Application of Helium Microwave-Induced Plasma Emission Detection System to Analysis of Organotin Compounds in Biological Samples

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The potential of the gas chromatography/helium atmospheric pressure microwave-induced plasma/atomic emission detection system (GC/MIP/AED) for analysis of organotin compounds in biological samples was studied. After purifications, the extracted organotin compounds were treated with methylmagnesium bromide, and the resulting tetraalkylated organotin compounds were specified and quantified by GC/MIP/AED. The system proved to be very effective for the speciation and determination of organotin compounds even in high matrix samples such as marine products. The analytical results of an oyster sample by GC/MIP/AED showed the presence of 12 organotin compounds and agreed well with those determined by gas chromatography/mass spectrometry/selective ion monitoring (GC/MS/SIM). Furthermore, the sensitivities by GC/MIP/AED were revealed to be superior to those by GC/MS/SIM. It was also clarified that this method is applicable not only to marine products but also to biological materials of animal origin such as rat liver, blood, and urine.

INTRODUCTION

Organotin compounds have been used as biocides for boat paints or fishing nets, and their increasing annual use raises the probability of environmental pollution (Mueller, 1984; Maguire and Tkacz, 1985; Takami et al., 1987; Ishizaka et al., 1989a,b).

In previous papers we identified the modified chemical forms of tri-*n*-butyltin compounds in marine products and rats administered tri-*n*-butyltin chloride (Suzuki et al., 1992; Matsuda et al., 1993). For the analysis of these compounds, gas–liquid chromatography/mass spectrometry/selective ion monitoring (GC/MS/SIM) and gas–liquid chromatography/flame photometric detector (GC/FPD) have been used.

Meanwhile, the gas chromatography/helium atmospheric pressure microwave-induced plasma/atomic emission detection system (GC/MIP/AED) recently appeared on the market and has been used for organotin analysis because of its high sensitivity and unique ability to provide information on molecular elemental composition (Scott et al., 1991; Ting and Kho, 1991; Łobiński et al., 1992).

The present paper describes the application of GC/MIP/AED to the analysis of organotin compounds in biological samples such as marine products or animal organs, which extracts are usually rich in organic materials.

MATERIALS AND METHODS

GC/MIP/AED. An HP Model 5890 Series II gas chromatograph (Hewlett-Packard, Avondale, PA) equipped with a split/splitless injection port interfaced to an HP Model 5921A atomic emission detector equipped with a turbo makeup gas valve was used. Two capillary columns were used: a cross-linked methyl silicone (HP-1) [Hewlett-Packard; 0.32 mm (i.d.) × 25 m × 0.17 μm (film thickness)] and a cross-linked 5% phenyl methyl silicone (DB-5) [J&W Scientific, Folsom, CA; 0.25 mm (i.d.) × 30 m × 0.25 μm (film thickness)]. Operating conditions were as follows for the HP-1: column oven, programmed from 35 °C (hold 2 min) at the rate of 30 °C/min to 200 °C (hold 0 min), followed by the rate of 15 °C/min to 250 °C (hold 0 min); injection port (splitless), 250 °C; AED solvent vent off time, 3 min; AED cavity temperature, 280 °C; AED cavity pressure, 1.5 psi; AED cavity scavenger gases, 3.5 kg/cm² (H_2), 1.4 kg/cm² (O_2); AED spectrometer purge flow (N_2), 2 L/min; wavelengths for measurement, 303.319 or 270.651 nm. Operating conditions were as follows for the DB-5: column oven, programmed from 35 °C (hold 2 min) at the rate of 30 °C/min to 200 °C (hold 0 min), followed by the rate of 15 °C/min to 280 °C (hold 1 min); AED solvent vent off time, 4 min; other conditions were the same with those of HP-1. The gas flow rates (head pressure) for He carrier gas were 145 (HP-1) and 173 kPa (DB-5). Quantitative determination was performed by the external standards method.

