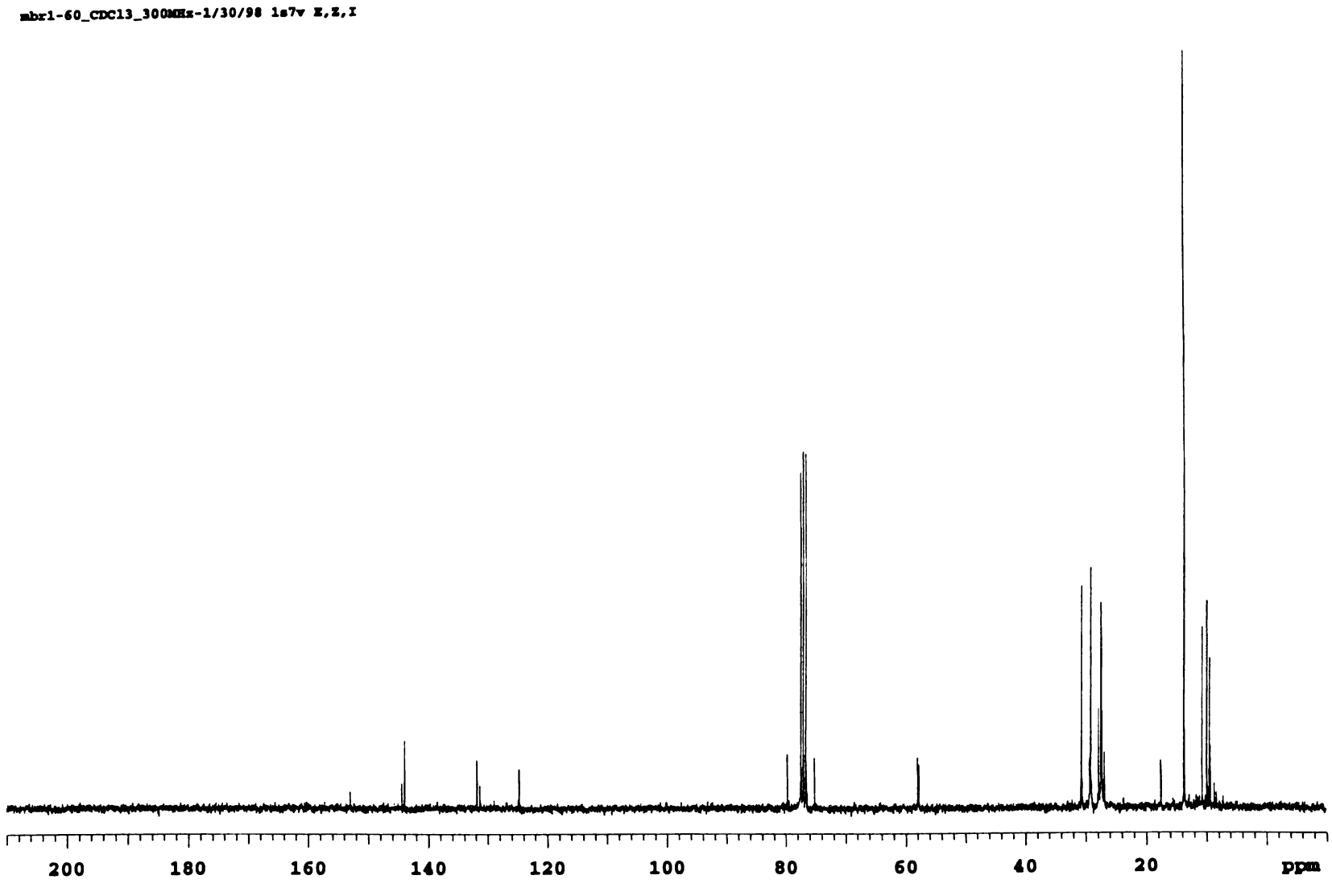
mbr1-60

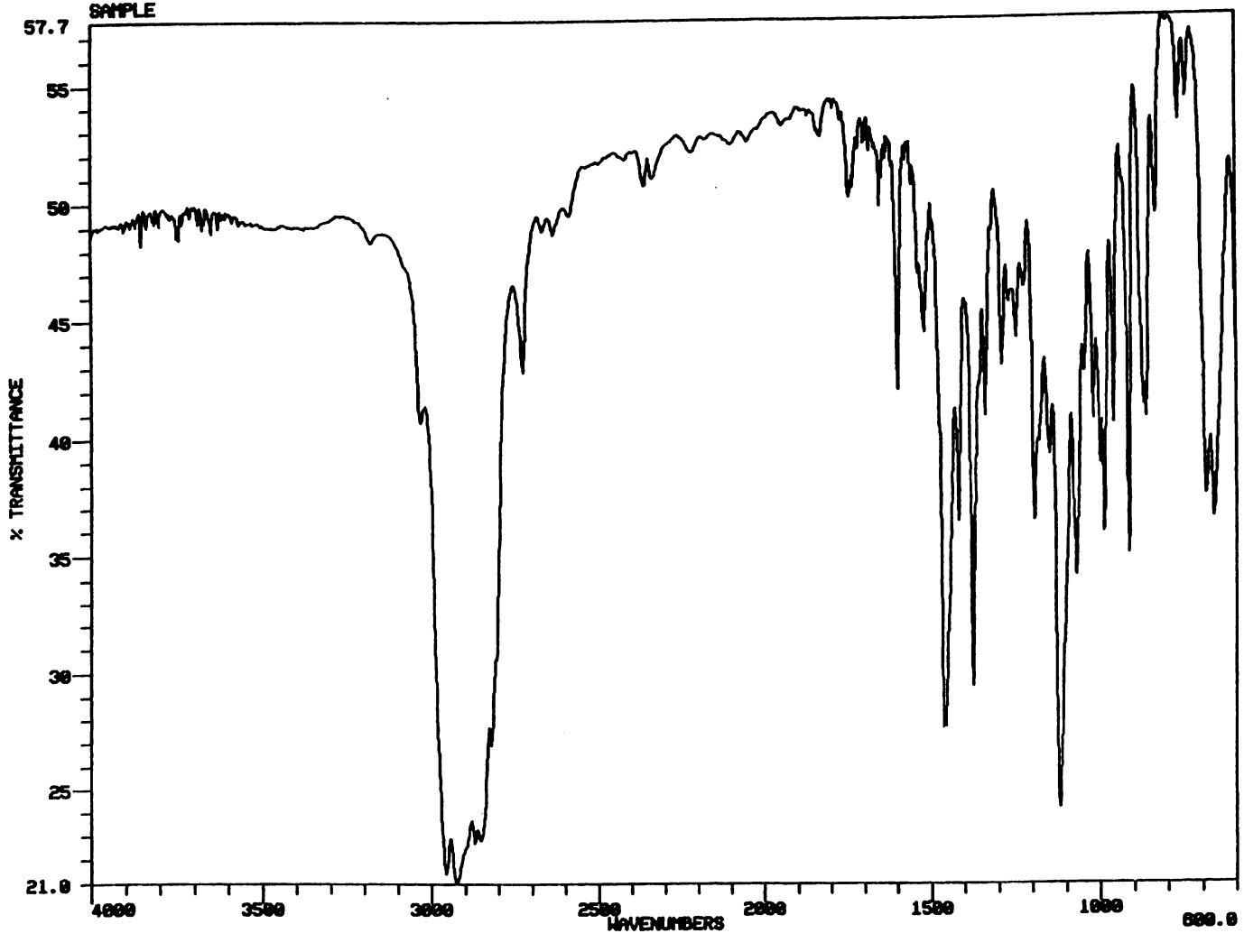
SCANS: 32 RES: 4.0 TIME: 05/09/99 18:53:47


mbr1-60_CDCl3_300MHz-1/30/98 1s13-20v E
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0 ppm


mbr1-60_CDCl3_300MHz-1/30/98 1s7v E,Z,I
Bu3Sn
O
Bu3Sn
O
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0 ppm


mbr1-60_CDCl3_300MHz-1/30/98 1s13-20v E
200
180
160
140
120
100
80
60
40
20
ppm

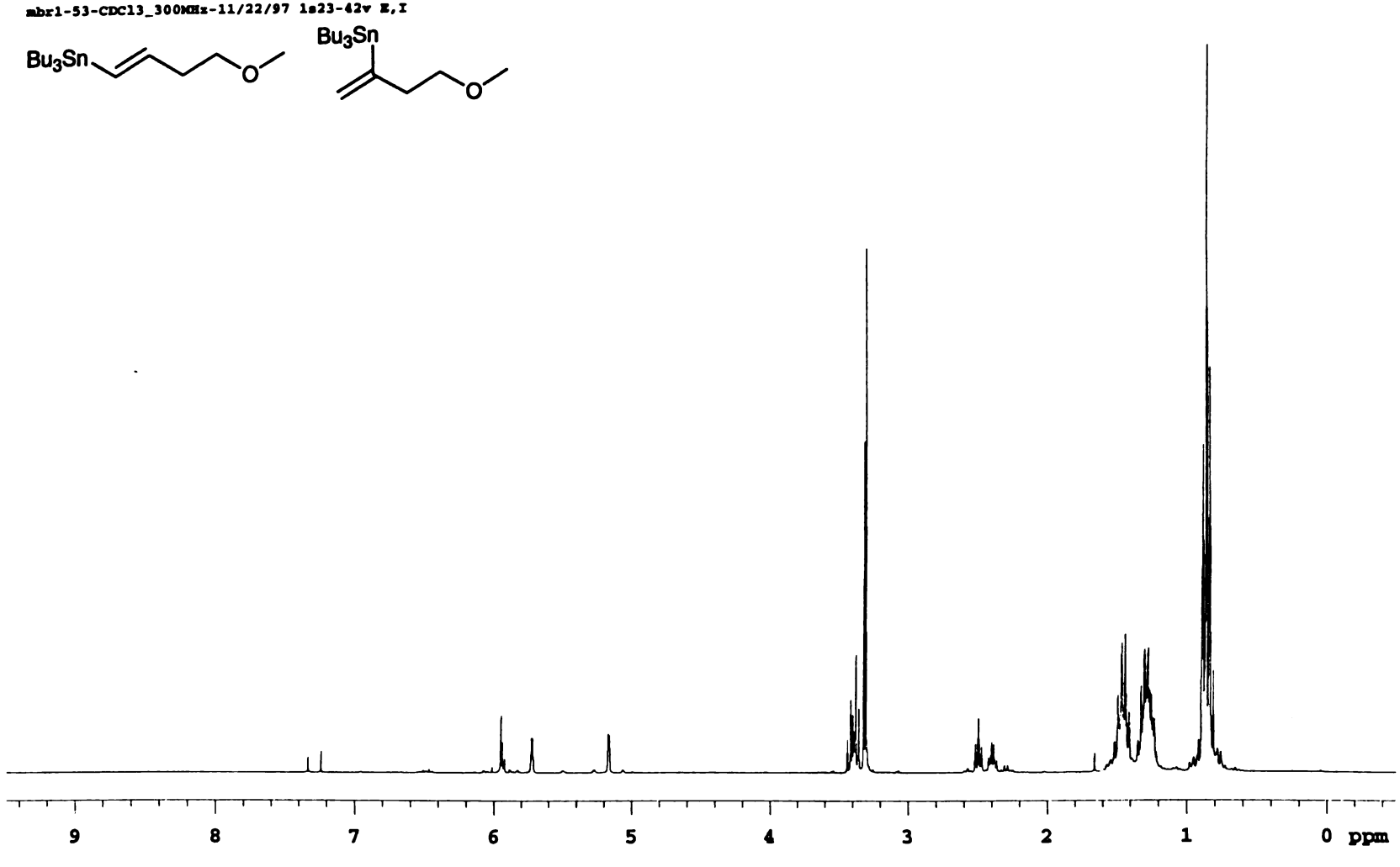

mbr1-60_CDC13_300MHz-1/30/98 1s7v E,Z,I
200
180
160
140
120
100
80
60
40
20
ppm



Nicolet Instrument Corporation

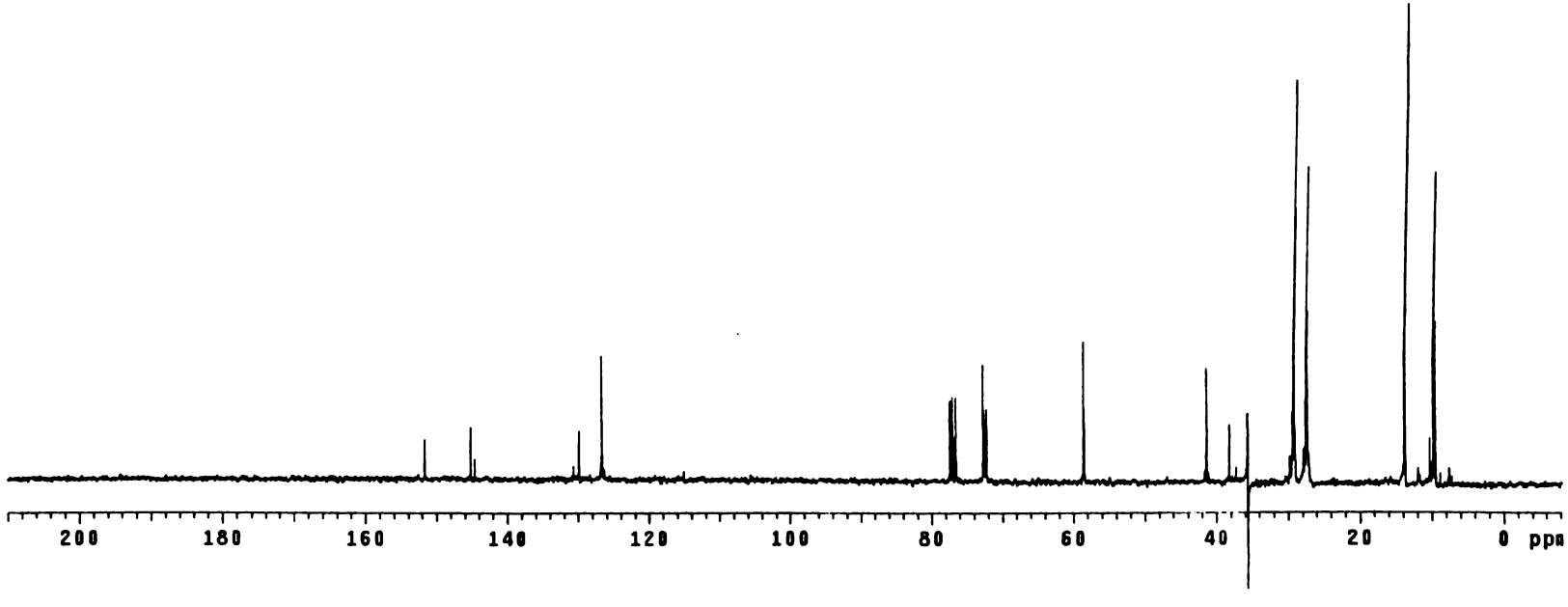
mbr1-53

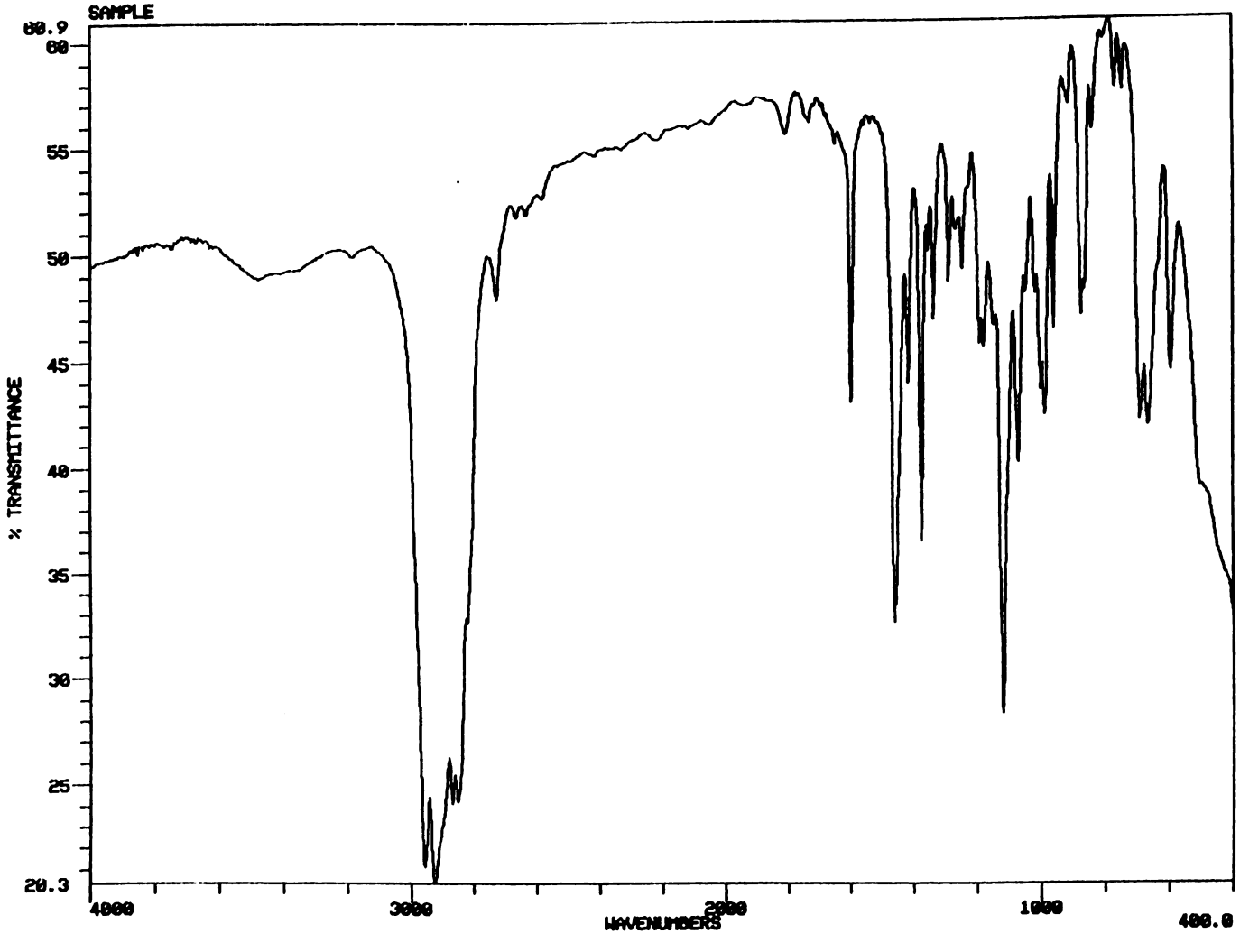
SCANS: 32 RES: 4.0 TIME: 05/09/99 16:37:22


mbr1-53-CDCl3_300MHz-11/22/97 1s23-42v E,I
Bu3Sn
O
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0 ppm