Table 1. Standards and Abbreviations

standard	abbrev
n-butyltin trichloride	MBTC
di-*n*-butyltin dichloride	DBTC
n-butyl(3-hydroxybutyl)tin dichloride	D3OH
n-butyl(3-oxobutyl)tin dichloride	D3CO
tri-n-butyltin chloride	TBTC
n-butyl(4-hydroxybutyl)tin dichloride	D4OH
n-butyl(3-carboxypropyl)tin dichloride	DCOOH
di-*n*-butyl(3-hydroxybutyl)tin chloride	T3OH
di-*n*-butyl(3-oxybutyl)tin chloride	T3CO
diphenyltin dichloride	DPTC
di-*n*-butyl(4-hydroxybutyl)tin chloride	T4OH
di-*n*-butyl(3-carboxypropyl)tin chloride	TCOOH
triphenyltin chloride	TPTC

Authentic Standards. All standards were purchased or prepared according to the papers (Fish et al., 1976; Ishizaka et al., 1989a,b; Suzuki et al., 1992). The chemical names and their abbreviations are shown in Table 1. Standard solutions for calibration were prepared according to the previous paper (Suzuki et al., 1992) (*Caution*: Organotin compounds are harmful, irritating to skin, and readily absorbed through skin. Avoid skin contact!).

GC/MS/SIM. GC/MS/SIM was measured by an HP 5917A (Hewlett-Packard) in the electron impact mode at an ionization voltage of 70 eV. The column was a cross-linked methylsilicone [Hewlett-Packard; 0.2 mm (i.d.) × 12 m × 0.3 μm (film thickness)]. Operating temperatures were as follows: column oven, programmed from 35 °C (hold 2 min) at the rate of 30 °C/min to 200 °C (hold 0 min), followed by the rate of 15 °C/min to 250 °C (hold 10 min); injection port, 250 °C; radiator temperature, 185 °C; mass filter, 150 °C. The gas flow rate for He carrier gas was 20 kPa (head pressure). Quantitative measurement was carried out using *m/z* 165 for MBTC, *m/z* 205 for DBTC, *m/z* 223 for

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D3OH, m/z 217 for D3CO, m/z 193 for TBTC, m/z 223 for D4OH, m/z 233 for DCOOH, m/z 265 for T3OH, m/z 209 for T3CO, m/z 289 for DPTC, m/z 265 for T4OH, m/z 275 for TCOOH, and m/z 351 for TPTC. Quantitative determination was performed by the external standards method. Details are described in the previous paper (Suzuki et al., 1992).

Treatment of Animals. Wistar rats (male, 9 weeks old) were housed at 23.0 ± 2 °C and 50% relative humidity. TBTC was dissolved in soybean oil and orally administered at a dose of 2 mg/kg after 12 h of fasting. The rats were housed in metabolic cages and given access to food and water ad libitum and sacrificed by decapitation 48 h after the administration. Liver and blood were excised or collected and frozen until used. Urine was collected for every 24-h period.