mbri-53 e/int C13

Pulse Sequence: s2pul

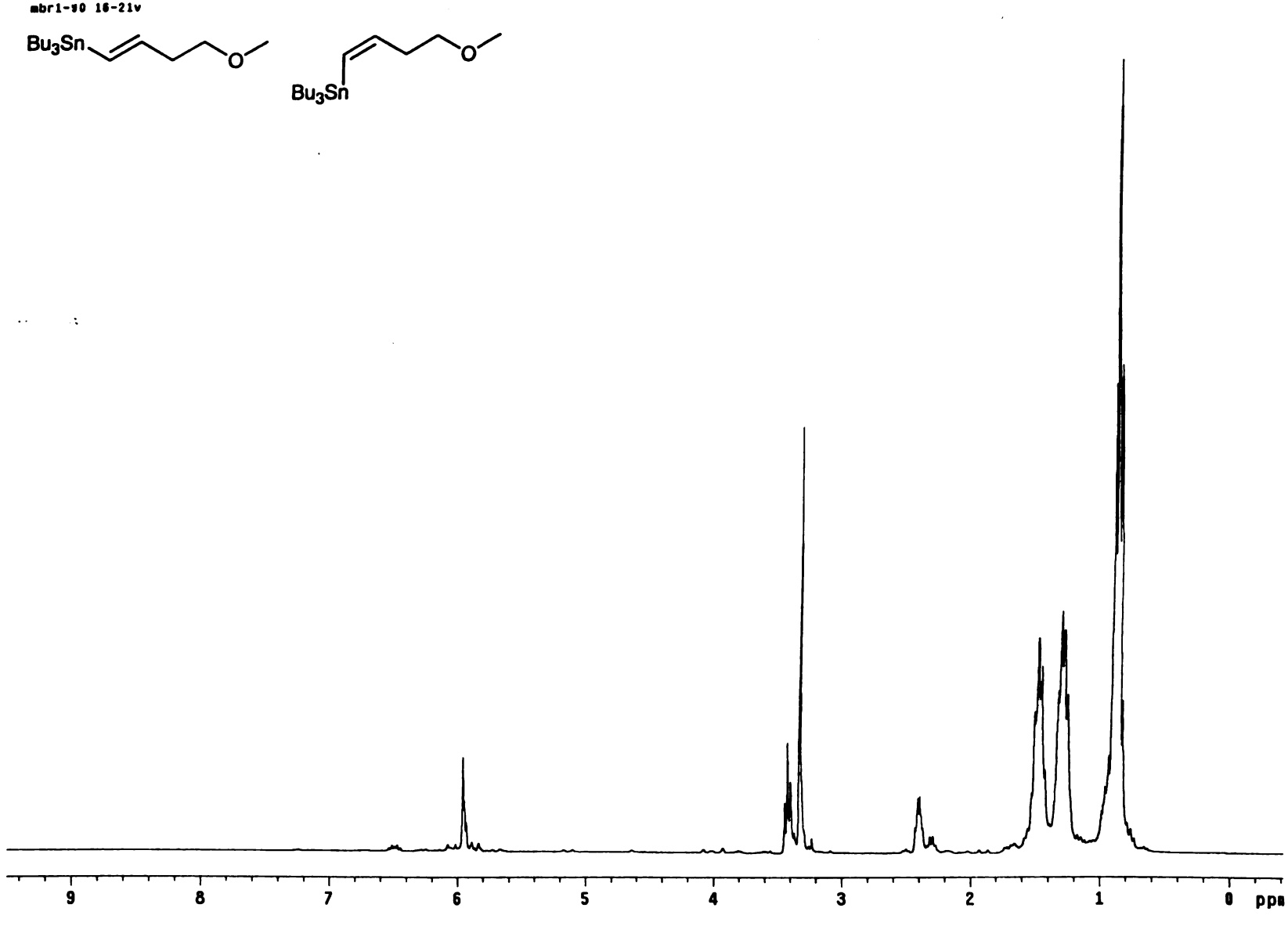




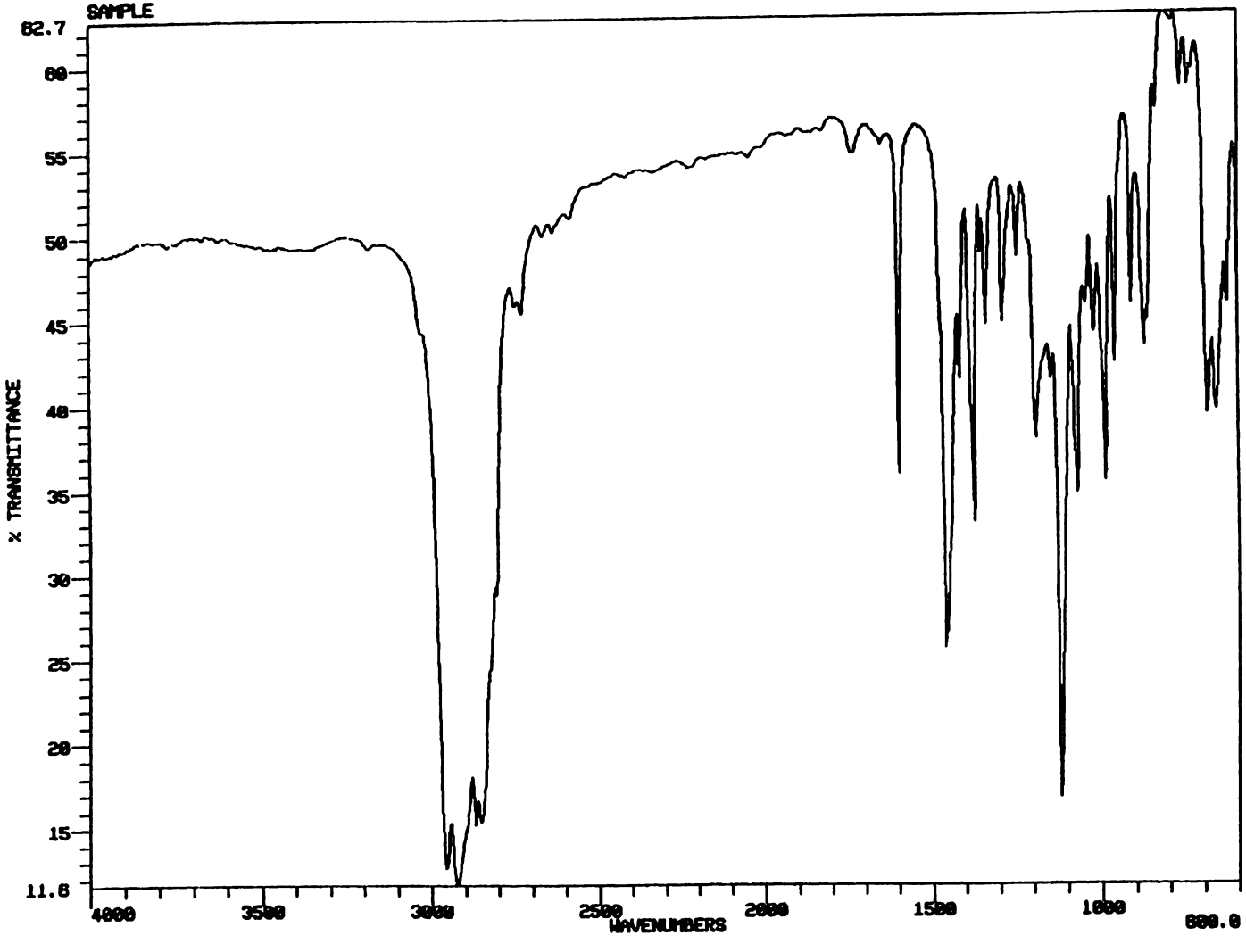
Nicolet Instrument Corporation

mbr1-98

SCANS: 64 RES: 4.0 TIME: 05/31/99 19:09:05


mbr1-90 16-21v
Bu3Sn
O
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0
ppm

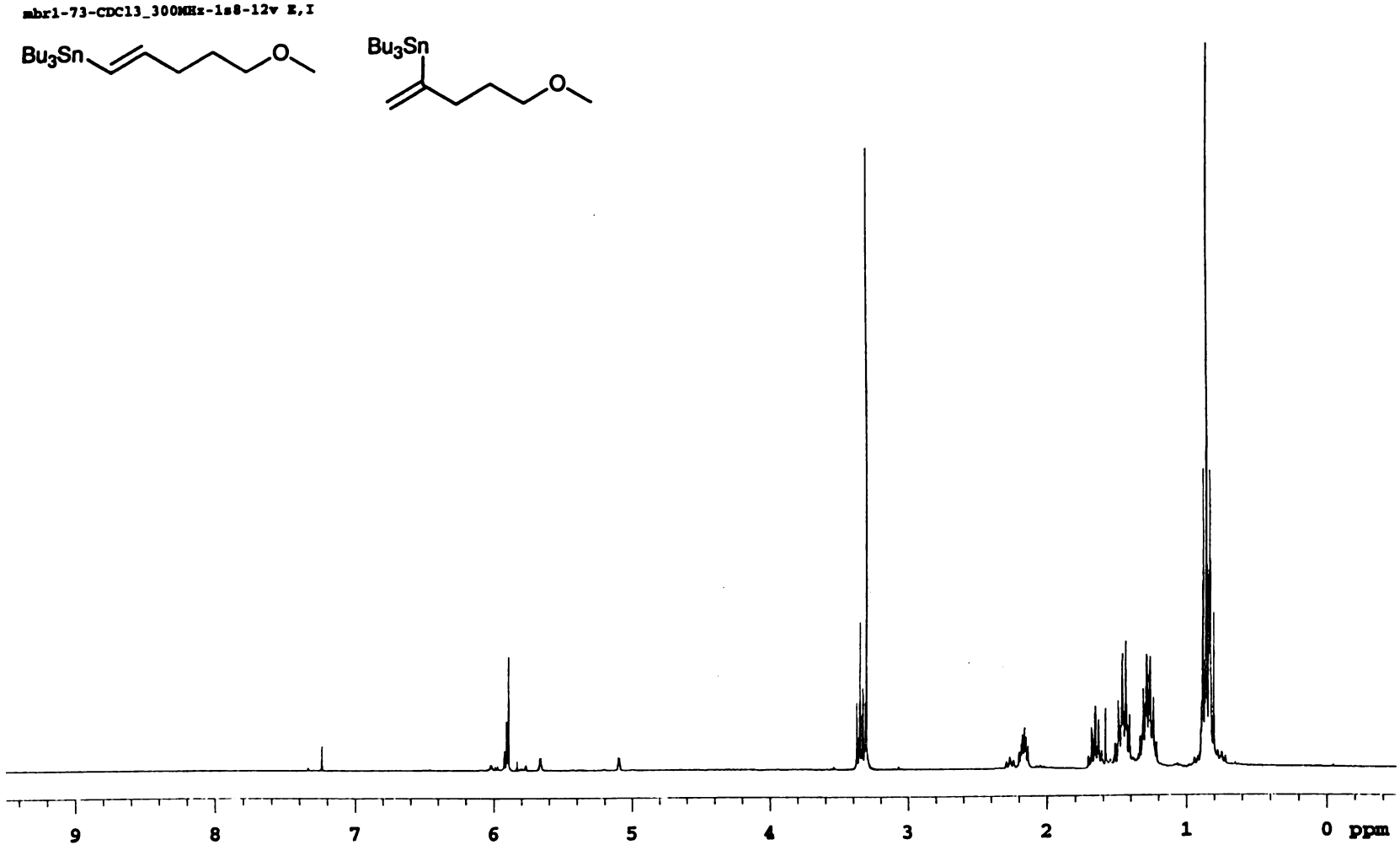
mbr1-98 11-21v
200
180
160
140
120
100
80
60
40
20
0 ppm

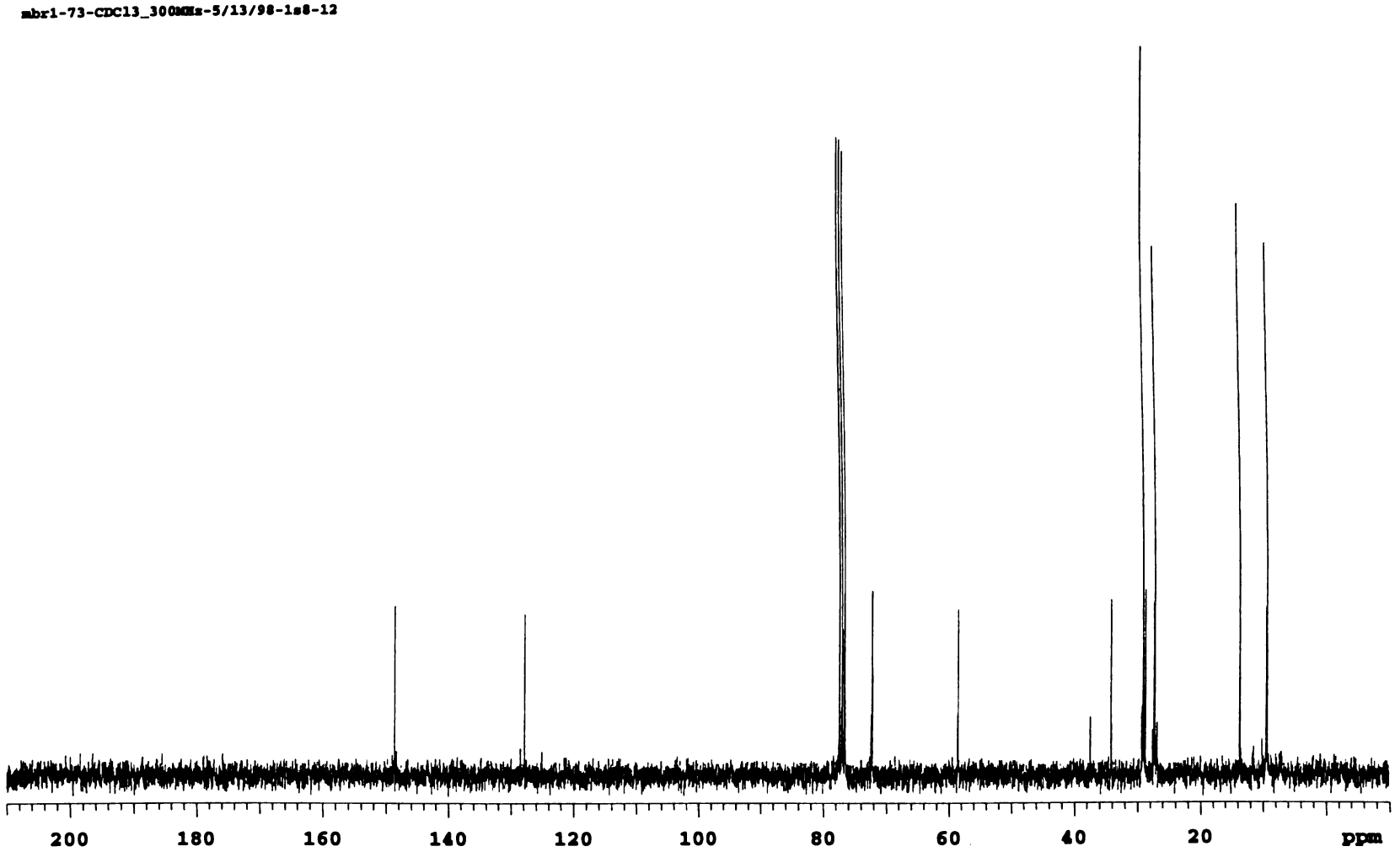


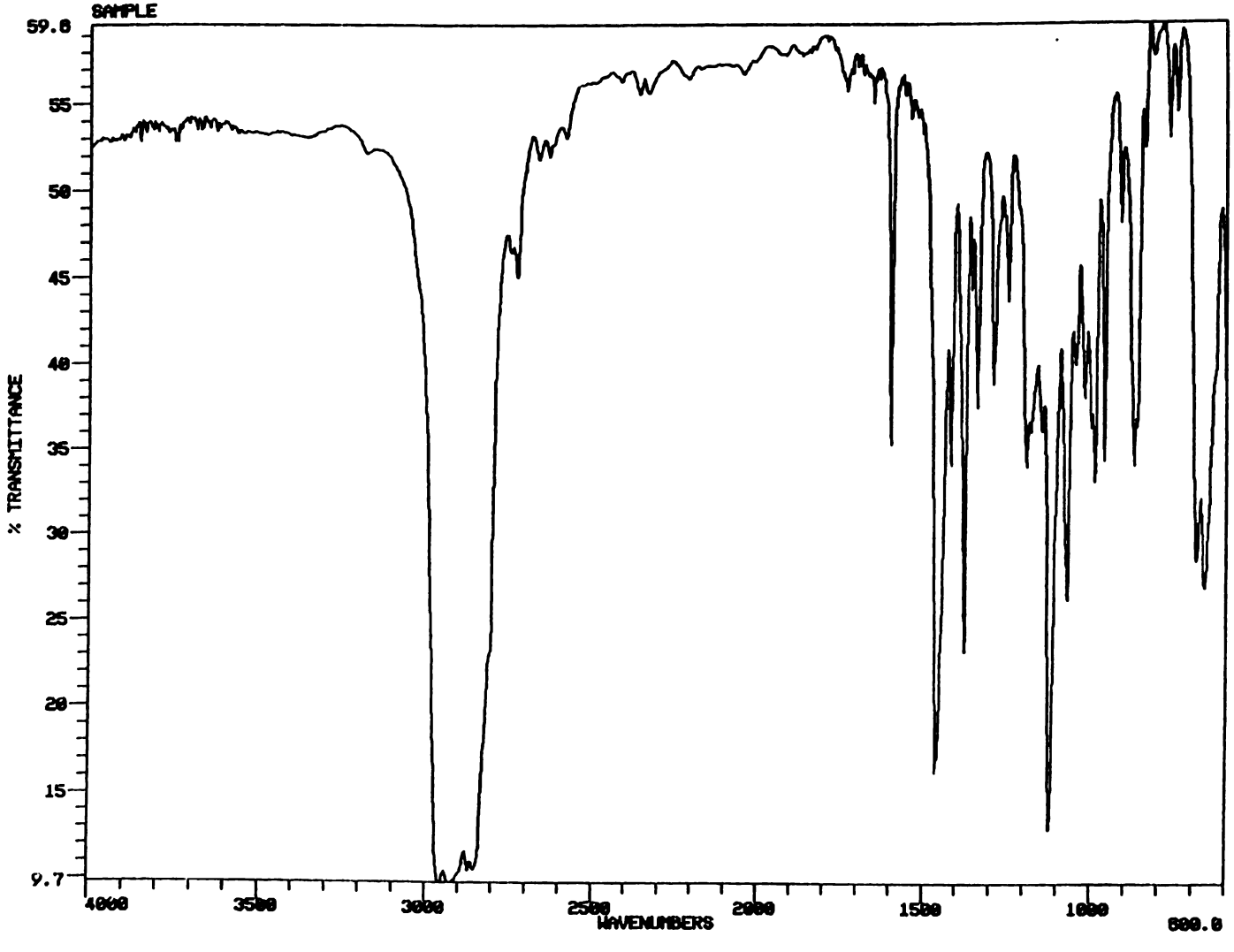
Nicolet Instrument
Corporation

mbr1-73

SCANS: 32 RES: 4.0 TIME: 05/09/99 15:11:14


mbr1-73-CDCl3_300MHz-1s8-12v E,I
Bu3Sn
O
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0 ppm