Sample Preparation. *Marine Products.* A dab fish was purchased whole in a retail store in the Tokyo metropolitan area (April 1991), and organs were separated before freezing. An oyster sample was collected in the Sagami bay (September 1991) and frozen until sample preparation. After addition of 0.9% saline (10 mL) to the marine product (5 g) in a 50-mL centrifuge tube with a screw cap, the mixture was homogenized with a Biotron (Biotrona 6403, Küssnacht, SZ). Hydrochloric acid (HCl) (36%, 12 mL) was added to the homogenate, and the mixture was shaken vigorously and allowed to stand for 10 min. After the addition of ether (Et_2O, 20 mL) and NaCl (2 g), the mixture was shaken for 10 min on a KM shaker (Iwaki Co., Ltd.), followed by centrifugation at 3000 rpm for 5 min. This extraction procedure was repeated twice. The supernatant extract was dried over anhydrous sodium sulfate (Na_2SO_4) and evaporated in vacuo, and the residue was dissolved in *n*-hexane (20 mL) saturated with acetonitrile (MeCN). The solution was transferred to a 50-mL centrifuge tube with a screw cap on it, to which MeCN (20 mL) saturated with *n*-hexane was added, and the mixture was shaken vigorously and centrifuged. The underlayer (MeCN layer) was removed by pipetting with a Pasteur pipet. This extraction from the *n*-hexane layer by MeCN (20 mL) saturated with *n*-hexane was repeated once more. The remaining *n*-hexane layer was concentrated to dryness in vacuo below 35 °C, and the residue was dissolved in a small volume of Et_2O and the organic solution was applied to a column (1 cm i.d.) prepared from a slurry of Florisil (Floridin Co., Hancock, WV; 3 g) and Et_2O (50 mL). The column was washed with Et_2O (40 mL) and then eluted with acetic acid (AcOH)–Et_2O (1:99 v/v; 40 mL), which was evaporated under reduced pressure at 35 °C. Complete removal of AcOH is facilitated by the addition of a small amount of *n*-hexane to the residue. This residue was combined with the MeCN extract described above, the mixture was concentrated in vacuo to near dryness, and the final volume of solvent was removed under an N_2 atmosphere. The residue was dissolved in a small volume of *n*-hexane–ethyl acetate (EtOAc) (2:1 v/v), and the resulting solution was transferred to a 1 cm i.d. chromatographic column containing 5 g of HCl-treated silica gel (Wakogel C-100) (Hattori et al., 1984), prepared with *n*-hexane, with 1 cm of anhydrous Na_2SO_4 on the top. The column was eluted with a mixture of *n*-hexane–EtOAc (2:1 v/v; 50 mL). The eluate was evaporated in vacuo, and the residue was dissolved in Et_2O (5 mL) and transferred into a screw-capped centrifuge tube (50 mL). Methylmagnesium bromide (MeMgBr) (Tokyo Kasei Kogyo) (ca. 3 M in Et_2O, 4 mL) (*Caution*: MeMgBr/Et_2O is a corrosive and flammable liquid and reacts violently with water.) was added carefully to the solution described above, mixed gently, screw-capped, and then allowed to stand for 1 h in a water bath at 40 °C. A 2-mL portion of Et_2O and 10 mL of water were then added drop by drop to the solution in an ice bath until violet bubbling ceased after addition of water (1–2 mL). After gentle mixing, anhydrous Na_2SO_3 (0.2 g) and saturated NH_4Cl (6 mL) were added to the solution, and then it was shaken vigorously. This reaction mixture was extracted twice with *n*-hexane (6 mL), and the combined *n*-hexane extract was dried over anhydrous Na_2SO_4 and then concentrated exactly to 2 mL.

Animal Sample. (*1*) *Organs.* Excised liver (4 g) from rat was extracted in the same way as marine product samples. The Et_2O extract was evaporated in vacuo, and the residue was dissolved in *n*-hexane–EtOAc (2:1 v/v; 5 mL). The solution was submitted to HCl-treated silica gel column chromatography in the same way as marine product sample without partitioning between MeCN and *n*-hexane, and then the residue obtained was alkylated with MeMgBr (2 mL). The reaction mixture was treated in the same way as marine product samples described above to give a sample solution (5 mL). Details are given in the previous paper (Matsuda et al., 1993).

(*2*) *Blood.* HCl (20 mL) was added to blood (about 5 mL), and the mixture was diluted with distilled water to 50 mL, extracted with Et_2O (40mL) and NaCl (5g) by mechanical shaking for 5 min, and then centrifuged for 5 min at 3000 rpm. This extraction procedure was repeated twice. The combined Et_2O extracts were washed with 4 N HCl (50 mL) containing NaCl (5 g) and evaporated in vacuo. The residue was dissolved in methanol (0.5 mL), and then a mixture of *n*-hexane–EtOAc (2:1, 4.5 mL) was added. This mixture was transferred to a 1 cm i.d. chromatographic column containing HCl-treated silica gel (Wakogel C-100, 5 g) with 1 cm of anhydrous Na_2SO_4 on the top and treated in the same way as described above for animal organs to give a sample solution (2 mL).

(*3*) *Urine.* Urine (5 mL) was diluted with water to 30 mL, and HCl (50 mL) was carefully added. The mixture was mixed thoroughly and allowed to stand for 5 min. The mixture was shaken with Et_2O (40 mL) and NaCl (5 g), followed by centrifugation for 5 min at 3000 rpm at 0 °C. This extraction procedure was repeated twice. The combined Et_2O extracts were evaporated in vacuo and treated in the same way as animal organs to give a sample solution (5 mL).

Results of recovery test by these sample preparation methods were already reported in the previous paper (Matsuda et al., 1993).

RESULTS AND DISCUSSION

Optimization of GC/MIP/AED Conditions. *Wavelength.* The commercially available instrument allows for the measurement of tin emission signal at two wavelengths: 270.651 (channel 271) and 303.419 nm (channel 303). Łobiński et al. (1992) reported that both channels have the same sensitivity, but datails are not clear. So their applicabilities were examined. Figure 1 shows the chromatograms of dab flesh sample on HP-1 using channels 303 (Figure 1A) and 271 (Figure 1B) when the same amount of extract was injected. Each peak was assigned to the authentic standard shown on the respective figures, depending on their RTs (their formal names and the abbreviations are shown in Table 1). There were no big differences in sensitivity (data not shown) or in interfering peaks due to the matrices between the two channels; channel 303 was arbitrarily selected for further experiments.

Solvent Vent Off Time. The times required for solvent vent on, which allows the solvent used to escape through a vent tube and protect the discharge tube from deposition of carbon derived from the solvent, were made 3 and 4 min for the HP-1 and DB-5 columns, respectively, on the basis of the ending time for elution of *n*-hexane and the RTs of the methylated product of MBTC (5.066 min on DB-5; 3.567 min on HP-1), which showed the shortest RTs on the gas chromatograms.

Makeup Gas Flow Rate and Cavity-Oxygen and -Hydrogen Pressures. Łobiński et al. (1992) reported that oxygen and hydrogen gases were necessary as reagent gases for analysis of tin compounds by GC/MIP/AED, because oxygen prevents carbon deposition derived from hydrocarbon in the discharge tube and hydrogen compensates for the formation of tin oxide by the presence of oxygen. Following a detailed re-examination of the conditions described by Łobiński et al. (1992), their conditions were found to be appropriate and no modification was made.

Sample Injection. When the standards were injected into the gas chromatograph, the peak responses were sometimes low for several compounds. However, their responses were greatly improved when a fish extract was

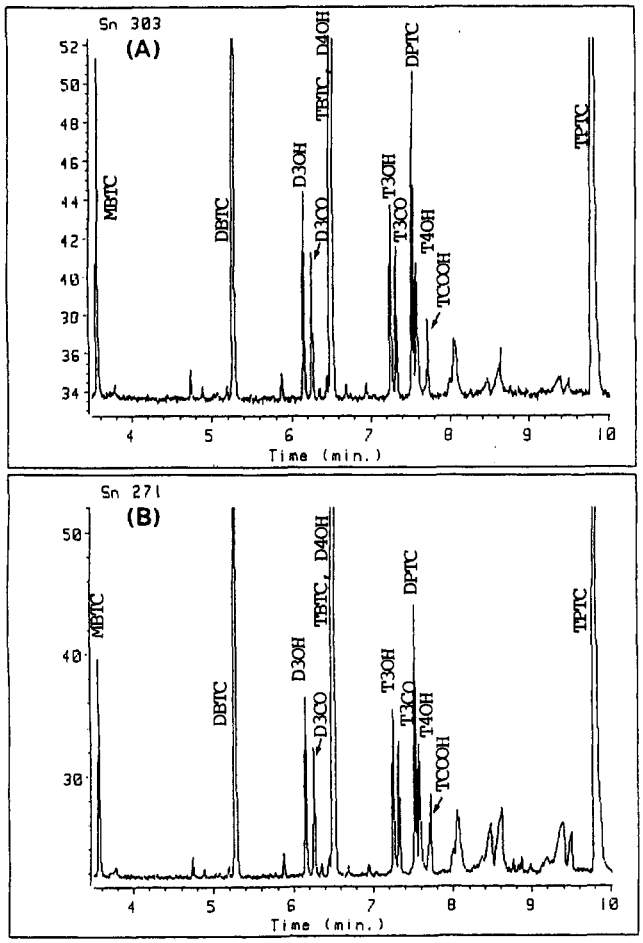

Figure 1. GC/MIP/AED chromatograms of alkylated dab flesh extract: (A) channel 303; (B) channel 271.

injected preceding the injection of the standard mixture. Therefore, to obtain a calibration curve, the sample to be analyzed was always injected prior to the injection of standards. These kinds of phenomena, which are called matrix effects, are explained by the interaction of the compounds with the active sites of the column. These effects have often been observed in the gas chromatography of pesticides which are polar and heat labile (Lafuente and Tadeo, 1987).