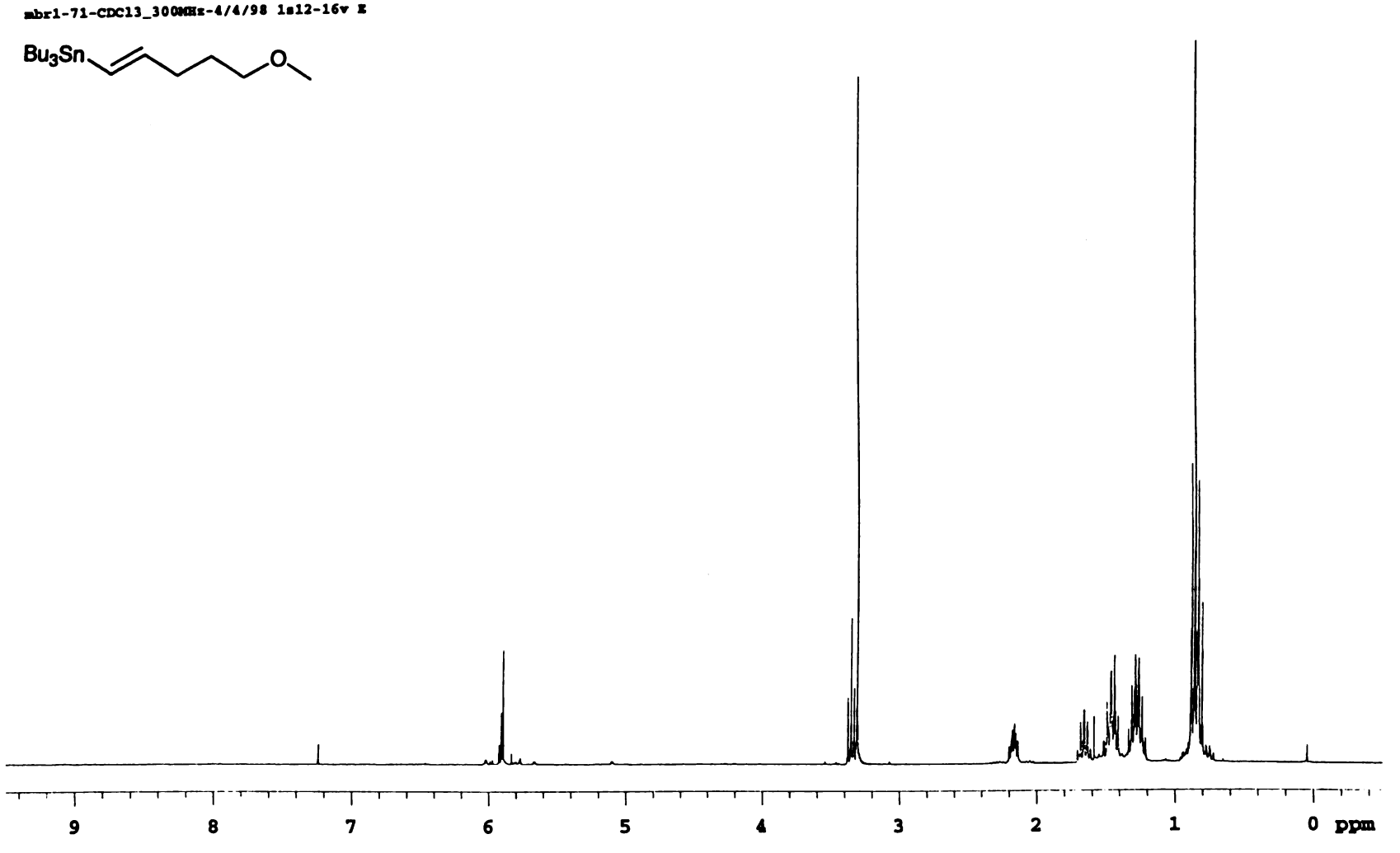

mbr1-73-CDCl3_300MHz-5/13/98-1s8-12
200
180
160
140
120
100
80
60
40
20
ppm

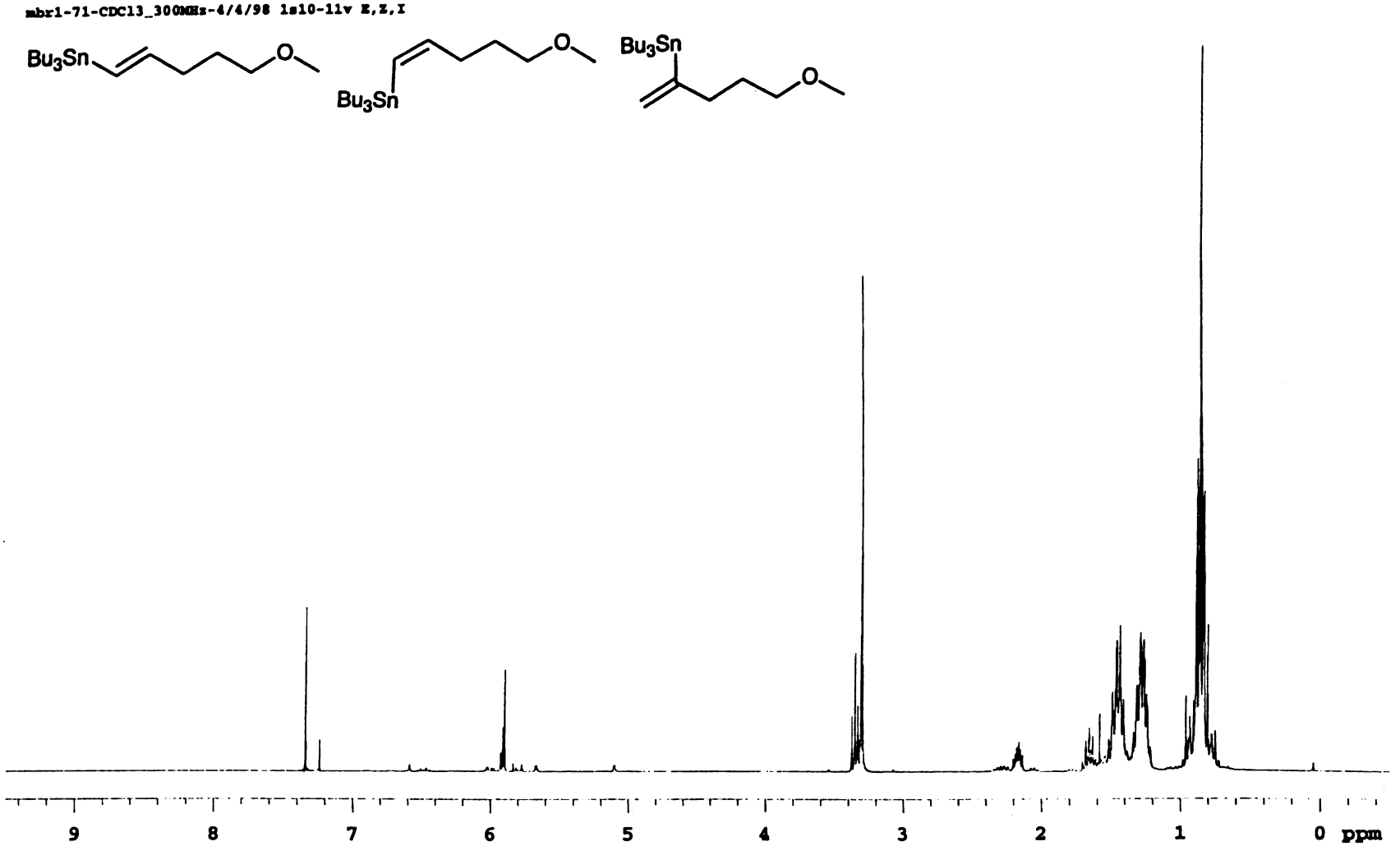


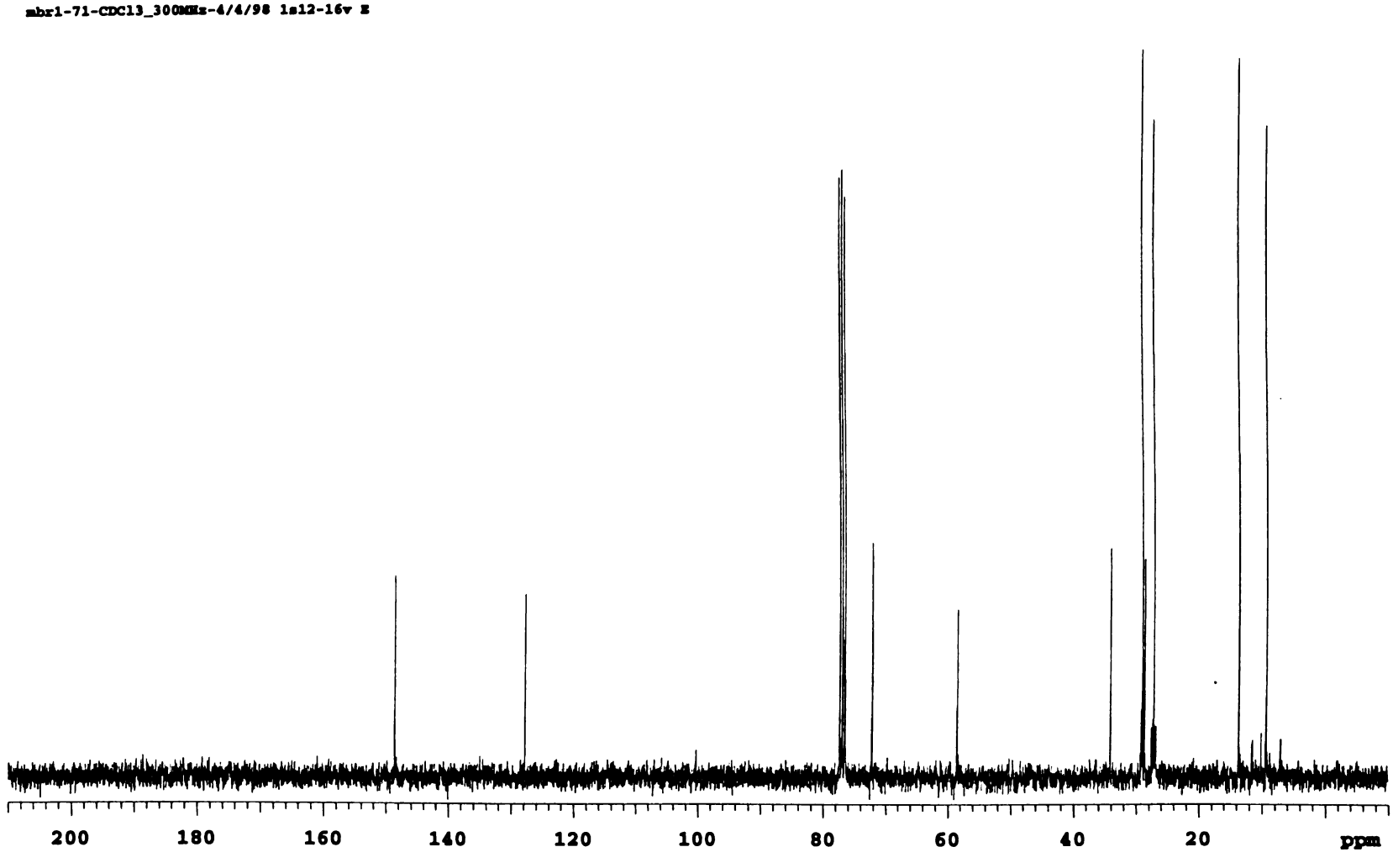
Nicolet Instrument Corporation

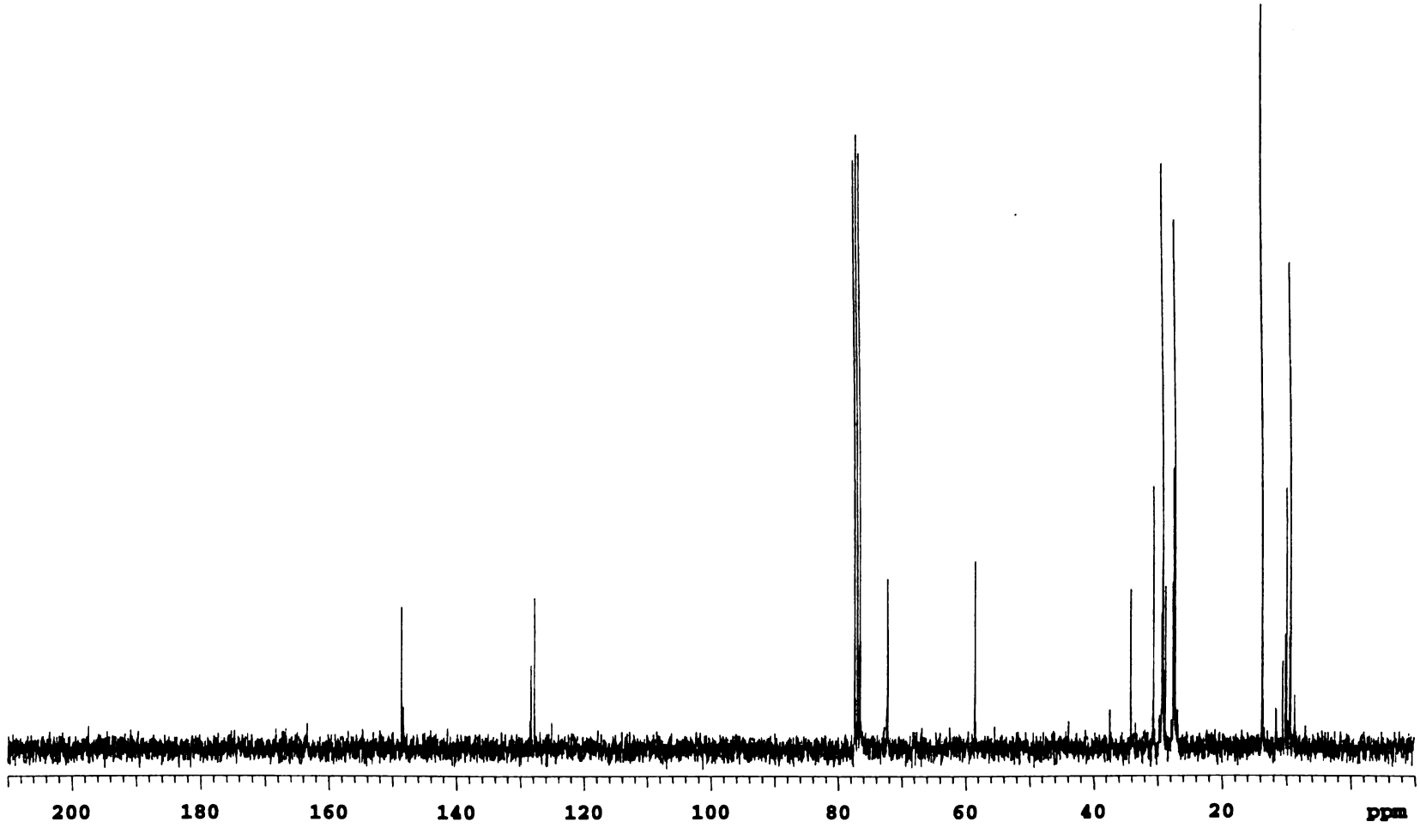
mbr1-71

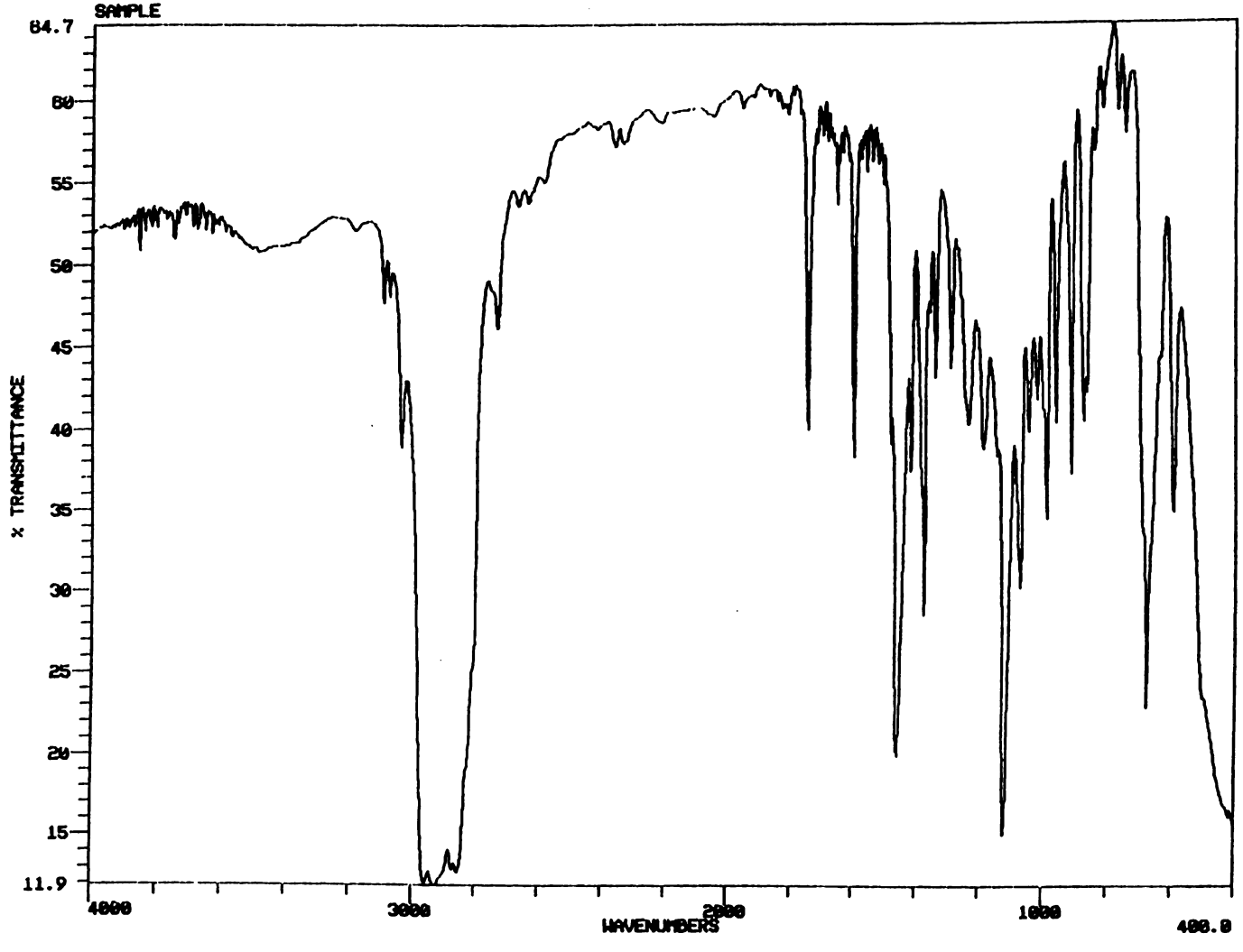
SCANS: 32 RES: 4.0 TIME: 05/09/99 16:17:22


mbr1-71-CDCl3_300MHz-4/4/98 1s12-16v E
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0
ppm


mbr1-71-CDCl3_300MHz-4/4/98 1s10-11v E,Z,I
Bu3Sn
O
Bu3Sn
O
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0
ppm


mbr1-71-CDCl3_300MHz-4/4/98 1s12-16v E
200
180
160
140
120
100
80
60
40
20
ppm

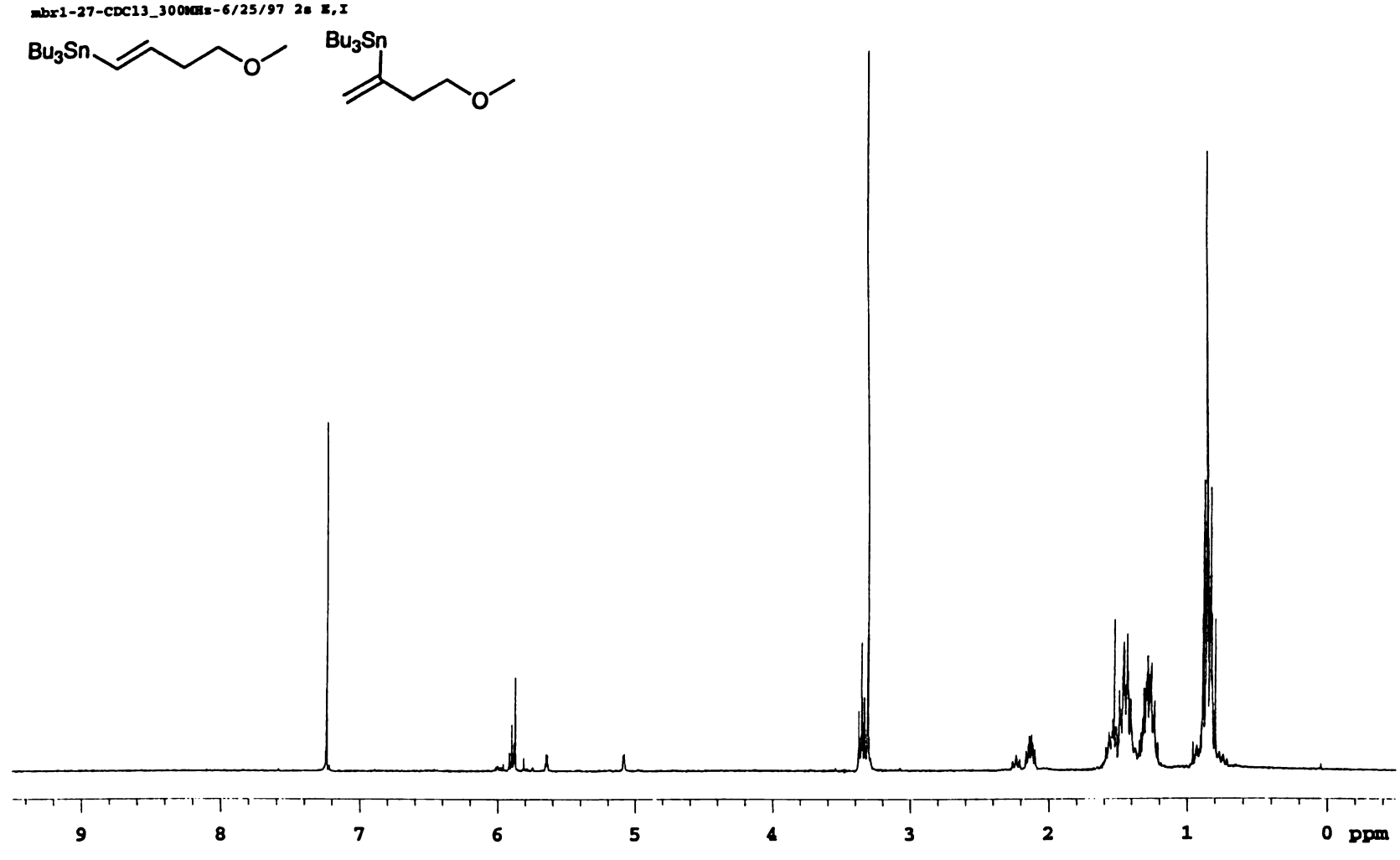

mbr1-71-CDCl3_300MHz-4/4/98 ls10-11v E,Z,I
200
180
160
140
120
100
80
60
40
20
ppm



Nicolet Instrument Corporation

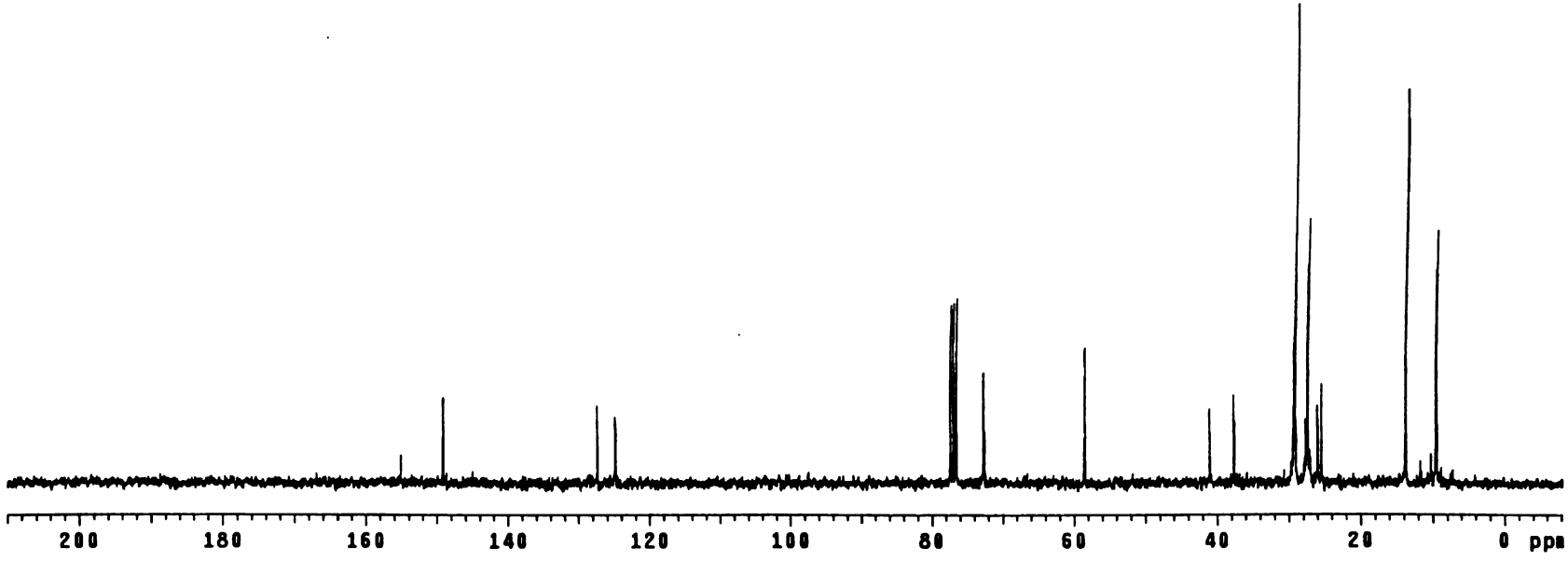
mbr1-27

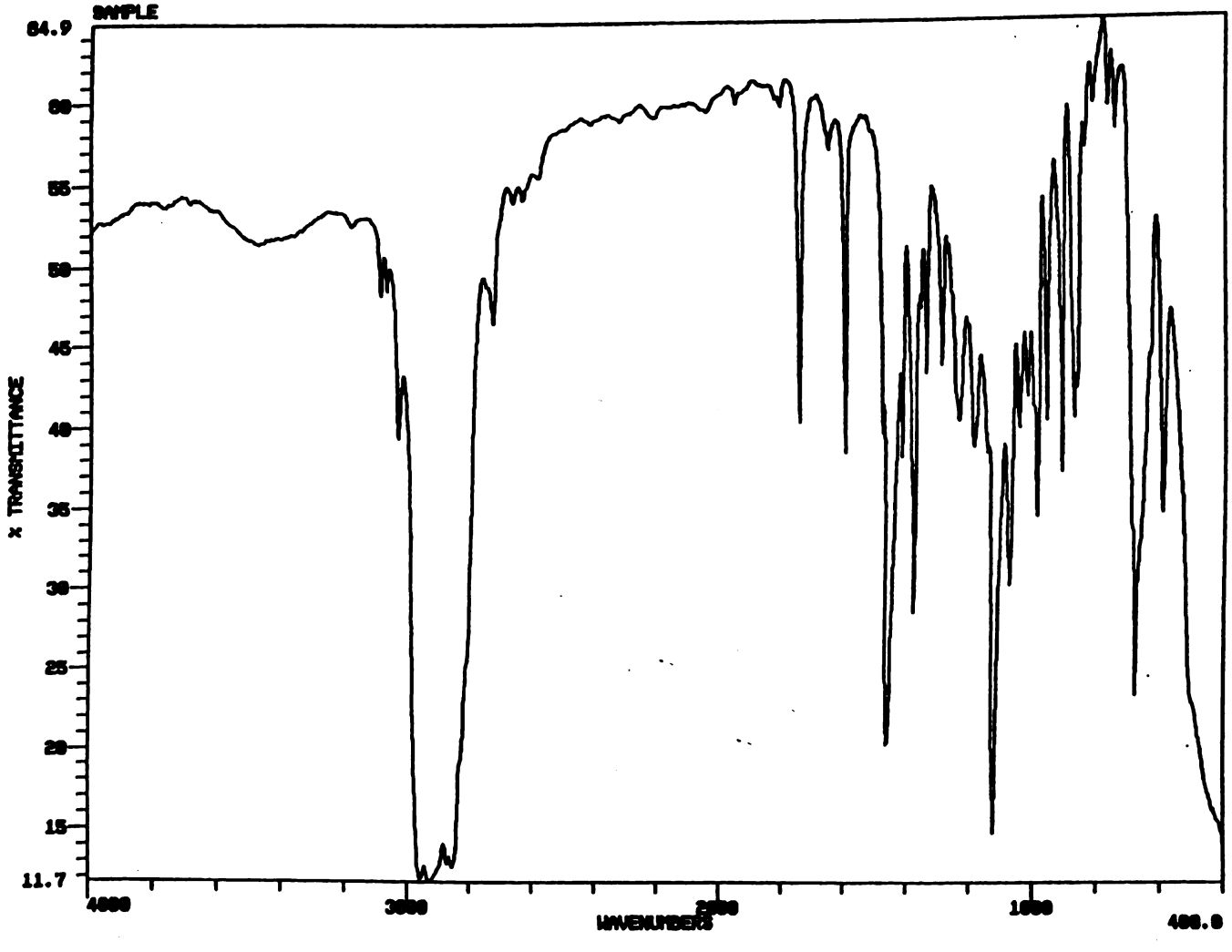
SCANS: 32 RES: 4.0 TIME: 05/17/99 15:20:04