Dynamic Ranges, Calibration Curves, and Detection Limits. Dynamic ranges were obtained over 2.0–62.5 pg for MBTC, DBTC, and TBTC, 3.9–62.5 pg for DPTC, 7.8–125 pg for DCOOH and TCOOH, and 3.9–125 pg for the other compounds (as chloride) (Table 2). However, these ranges are appreciably narrower than those reported by Łobiński et al. (1992): 0.1–100 pg as tin. The absolute detection limits calculated as 3 times the standard deviation of the noise were from 0.15 to 1.37 pg according to the chemical structures in the peak height mode, as shown in Table 2. Organotin compounds that had intact alkyl groups or aryl groups such as MBTC, DBTC, TBTC, DPTC, and TPTC showed relatively high sensitivity, probably due to the characteristics of the compounds to the columns used. Generally it is known that all of the compounds respond similarly in plasma, irrespective of their structure. But Huang et al. (1990) and Łobiński et al. (1992) have stated that this is not strictly correct and that the response depends on the molecular structure. In addition to this, the interaction of the compound with the column used is also an important factor. This means care must be taken in the selection of an internal standard and in the elemental analysis by GC/MIP/AED.

Table 2. Analytical Figures of Merit for the Calibration Curves: $y = A + Bx$ for Organotin Compounds

compd	dynamic range (pg)	min det amount[a] (pg)	A intercept	B slope	correl coeff	column
MBTC	2.0–62.5	0.37	1.652	0.8188	0.9989	DB-5
DBTC	2.0–62.5	0.15	3.003	1.440	0.9992	DB-5
D3OH	3.9–125	0.37	5.982	0.4788	0.9989	DB-5
D3CO	3.9–125	0.38	6.708	0.5082	0.9986	DB-5
TBTC	2.0–62.5	0.28	1.433	0.9432	0.9992	DB-5
D4OH	3.9–125	0.49	7.678	0.5391	0.9994	DB-5
DCOOH	7.8–125	1.37	1.714	0.2914	0.9998	DB-5
T3OH	3.9–125	0.34	9.603	0.5134	0.9995	DB-5
T3CO	3.9–125	0.41	8.492	0.4715	0.9997	DB-5
DPTC	3.9–62.5	0.22	5.234	0.7451	0.9972	HP-1
T4OH	3.9–125	0.42	3.225	0.3979	0.9998	DB-5
TCOOH	7.8–125	0.91	1.886	0.2585	0.9978	HP-1
TPTC	3.9–125	0.17	6.734	0.4142	0.9999	DB-5

[a] Calculated as 3 times the standard deviation of the noise levels of peak height.

Analysis of Biological Samples. Procedures for the speciation of tin in fish and rat organs have been recently developed in our laboratory. Briefly, they involve the extraction of organotin compounds from fish or rat organs into ether under acidic conditions with hydrochloric acid. The extracted organotin compounds were cleaned up by column chromatography with hydrochloric acid-treated silica gel for rat organ (Matsuda et al., 1993) or *n*-hexane–acetonitrile partitioning, followed by column chromatography with hydrochloric acid-treated silica gel, for marine products (Suzuki et al., 1992). After treatment with methylmagnesium bromide, the tetraalkylated organotin compounds were qualified or quantified by GC/FPD or GC/MS/SIM.

GC/FPD is relatively specific for tetraalkylated organotin compounds, but unfavorable peak tailings which are characteristic of organotin compounds have been observed. These tailings attributable to the structural factors of FPD (Maguire and Huneault, 1981) often make it difficult to separate contiguous peaks, especially when small peaks appeared immediately after large peaks, even if a capillary column is used. For the present study, the separation of DPTC, which is usually found in marine products, from contiguous TCOOH by GC/FPD was difficult even on HP-1, which showed the best separation among the columns examined (HP-1, DB-5, DB-17, DB-210, and DB-1701), because of the tailing property. Quenching was also observed in determination of low levels of tin compounds in fish samples (Suzuki et al., 1992). On the other hand, GC/MS/SIM could distinguish DPTC from TCOOH or D4OH from TBTC with a single column, but it has difficulty in providing an overview of the entire picture and is useful only after the organotin compounds have been specified.