mbr1-27-CDCl3_300MHz-6/25/97 2a E,I
Bu3Sn
O
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0
ppm

mbr1-27

Pulse Sequence: s2pul

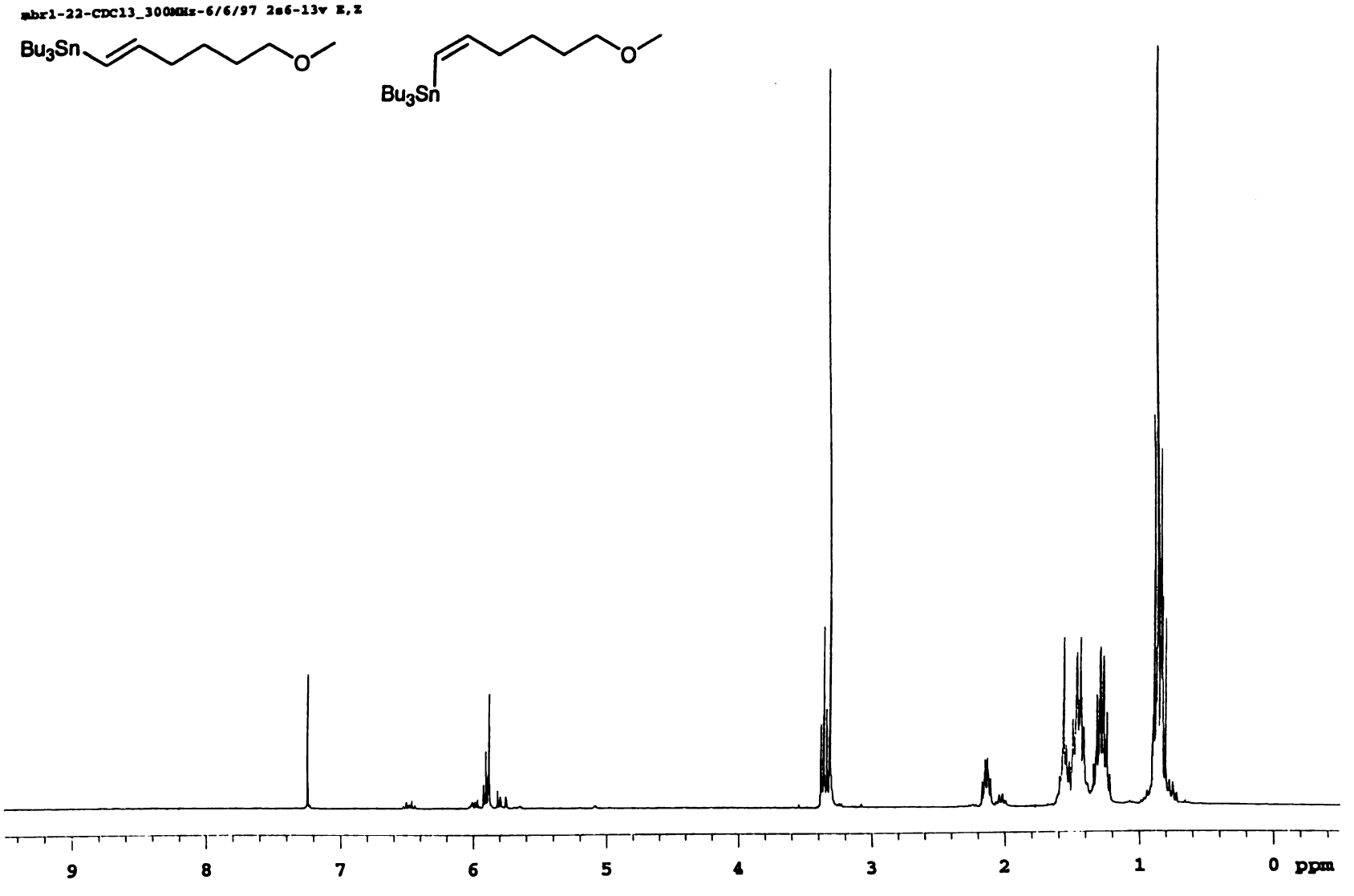


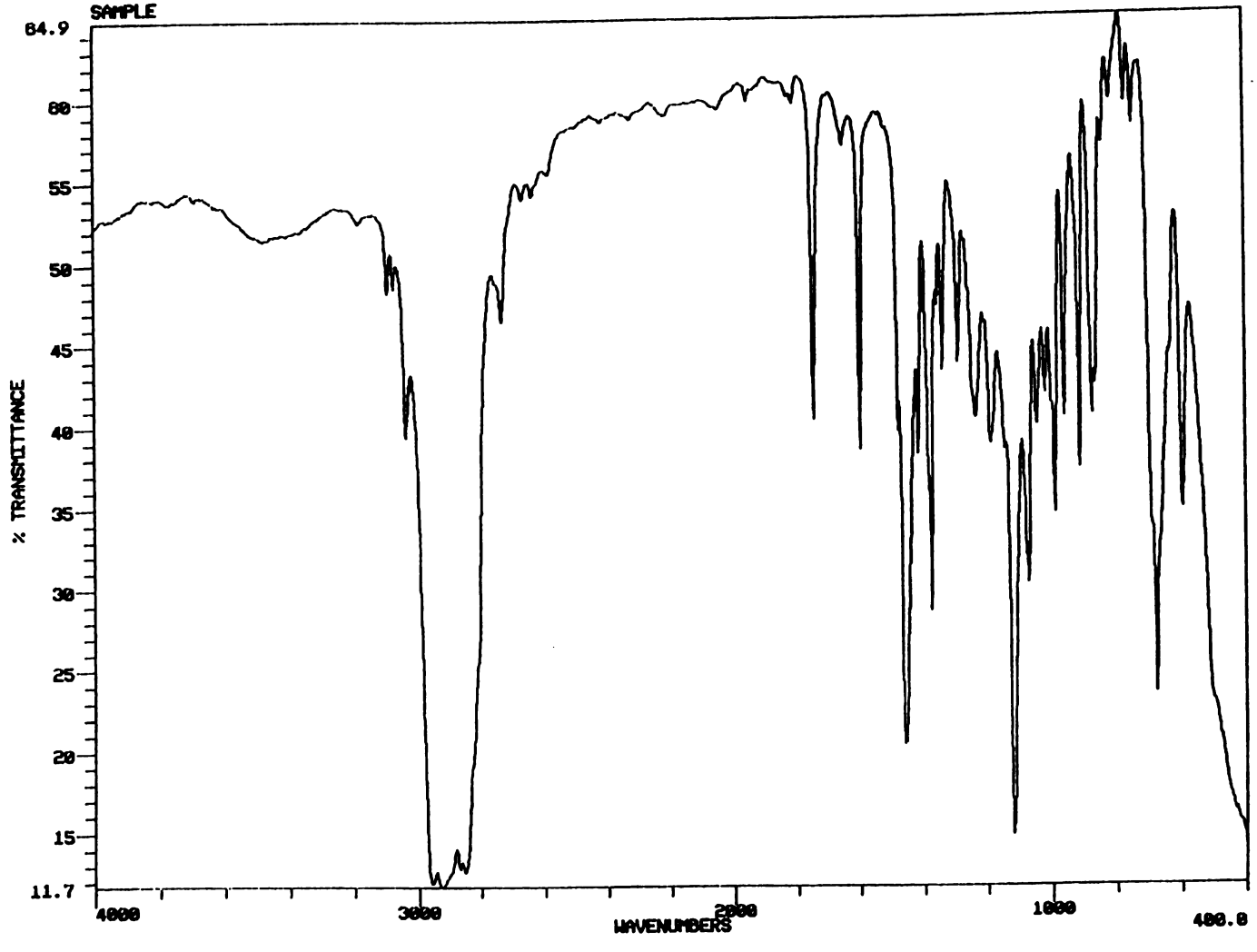


Nicolet Instrument Corporation

mbr1-22

SCANS: 32 RES: 4.0 TIME: 05/17/99 15:25:07

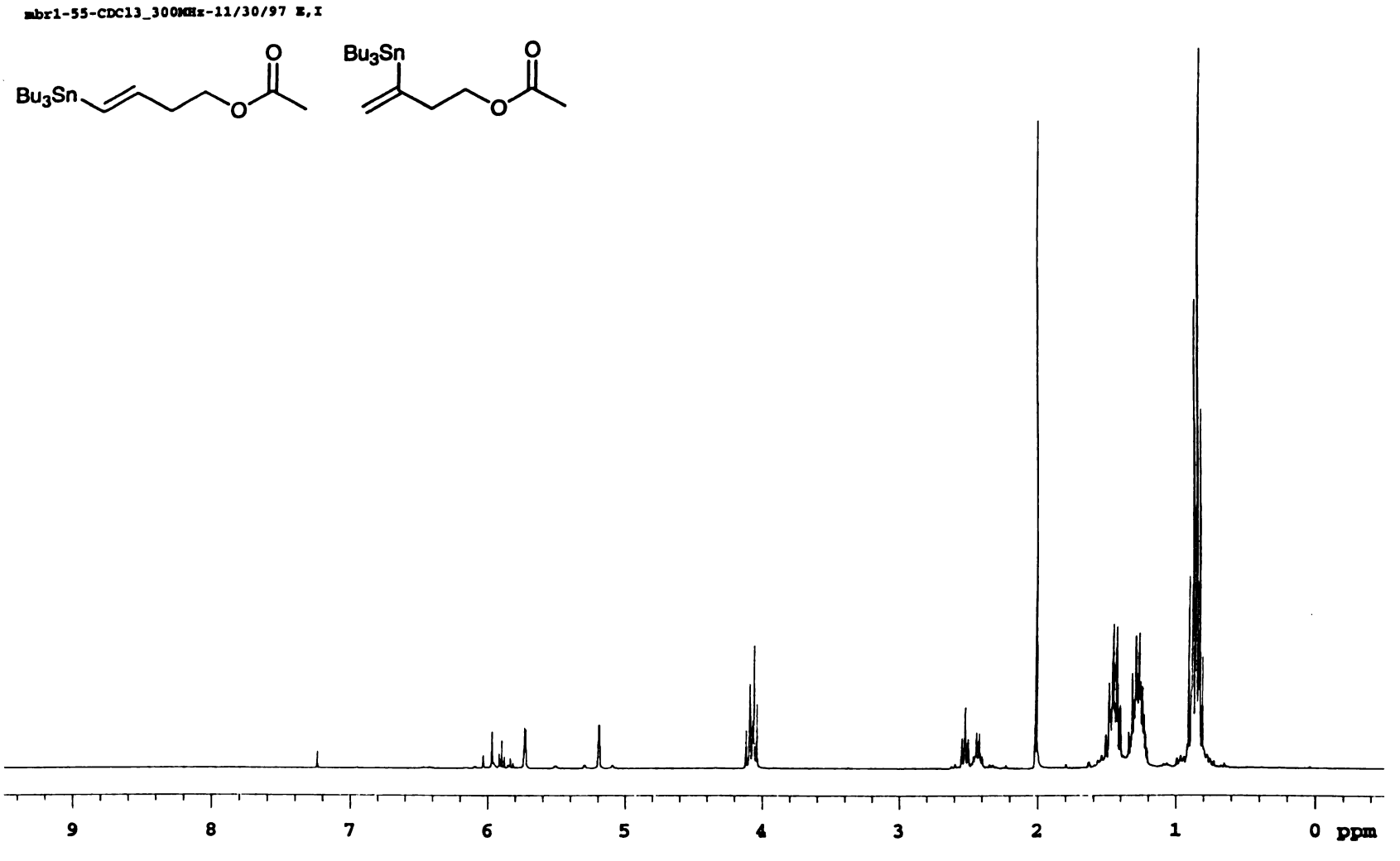

mbr1-22-CDCl3_300MHz-6/6/97 2s6-13v E,Z
Bu3Sn
O
Bu3Sn
O
9
8
7
6
5
4
3
2
1
0
ppm

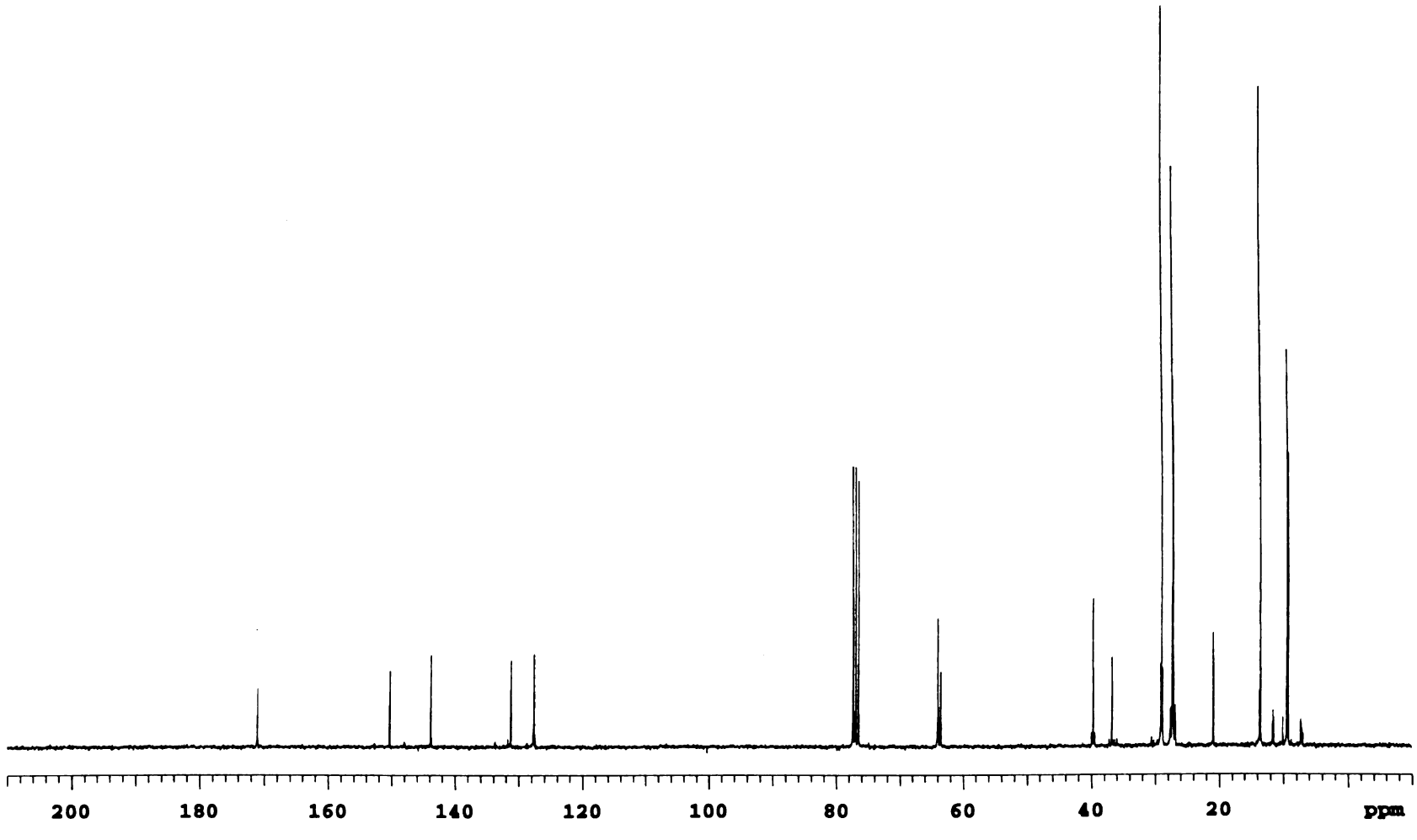


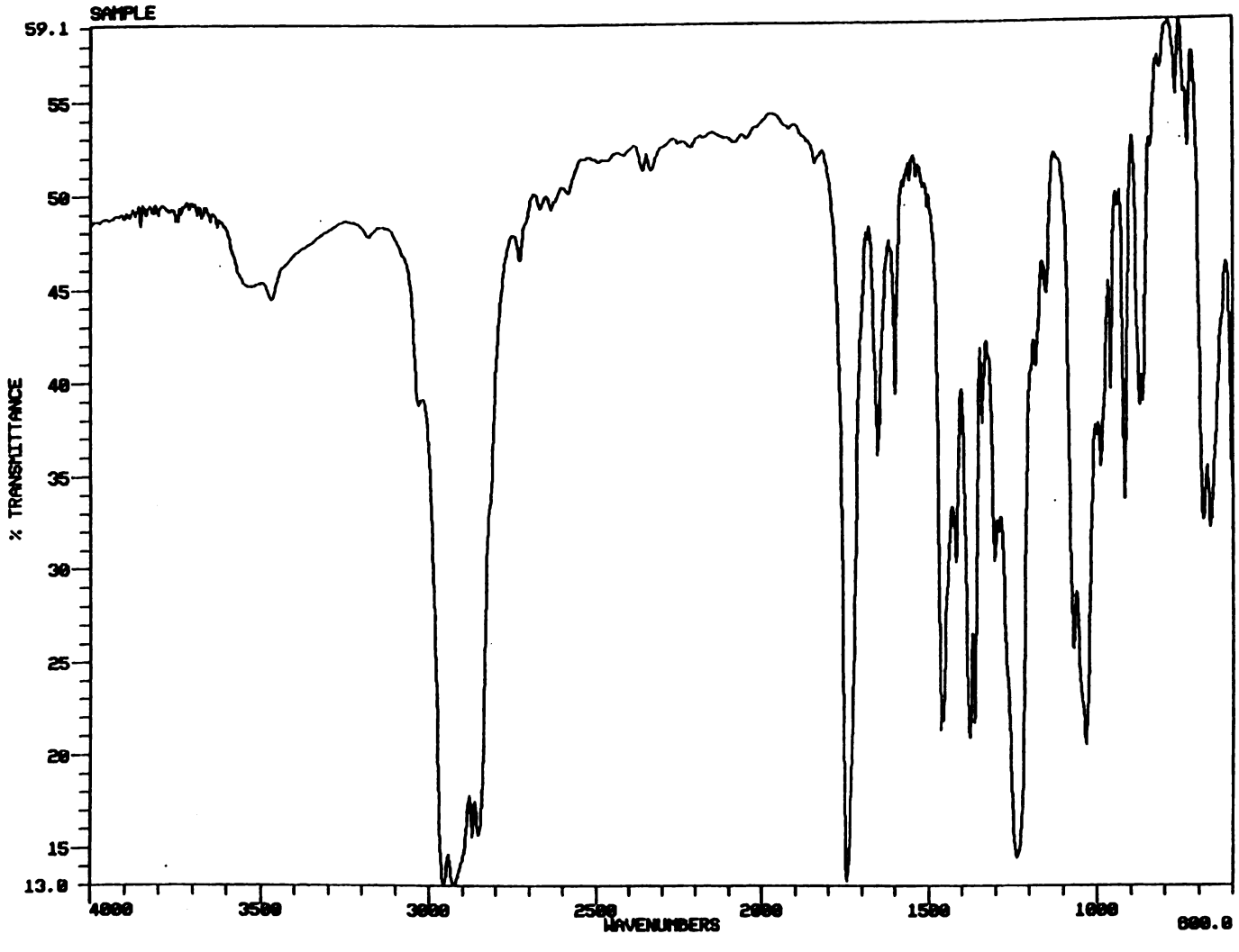
Nicolet Instrument Corporation

mbr1-22

SCANS: 32 RES: 4.0 TIME: 05/17/99 15:25:07


mbr1-55-CDCl3_300MHz-11/30/97 E,I
Bu3Sn
O
O
Bu3Sn
O
O
9
8
7
6
5
4
3
2
1
0
ppm

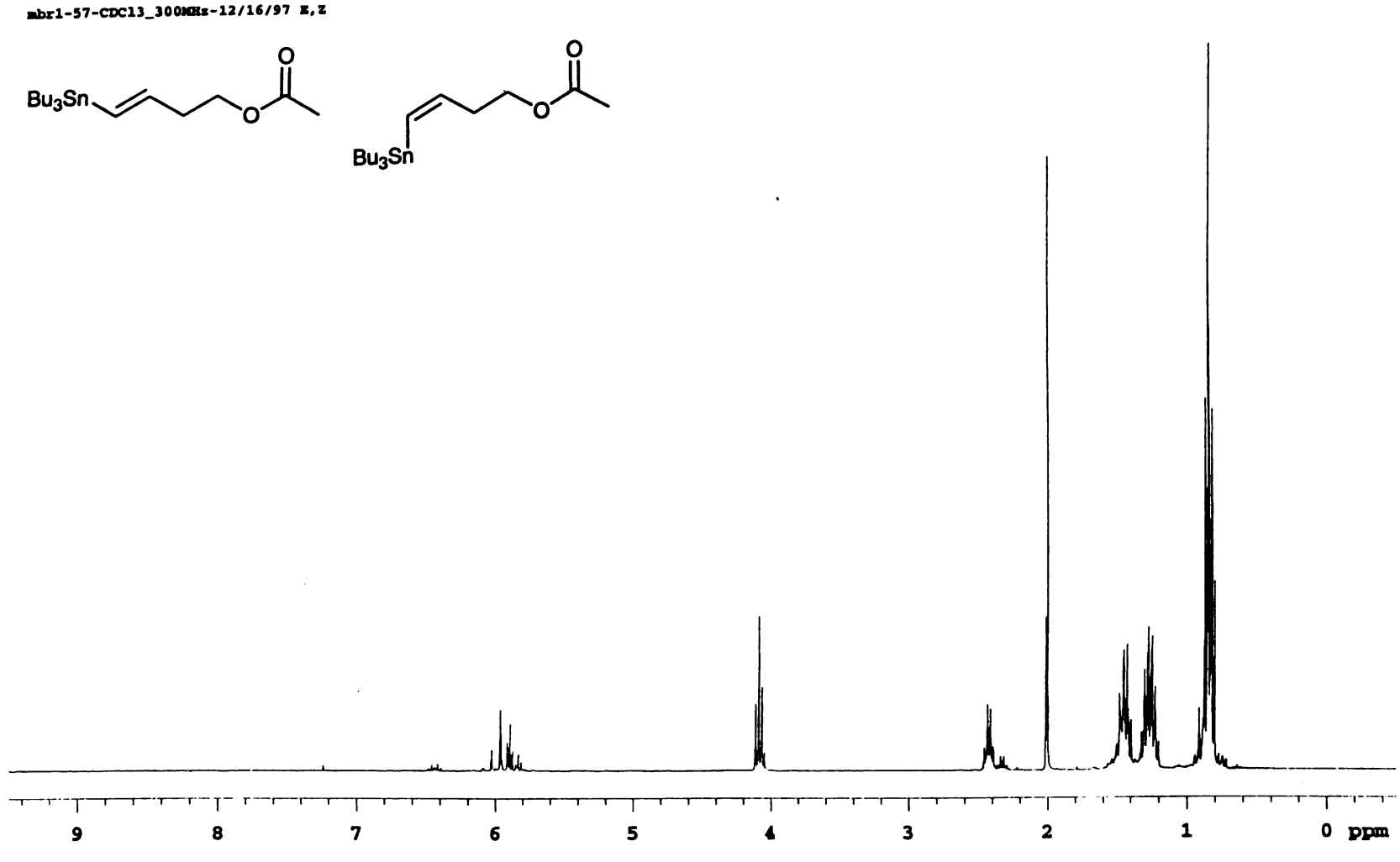

mbr1-55-CDCl3_300MHz-11/30/97 E,I
200
180
160
140
120
100
80
60
40
20
ppm

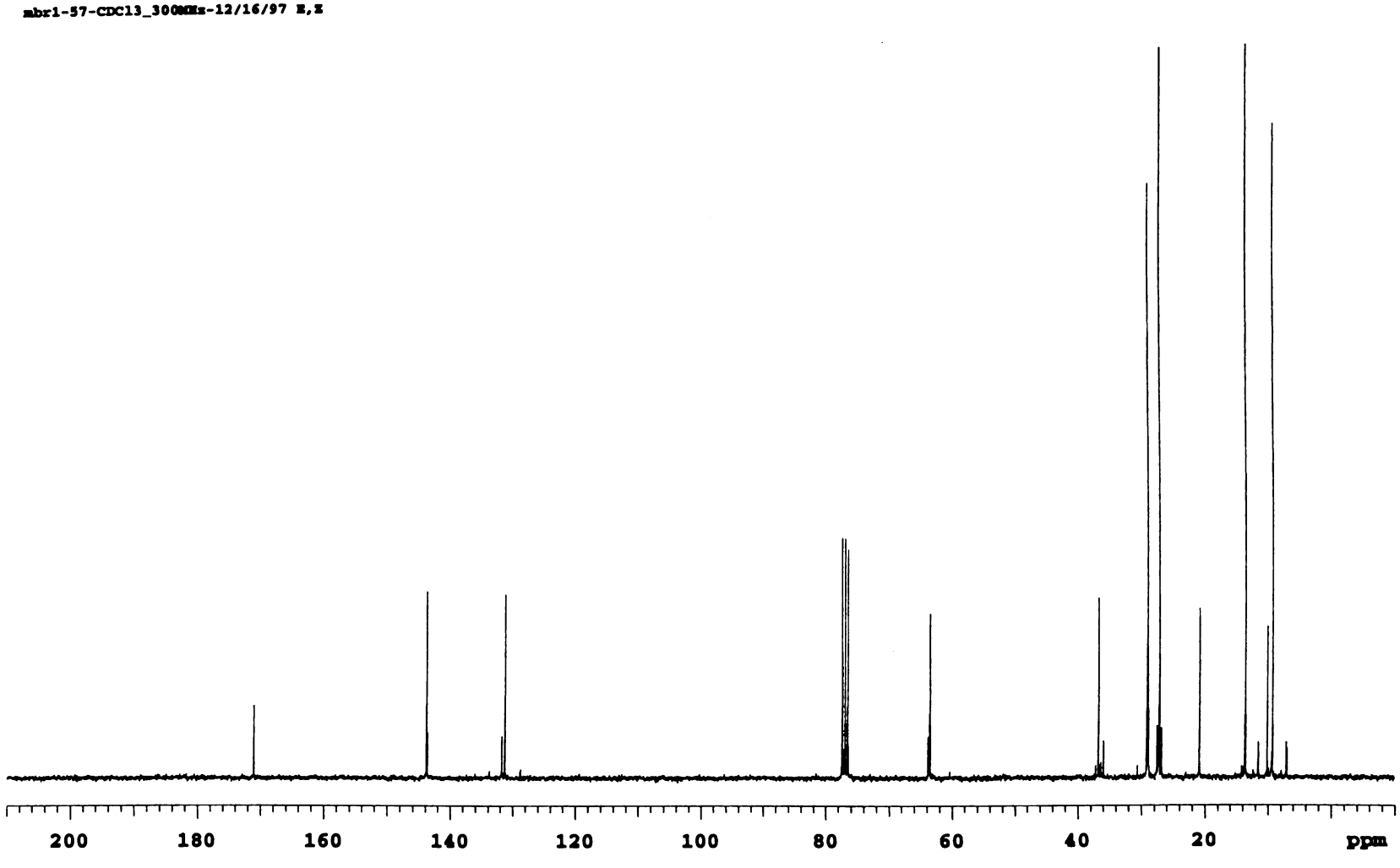


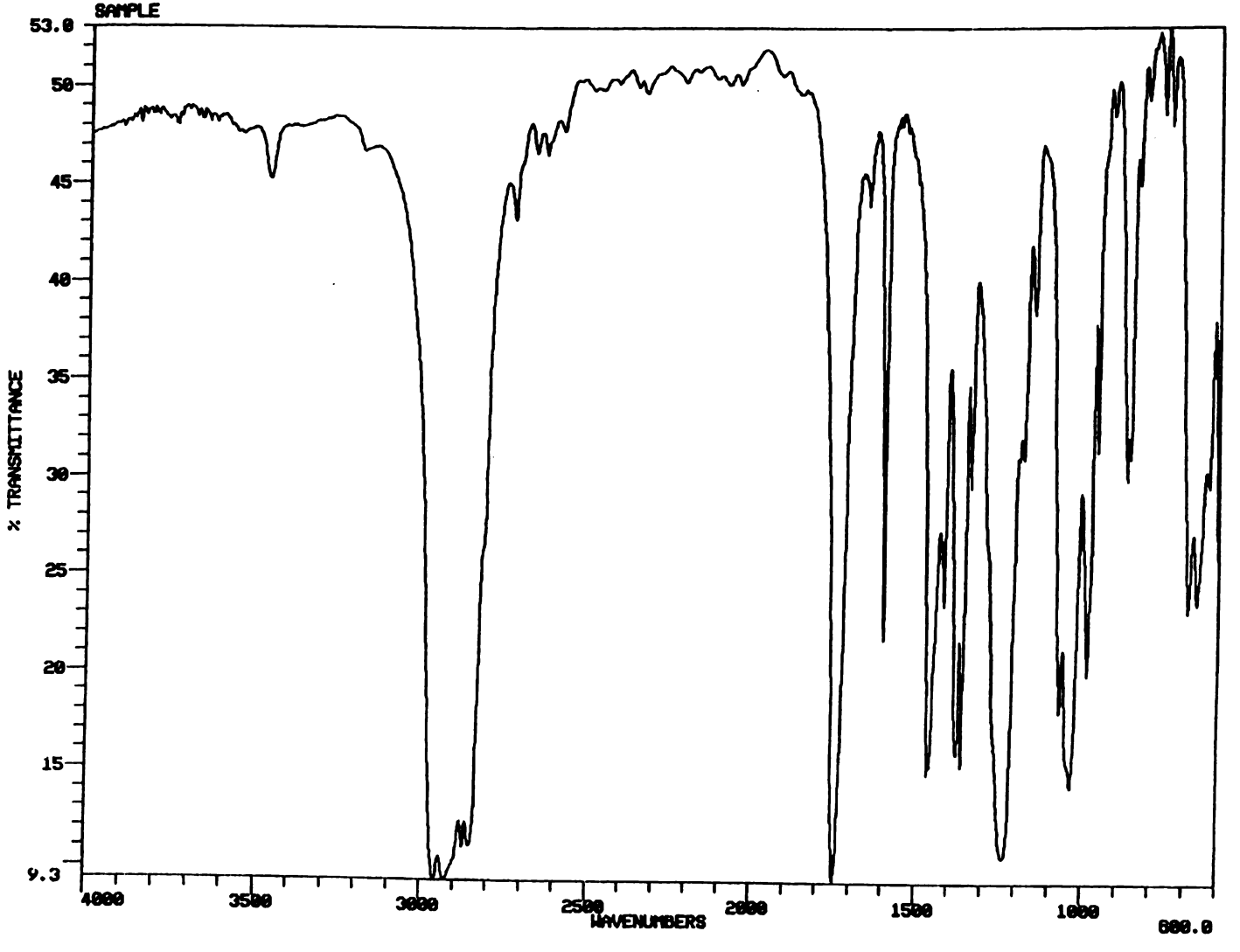
Nicolet Instrument Corporation

mbr1-55

SCANS: 32 RES: 4.0 TIME: 05/09/99 17:53:47


mbr1-57-CDCl3_300MHz-12/16/97 E,Z
Bu3Sn
O
O
Bu3Sn
O
O
9
8
7
6
5
4
3
2
1
0
ppm

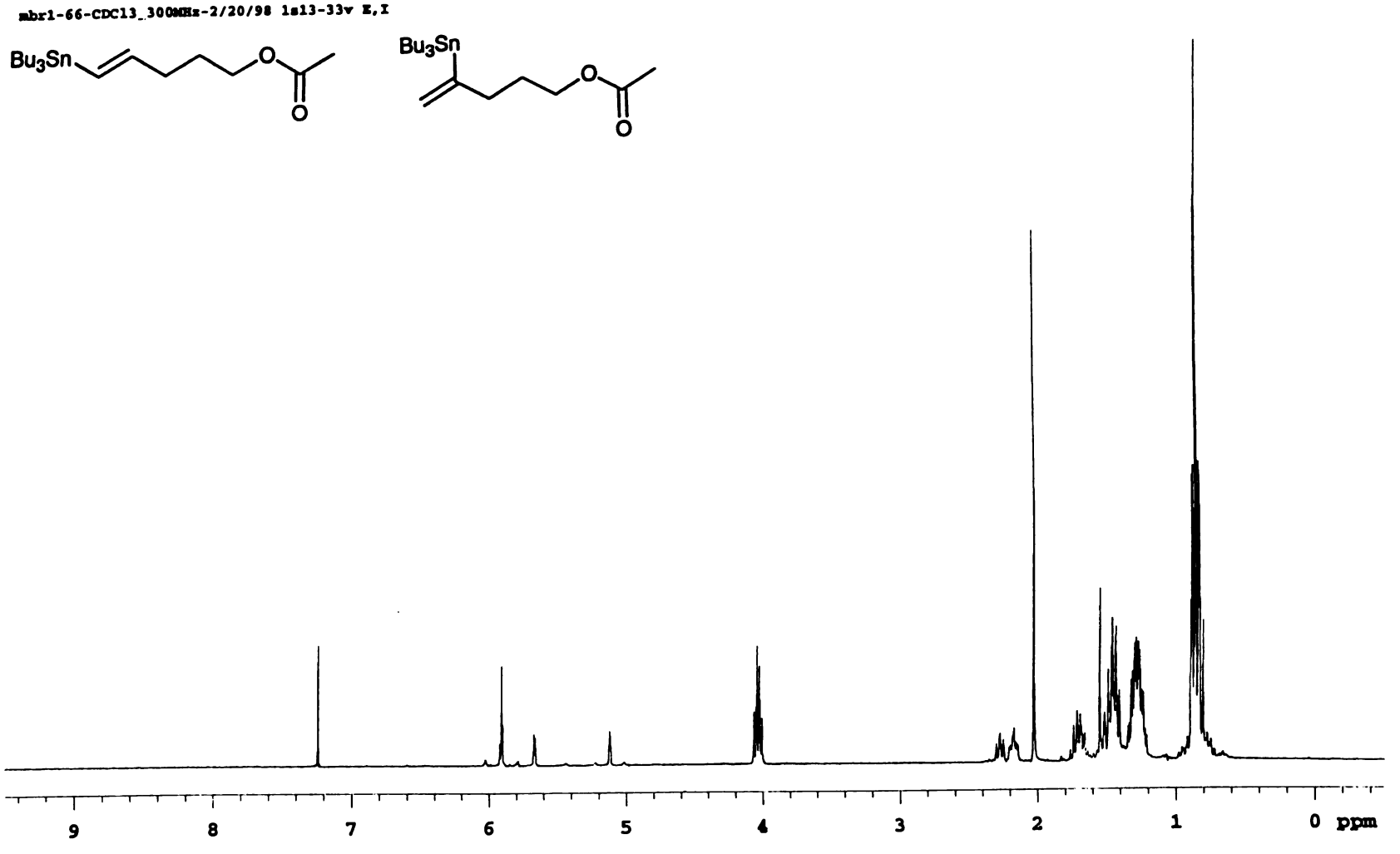

mbr1-57-CDCl3_300MHz-12/16/97 E,E
200
180
160
140
120
100
80
60
40
20
ppm

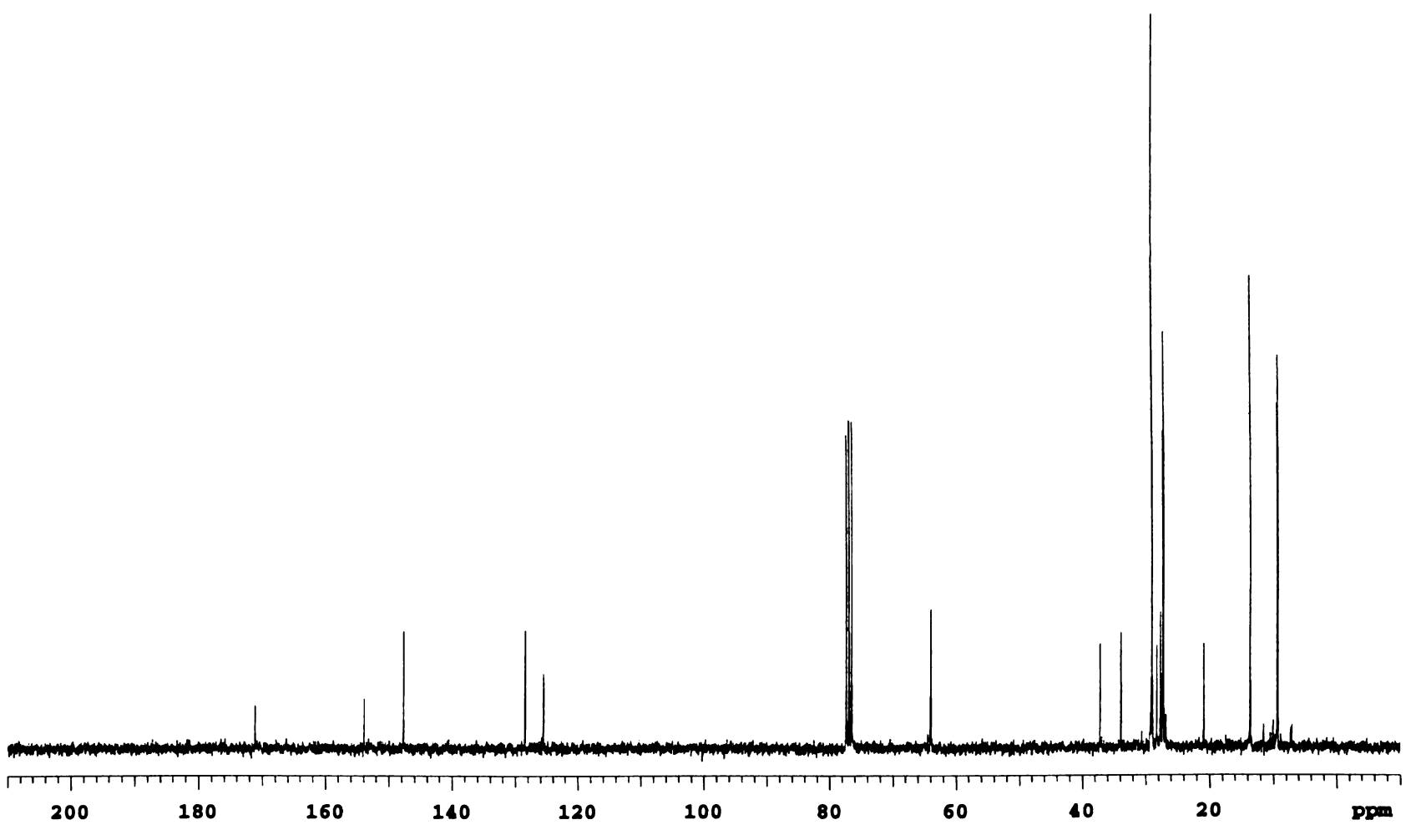


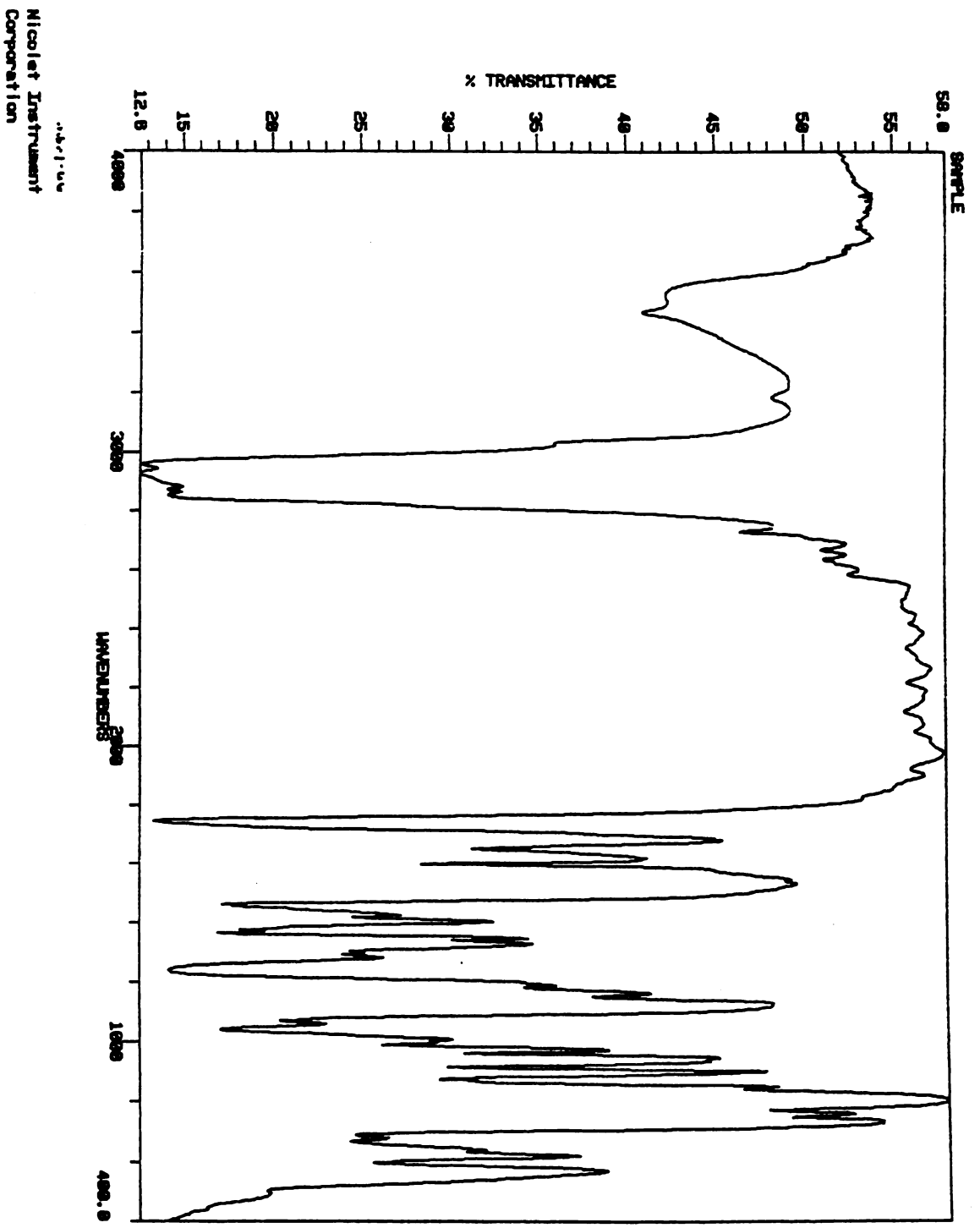
Nicolet Instrument Corporation

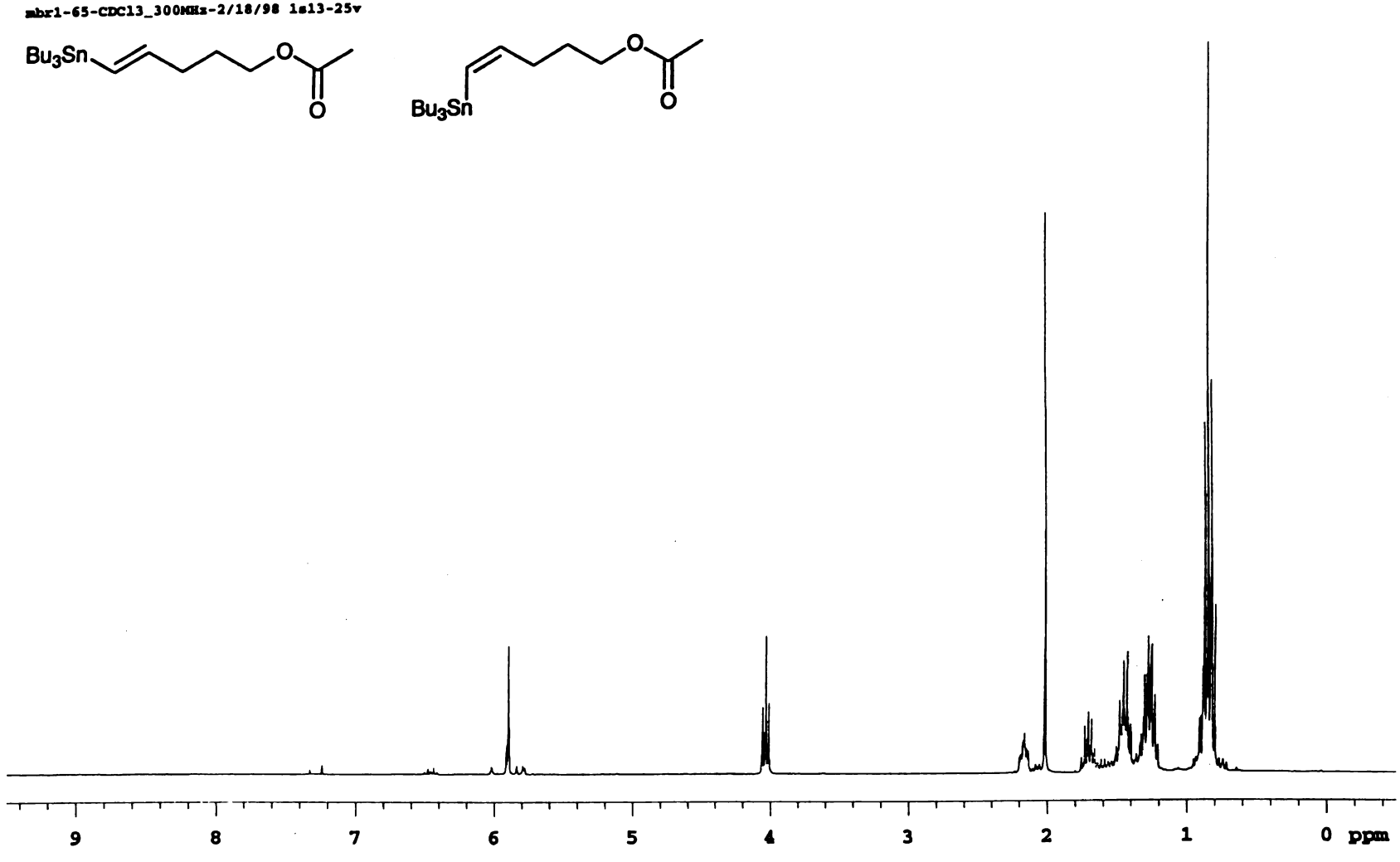
mbr1-57

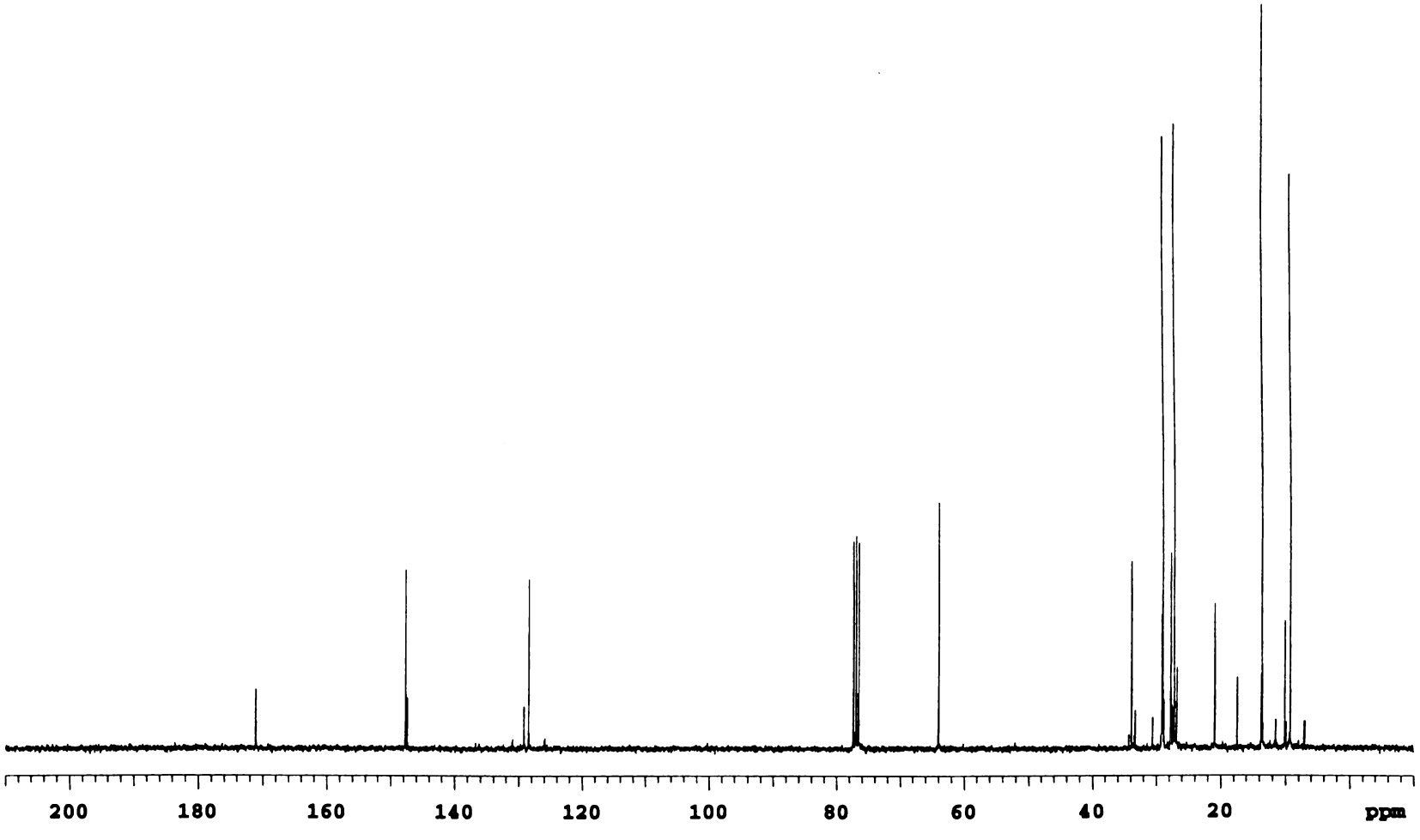
SCANS: 32 RES: 4.0 TIME: 05/09/99 10:01:40

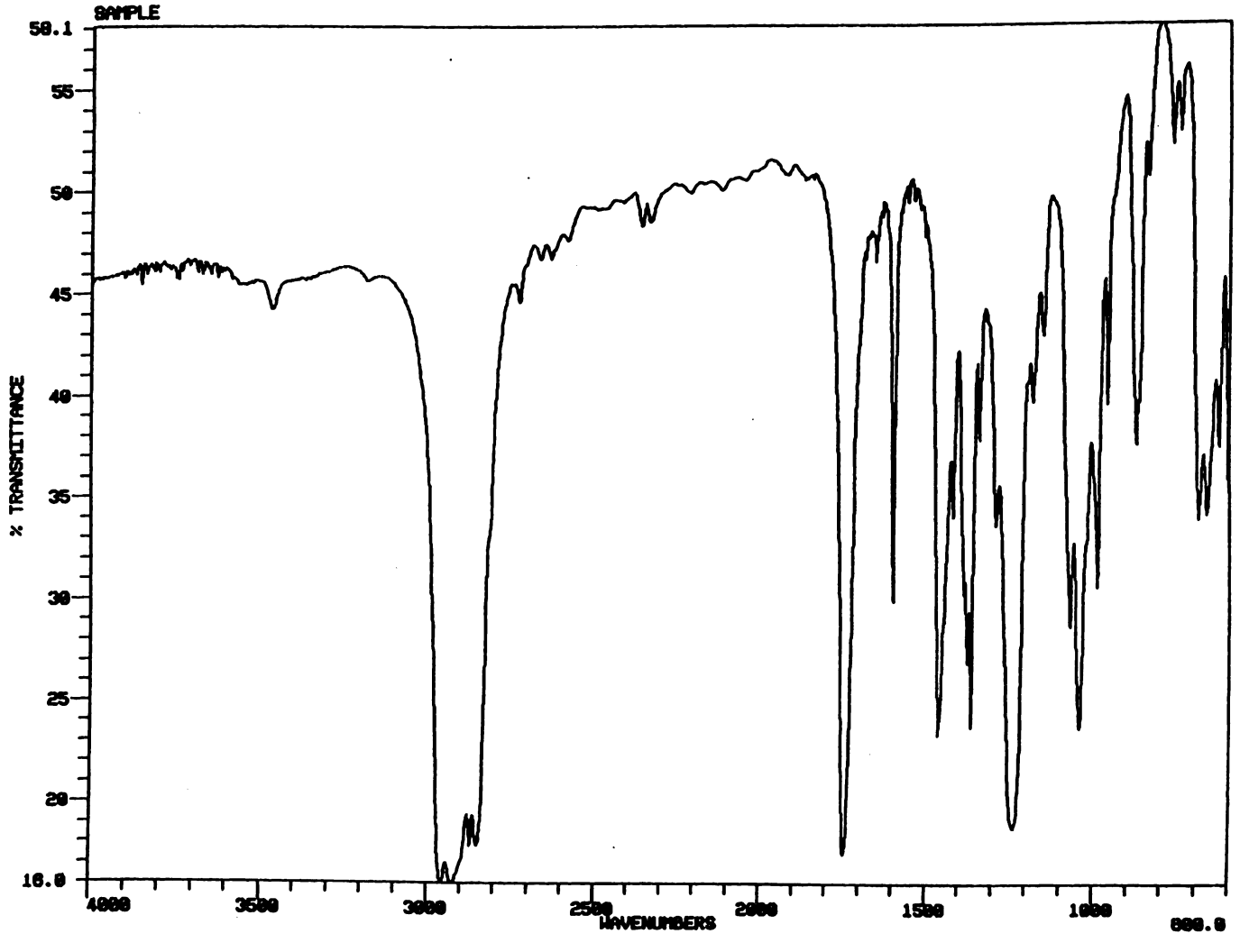

mbr1-66-CDCl3_300MHz-2/20/98 1s13-33v E,I
Bu3Sn
O
O
Bu3Sn
O
O
9
8
7
6
5
4