To overcome the above-mentioned problems, GC/MIP/AED was examined using the same sample and the same preparation methods as the previous papers (Suzuki et al., 1992; Matsuda et al., 1993).

Table 3 shows the organotin compounds determined in an oyster sample, which was collected at the Sagami Bay in Japan, using GC/MIP/AED and GC/MS/SIM. A good coincidence was observed between the two measurements, but the sensitivities by GC/MIP/AED were superior to those by GC/MS/SIM. The chromatograms of the oyster sample by GC/MIP/AED are shown in Figure 2 (A, HP-1; B, DB-5). Each peak was assigned in comparison with RTs to the authentic standard. TBTC and D4OH overlapped each other on HP-1, but DPTC and TCOOH were separated from each other (Figure 2A). On the other

Table 3. Results[a] of the Determination of Organotin Compounds in Oyster by GC/MS/SIM and GC/AED

compd	GC/MS/SIM HP-1	GC/AED HP-1	GC/AED DB-5
MBTC	815 ± 42	767 ● 69	836 ± 36
DBTC	1060 ± 150	1150 ± 90	1210 ± 36
D3OH	202 ± 12	178 ● 9	168 ± 0
D3CO	22 ± 3	22 ● 2	17 ± 1
TBTC	2270 ● 210	–[b]	2380 ± 220
D4OH	39 ± 3	–	32 ± 2
DCOOH	38 ± 18	32 ● 2	42 ± 4
T3OH	14 ± 1	18 ± 4	19 ± 3
T3CO	33 ± 3	28 ± 1	21 ● 4
DPTC	63 ± 6	88 ± 2	–
T4OH	ND[c]	ND[d]	ND[d]
TCOOH	27 ± 2	26 ± 1	–
TPTC	456 ± 14	494 ● 11	463 ± 24

[a] Means of three experiments ± SD (ppb as chloride). [b] Not determined. [c] Not detected (<15 ppb). [d] Not detected (<2.5 ppb).

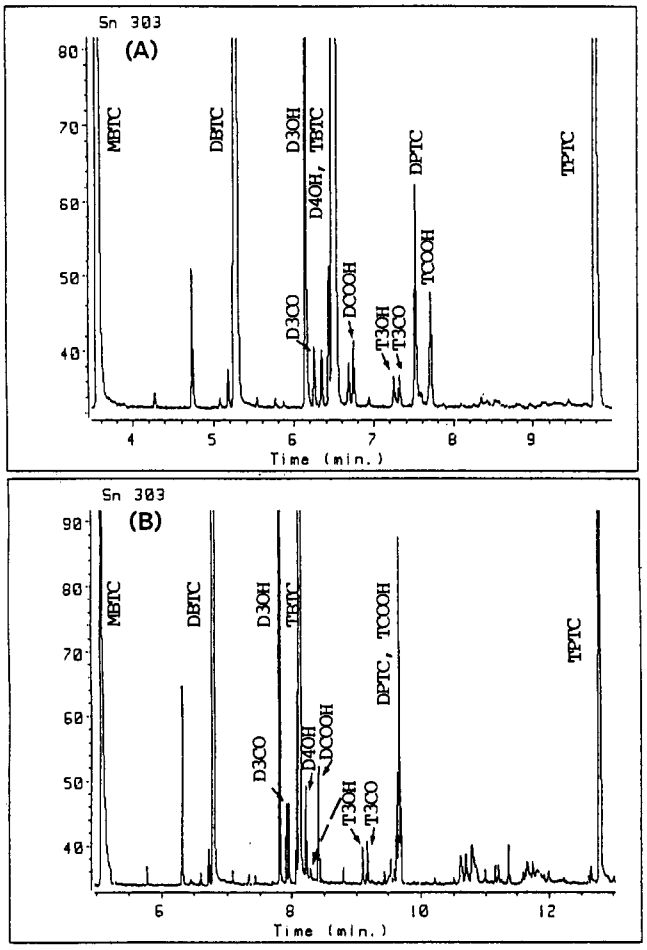

Figure 2. GC/MIP/AED chromatograms of an alkylated oyster extract on different columns: (A) HP-1; (B) DB-5.

hand, TBTC and D4OH were separated on DB-5, but DPTC and TCOOH were not (Figure 2B). Therefore, these two columns were used complementarily as shown in Table 3. The small peak indicated by a broken arrow (Figure 2B) was determined to be another product formed during the reaction of DCOOH with methylmagnesium bromide, because the same reaction product was obtained from the authentic DCOOH.