3
2
1
0 ppm


mbr1-66-CDCl3_300MHz-2/20/98 1s13-33v E,I
200
180
160
140
120
100
80
60
40
20
ppm


Nicolet Instrument Corporation
% TRANSMITTANCE
12.8
15
20
25
30
35
40
45
50
55
58.8
SAMPLE
4000
3000
2000
1500
400.0
WAVENUMBERS


mbr1-65-CDCl3_300MHz-2/18/98 1s13-25v
Bu3Sn
O
O
Bu3Sn
O
O
9
8
7
6
5
4
3
2
1
0
ppm

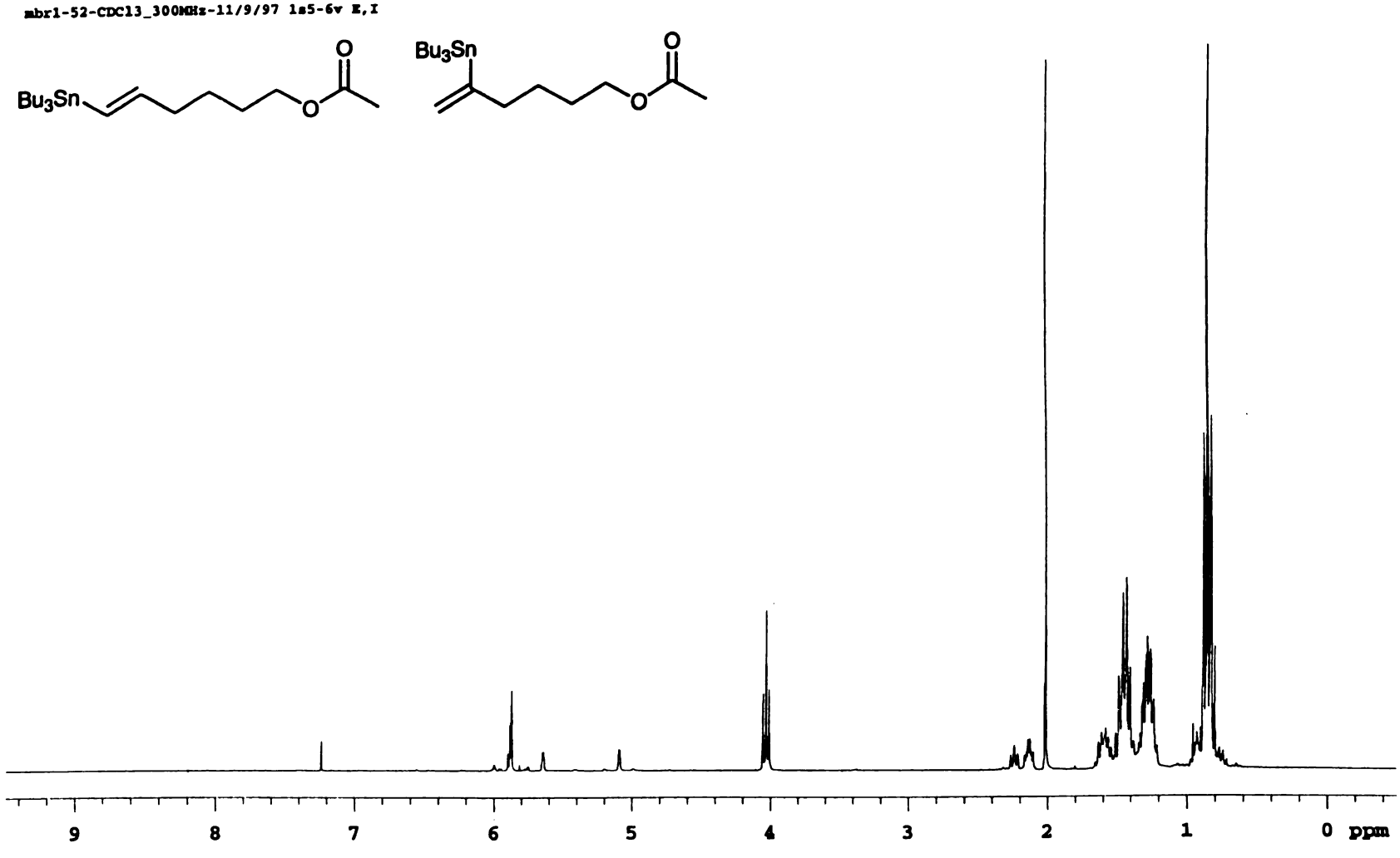

mbr1-65-CDCl3_300MHz-2/18/98 1s13-25v E,E
200
180
160
140
120
100
80
60
40
20
ppm



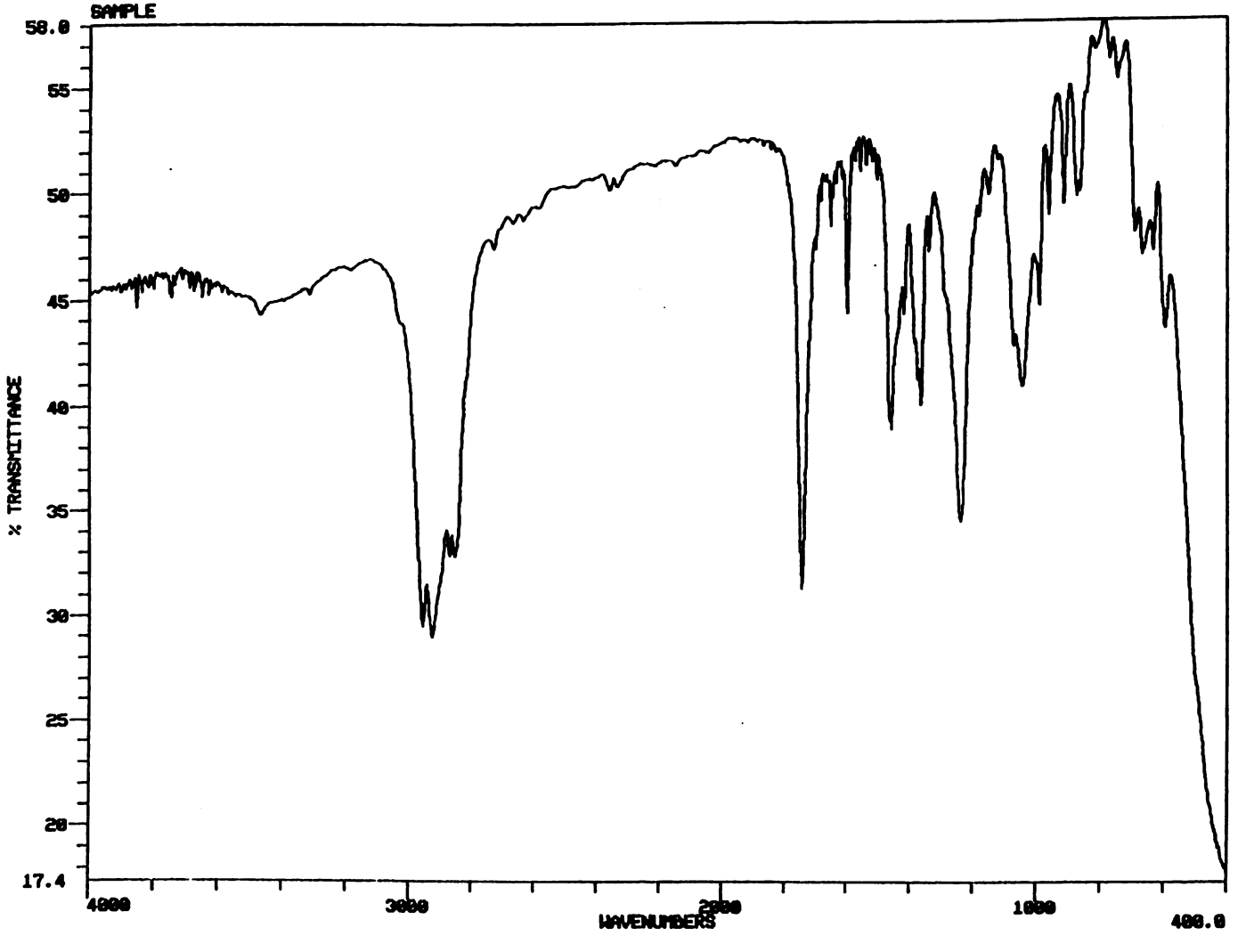
Nicolet Instrument Corporation

mbr1-65

SCANS: 32 RES: 4.0 TIME: 05/09/99 19:55:14


mbr1-52-CDCl3_300MHz-11/9/97 1a5-6v E,I
Bu3Sn
O
O
Bu3Sn
O
O
9
8
7
6
5
4
3
2
1
0 ppm

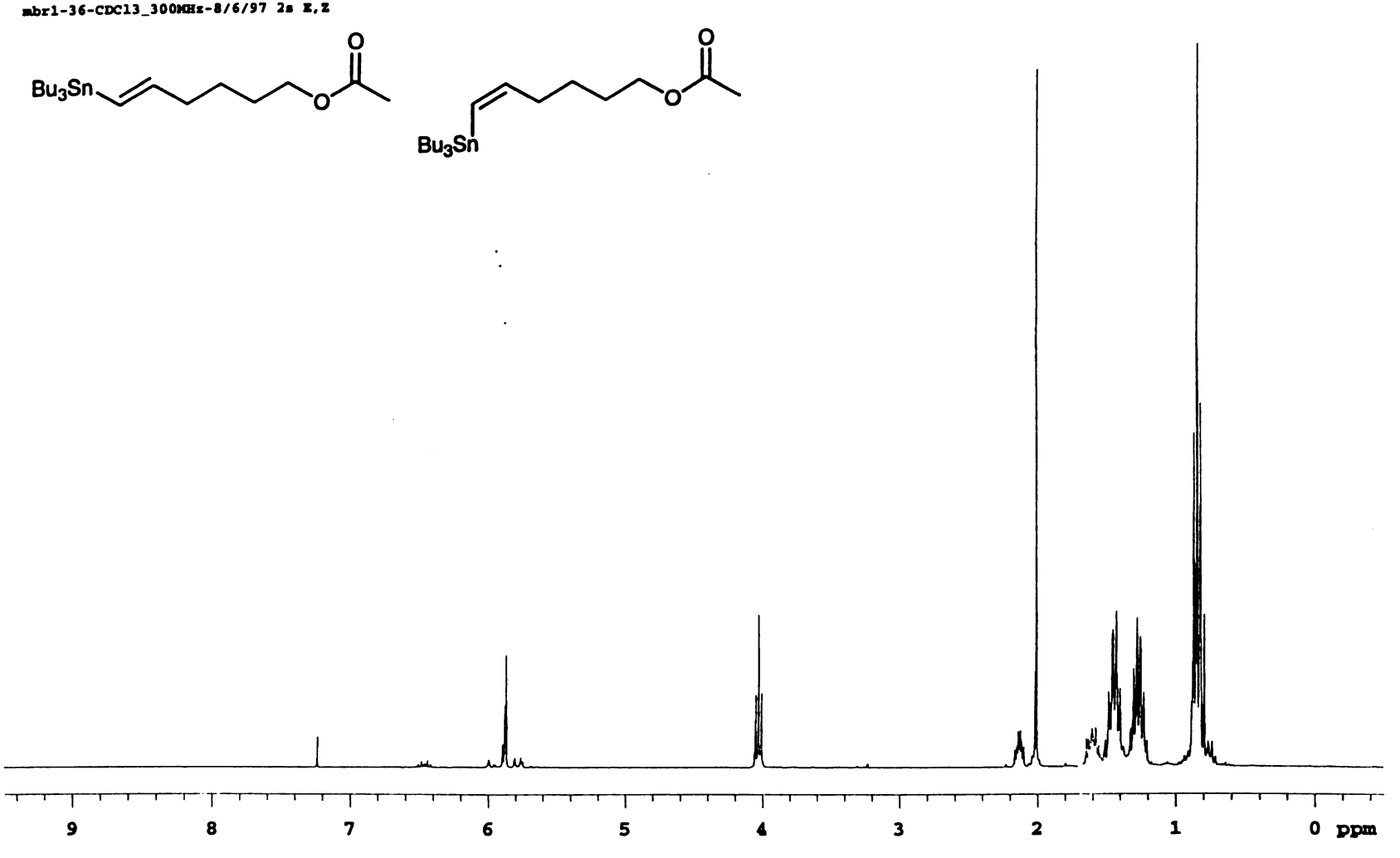
mbr1-s2
Pulse Sequence: s2pul
200
180
160
140
120
100
80
60
40
20
0
ppm

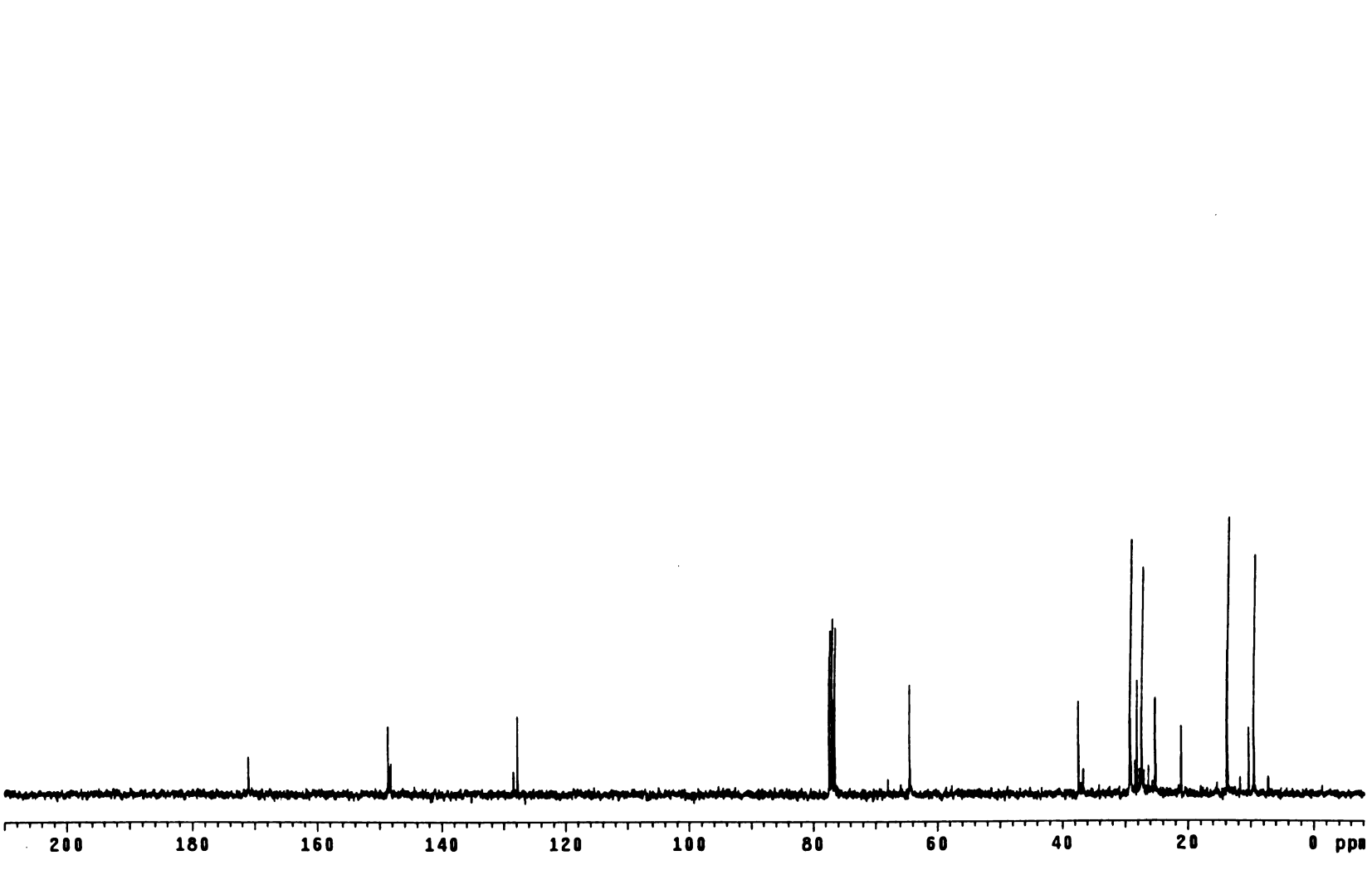


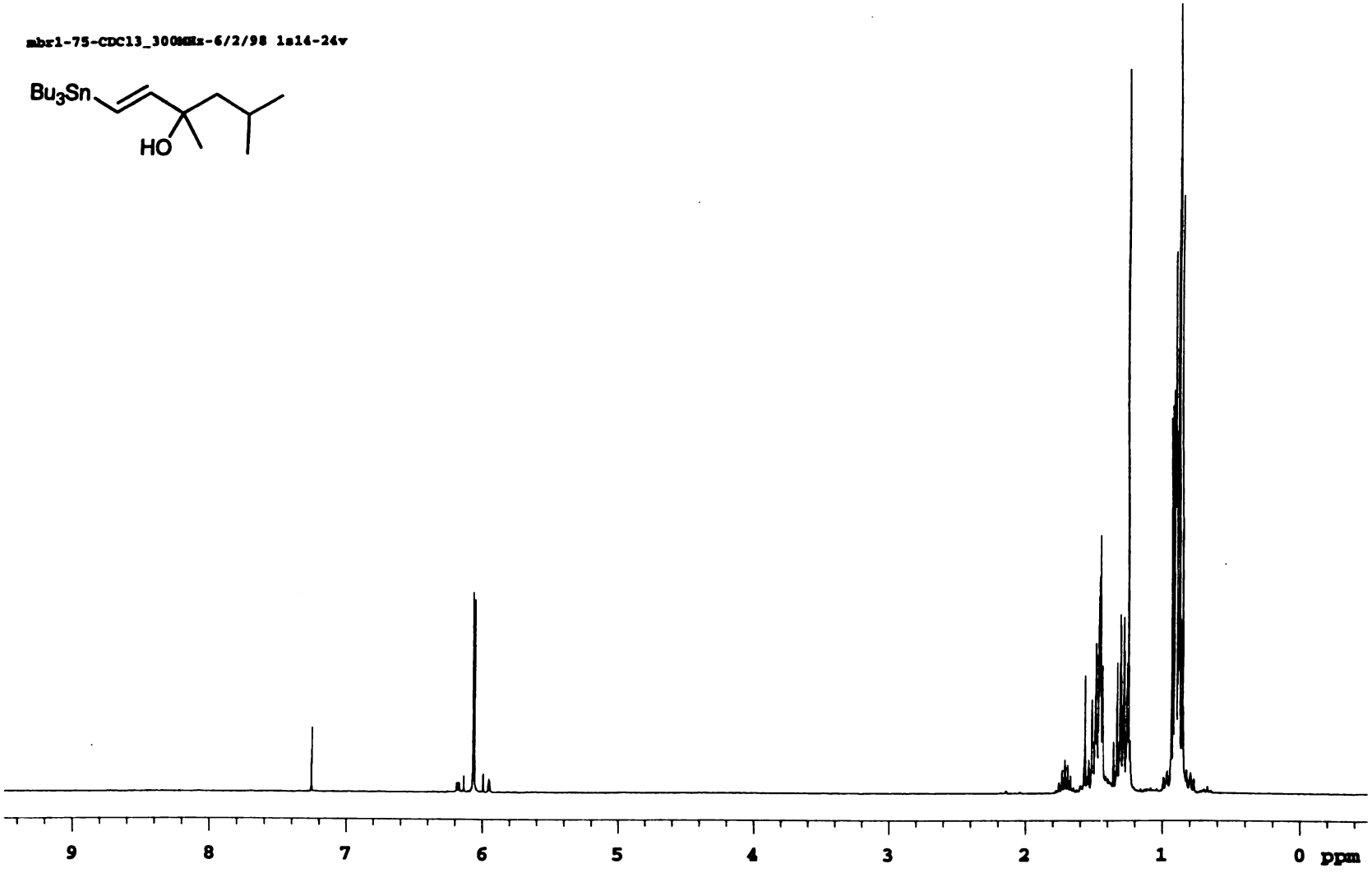
Nicolet Instrument Corporation

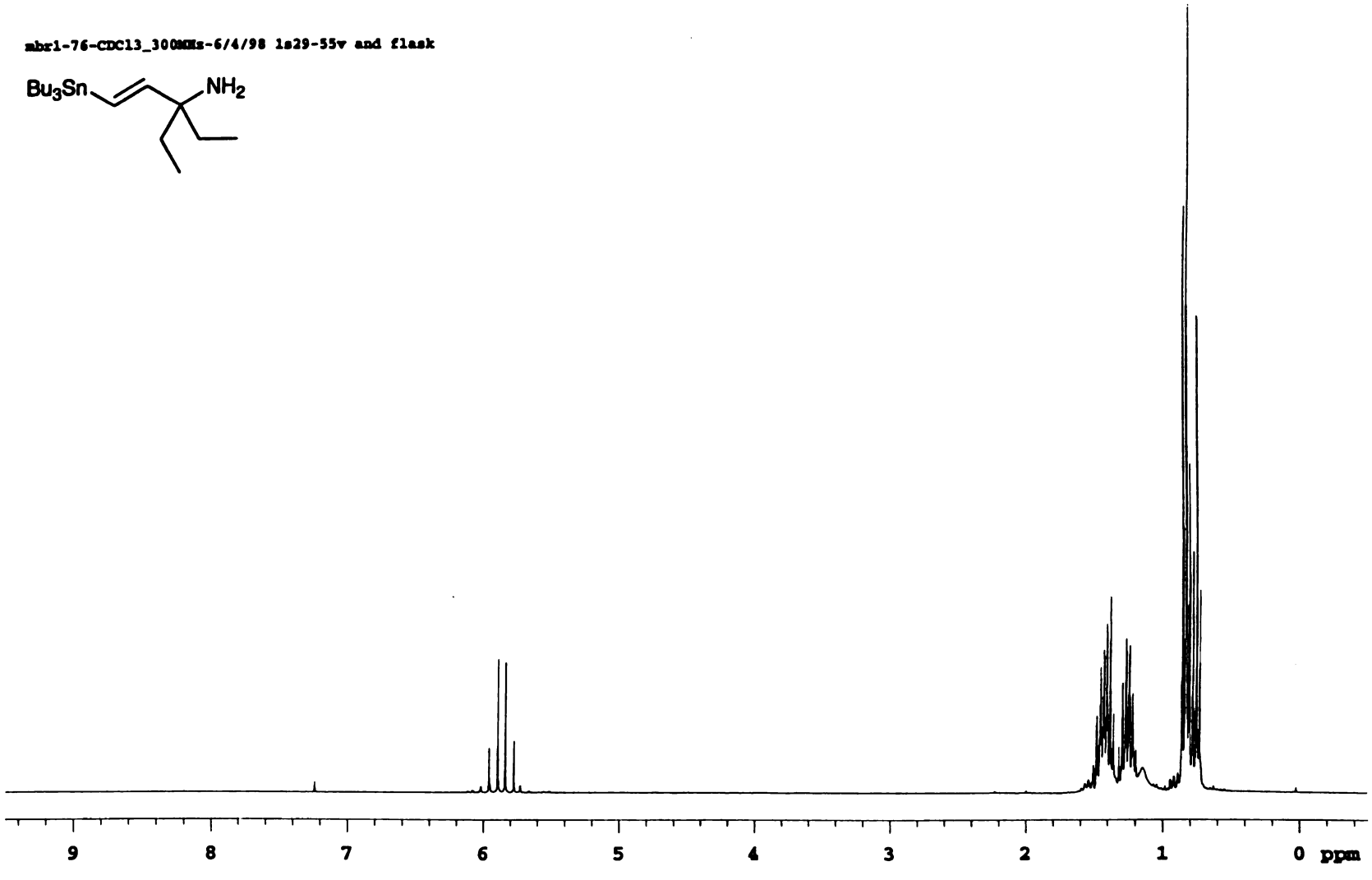
mbr1-52

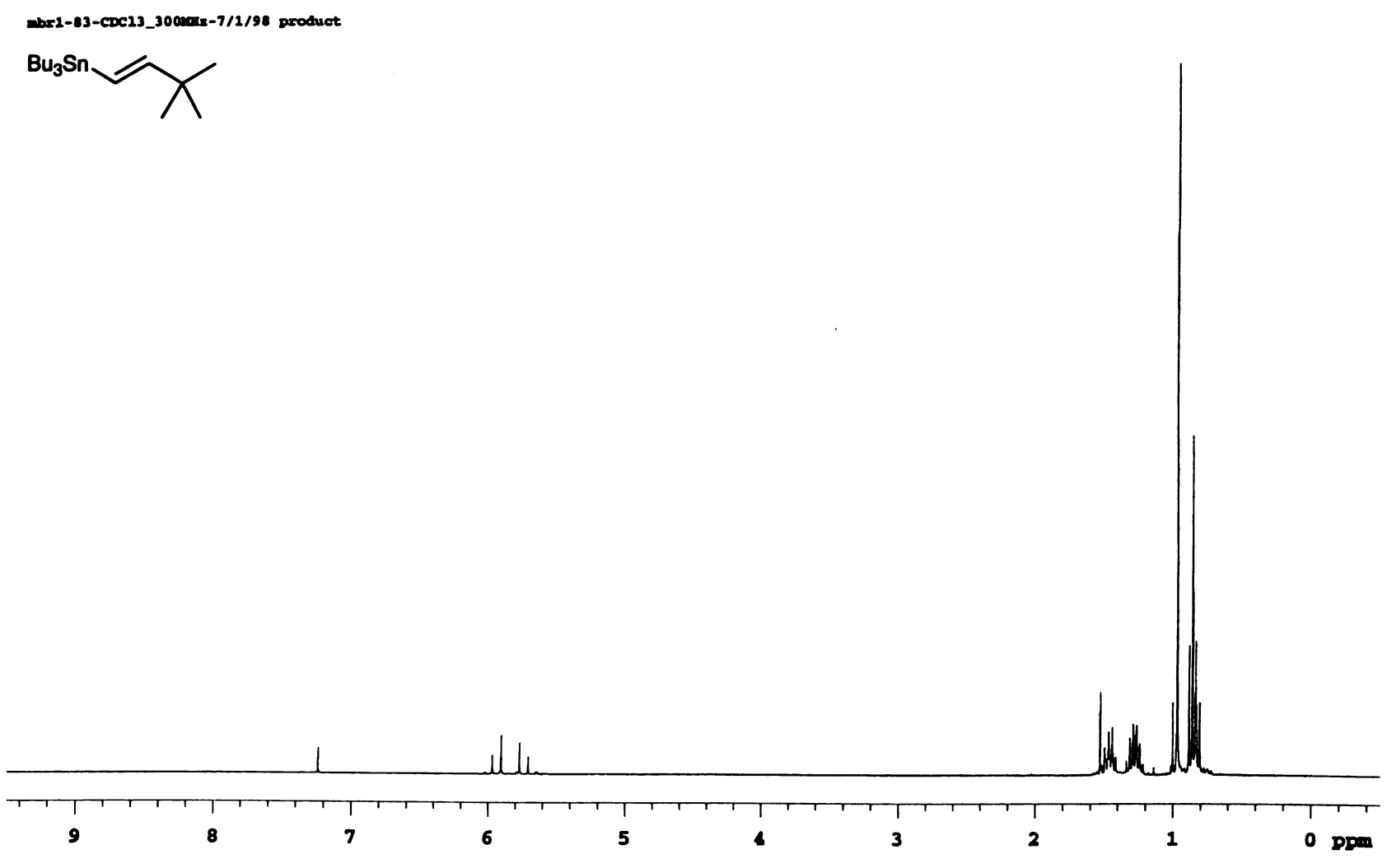
SCANS: 32 RES: 4.0 TIME: 05/31/99 19:38:02


mbr1-36-CDCl3_300MHz-8/6/97 2s E,Z
Bu3Sn
O
O
Bu3Sn
O
O
9
8
7
6
5
4
3
2
1
0
ppm

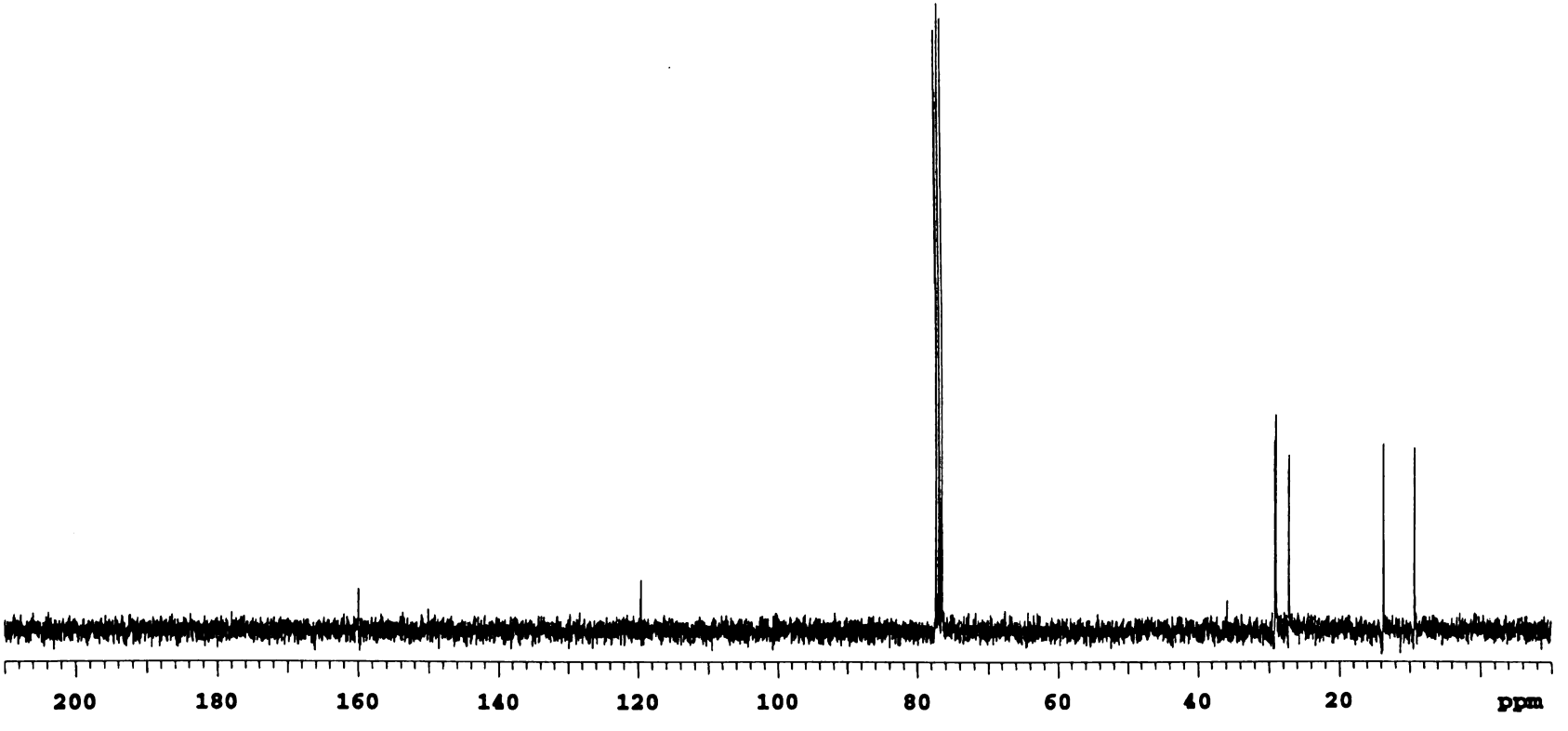

mbr1-36
200
180
160
140
120
100
80
60
40
20
0 ppm

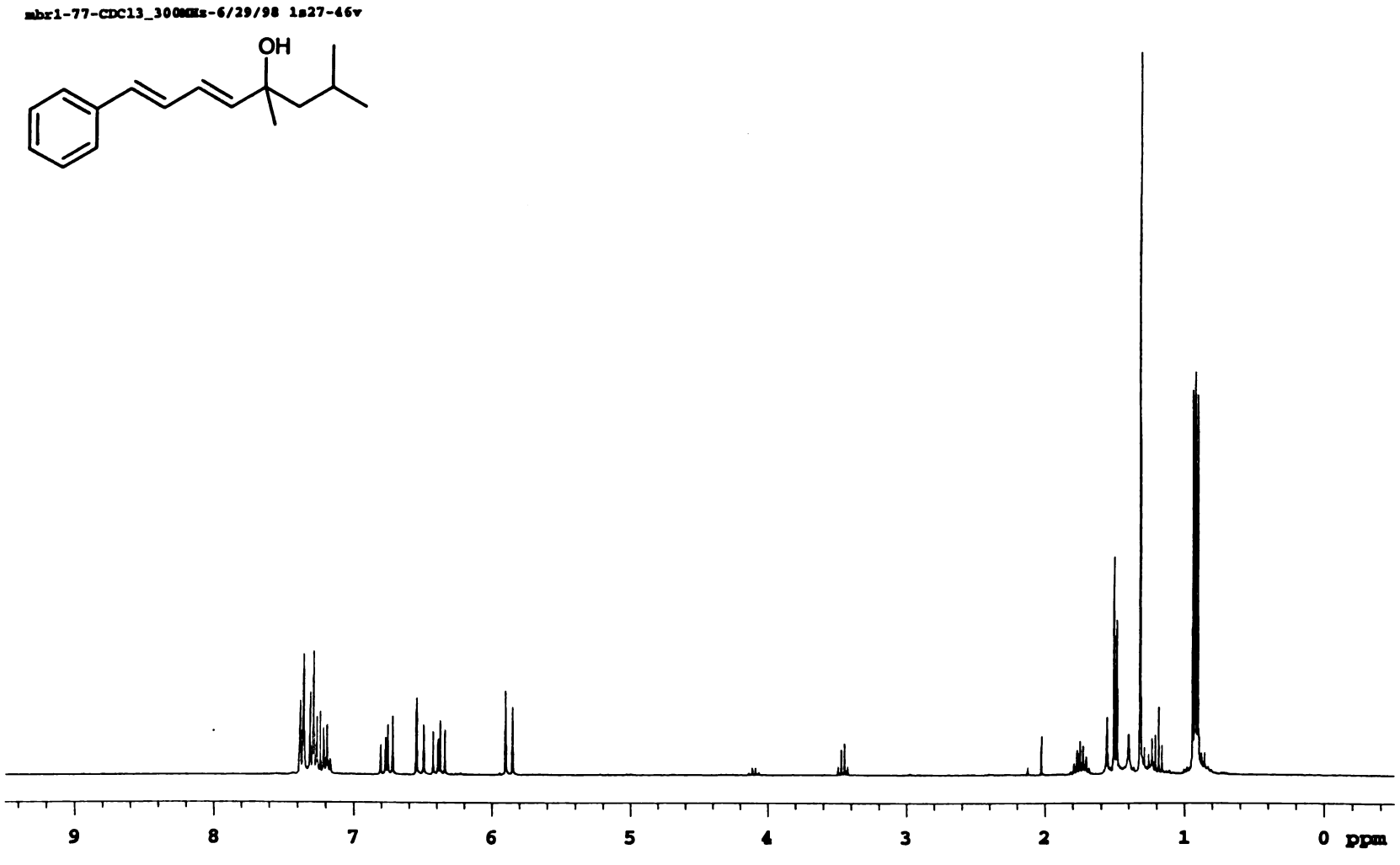

mbr1-75-CDCl3_300MHz-6/2/98 1s14-24v
Bu3Sn
HO
9
8
7
6
5
4
3
2
1
0
ppm

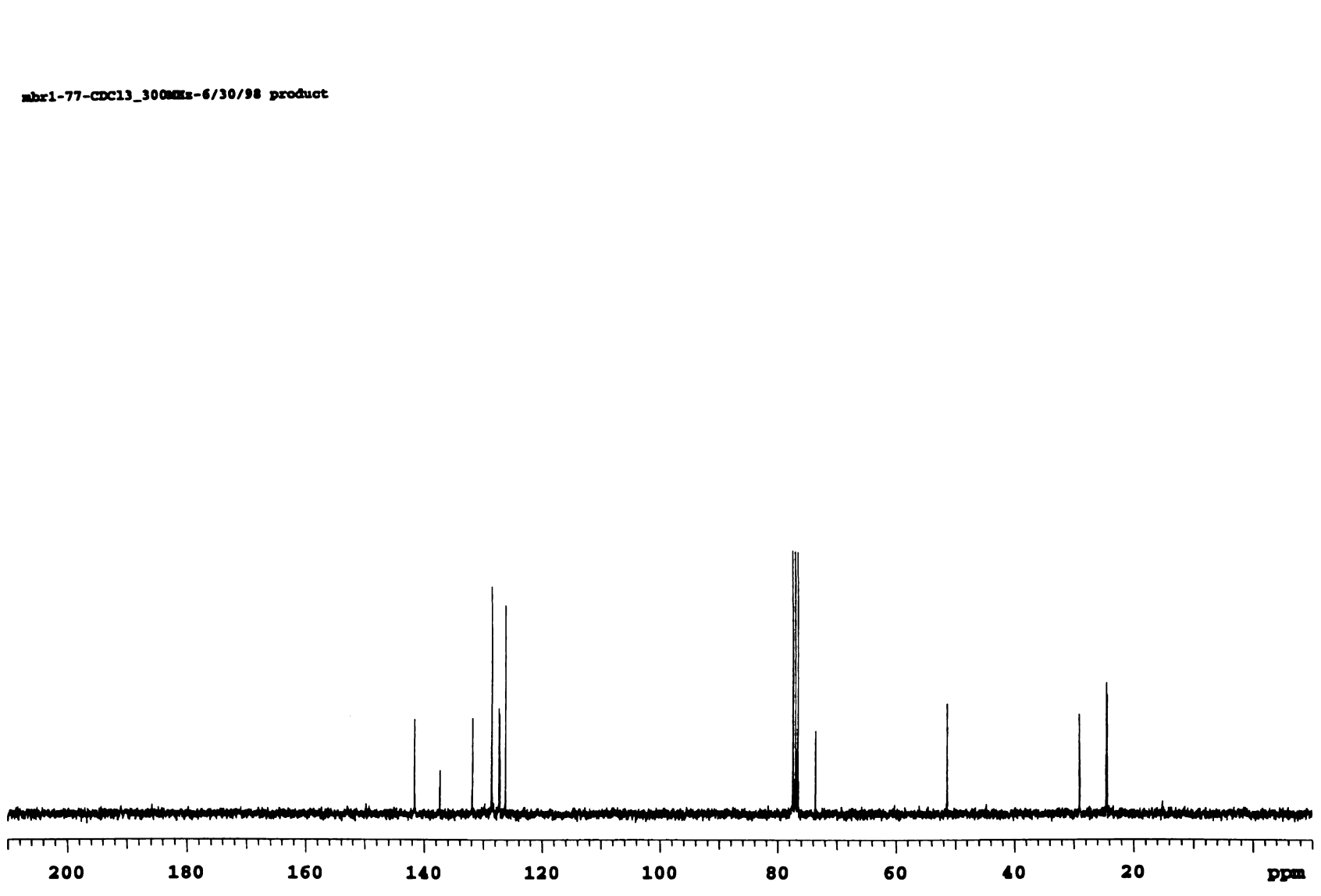

mbr1-76-CDCl3_300MHz-6/4/98 1s29-55v and flask
Bu3Sn
NH2
9
8
7
6
5
4
3
2
1
0
ppm

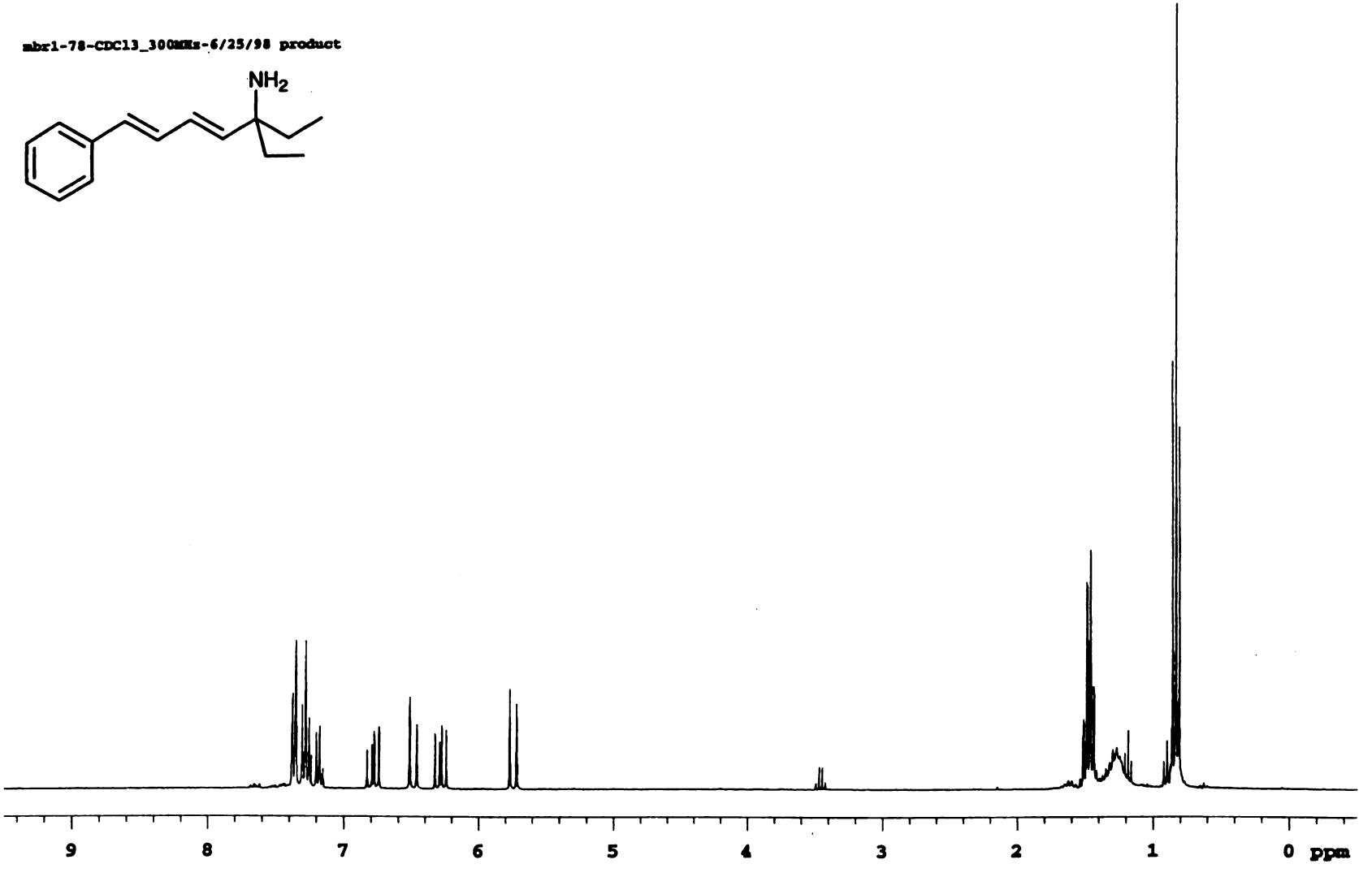

mbr1-83-CDCl3_300MHz-7/1/98 product
Bu3Sn
9
8
7
6
5
4
3
2
1
0 ppm

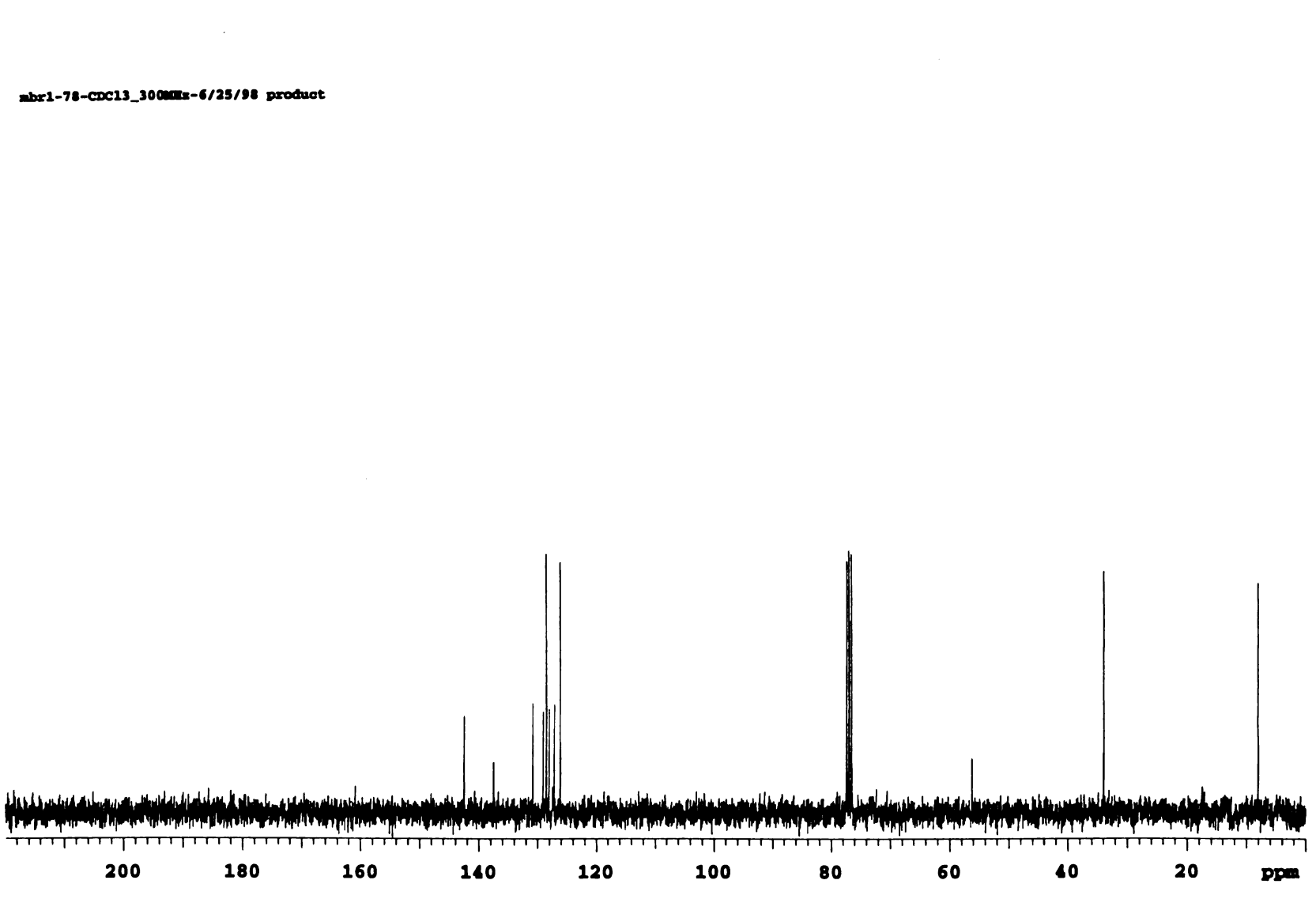
mbr1-83-CDCl3

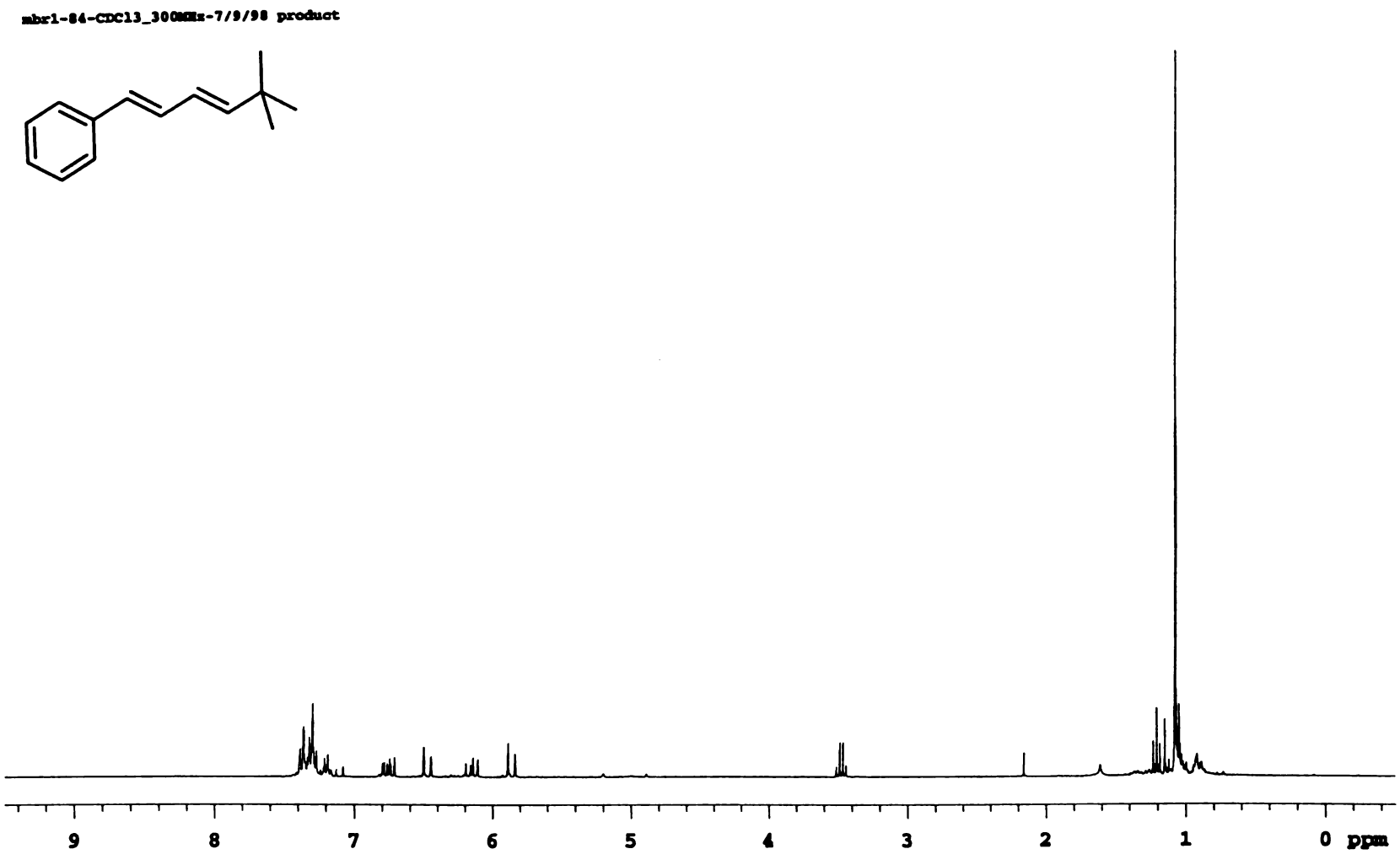



mbr1-77-CDCl3_300MHz-6/29/98 1s27-46v
OH
9
8
7
6
5
4
3
2
1
0
ppm

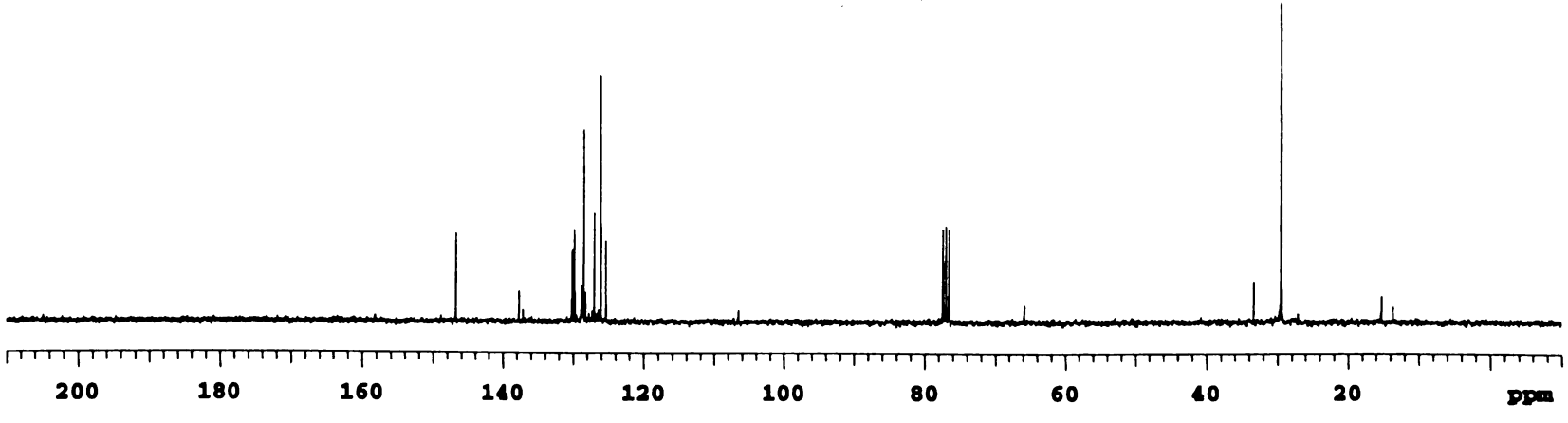

mbr1-77-CDCl3_300MHz-6/30/98 product
200
180
160
140
120
100
80
60
40
20
ppm


mbr1-78-CDCl3_300MHz-6/25/98 product
NH2
9
8
7
6
5
4
3
2
1
0
ppm


mbr1-78-CDCl3_300MHz-6/25/98 product
200
180
160
140
120
100
80
60
40
20
ppm


mbr1-84-CDCl3_300MHz-7/9/98 product
9
8
7
6
5
4
3
2
1
0
ppm

mbr1-84-CDCl3_300MHz-7/9/98 product



BIBLIOGRAPHY

1. Ichinose, Y.; Oda, H.; Oshima, K.; Utimoto, K. *Bull. Chem. Soc. Jpn.* **1988**, *60*, 3468.
2. Trost, B. M.; Li, C. *Synthesis* **1994**, 1267.
3. Betzer, J.; Delaloge, F.; Muller, B.; Pancrazi, A.; Prunet, J. *J. Org. Chem.* **1997**, *62*, 7768.
4. Guibé, F.; Zhang, H. *J. Org. Chem.* **1990**, *55*, 1857.
5. Kikukawa, K.; Umekawa, H.; Wada, F.; Matsuda, T. *Chem. Lett.* **1988**, 881.
6. Tostikov, G.; Miftakhov, M.; Danilova, N. *J. Org. Chem. USSR* **1983**, 1577.
7. Rossi, R.; Carpita, A.; Cossi, P. *Synth. Commun.* **1993**, *23*, 143.
8. Cochran, J.; Bronk, B.; Terrence, K.; Phillips, H. *Tetrahedron Lett.* **1990**, *31*, 6621.
9. Casaschi, A.; Grigg, R.; Sansano, J.; Wilson, D.; Redpath, J. *Tetrahedron Lett.* **1996**, *37*, 4413.
10. Cochran, J.; Terrence, K.; Phillips, H. *Organometallics* **1991**, *10*, 2411.
11. Miyake, H.; Yamamura, K. *Chem. Lett.* **1989**, 981.
12. Leusink, A; Budding, H.; Marsman, J. *J. Organometal. Chem.* **1967**, *9*, 285.
13. Leusink, A; Budding, H.; Drenth, W. *J. Organometal. Chem.* **1967**, *9*,, 295.
14. Leusink, A; Budding, H.; Drenth, W. *J. Organometal. Chem.* **1968**, *ii*,, 541.
15. Jung, M.; Light, L. *Tetrahedron Lett.* **1982**, *23*, 3851.
16. Nativi, C.; Taddei, M. *J. Org. Chem.* **1988**, *53*, 820.
17. Lee, E.; Chang, U.; park, C. *Tetrahedron Lett.* **1990**, *31*, 5039.
18. Lee, E.; Chang, U. *Tetrahedron Lett.* **1991**, *32*, 5101.
19. Stille, J. K. *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 508-525.
20. Harirchian B.; Magnus P. *J. C. Chem. Comm.* **1977**, 522.
21. Barluenga J.; Canteli R.; Florez J. *J. Org. Chem.* **1994**, *59*, 1586.
22. Oehlschlager, A; Sunaina S. *J. Org. Chem.* **1989**, *54*, 5064.
23. Stille, J. K. *J. Am. Chem. Soc.* **1987**, *109*, 813-817.
24. Stille, J. K.; Simpson, J. H. *J. Am. Chem. Soc.* **1987**, *109*, 2138-2152
25. Farina, V.; Krishnamurthy, V.; Scott, W. *Organic Reactions* **1997**, *50*, 1-652.
26. Hitchcock, S.; Mayhugh, D.; Gregory, G. *Tetrahedron Lett.* **1995**, *36*, 9085-9088.
27. Boden, C.; Pattenden, G.; Ye, T. *J. Chem. Soc., Perkin Trans. 1* **1996**, 2417-2419.
28. Zhang, H.; Guibe, F.; Balavoine, G. *Tetrahedron Lett.* **1988**, *29*, 619 - 626.
29. Taniguchi, M.; Takeyama, Y.; Fugami, K.; Oshima, K.; Utimoto, K. *Bull. Chem. Soc. Jpn.* **1991**, *64*, 2593-2595.
30. Baillargeon, V.P.; Stille, J. K. *J. Am. Chem. Soc.* **1986**, *108*, 452-461.
31. Smith III, A.; Condon, S.; McCauley, J.; Leazer, Jr. J.; Leahy, J.; Maleczka, Jr. R. *J. Am. Chem. Soc.* **1997**, *119*, 962.
32. Jackson, R.; Perlmutter P.; Smallridge A. *Aust. J. Chem.* **1988**, *41*, 251.
33. Tellier, F.; Descoins, C.; *Tetrahedron Lett.* **1990**, *31*, 2295.
34. Blaskovich, M.; Kahn, M. *J. Org. Chem.* **1998**, *63*, 1119.

35. Dyker, G *Chem. Ber. Recueil* **1997**, *130*, 1567-1578.
36. Maleczka, Jr. R.; Terstiege, I *J. Org. Chem.* **1998**, *63*, 9622-9623.