Figure 3 shows the GC/MIP/AED gas chromatogram of second-day liver extract of rats administered TBTC. The gas chromatogram by GC/FPD was already reported (Matsuda et al., 1993). Each peak was assigned in comparison with RTs to the methylated authentic standard. This clearly indicates that the main metabolite of

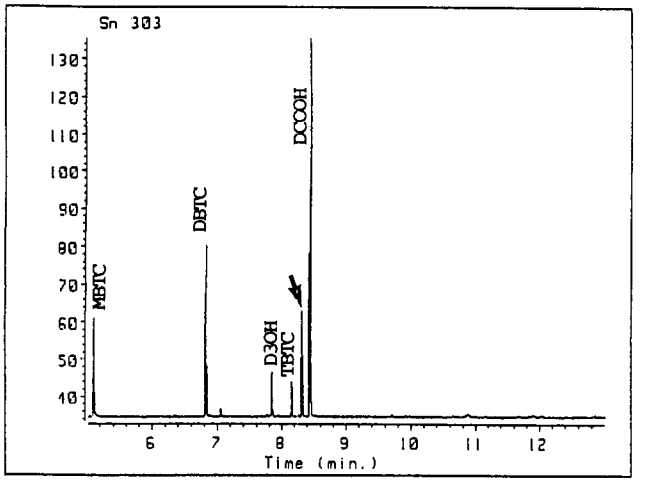

Figure 3. GC/MIP/AED chromatogram of alkylated liver extract obtained from rat administered tri-*n*-butyltin chloride (TBTC).

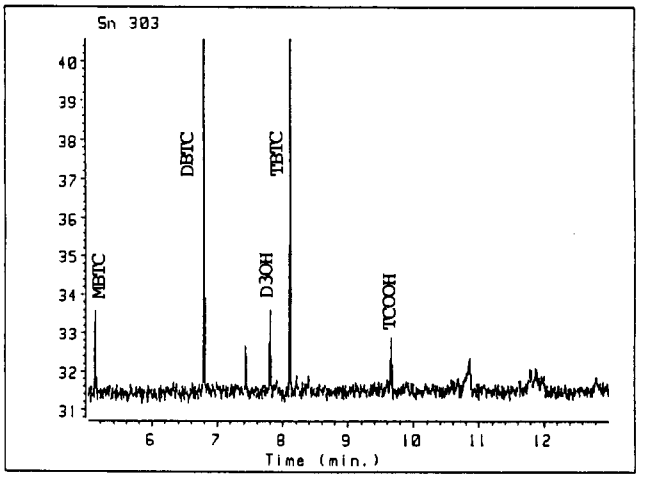

Figure 4. GC/MIP/AED chromatogram of alkylated blood extract obtained from rat administered tri-*n*-butyltin chloride (TBTC).

TBTC in rat liver is a carboxylic acid (DCOOH) oxygenated at the end of an alkyl group of DBTC and that there are no metabolites oxygenated or hydroxylated at an alkyl chain of TBTC, their presence being shown in rat liver microsomal metabolism of a tributyltin compound by Fish et al. (1976) and Kimmel et al. (1977). Only a small amount of TBTC administered was recovered. The peak observed adjacent to DCOOH (shown with an arrow) was considered to be a byproduct as already described above.

Figure 4 shows the chromatogram run on second-day blood collected from rats administered TBTC. Analysis by FPD/GC demonstrated the presence of MBTC, DBTC, and TBTC (Matsuda et al., 1993). However, the high sensitivity of GC/MIP/AED made it possible to detect two other products, D3OH and TCOOH, as shown in Figure 4, their levels being 3.5 ± 1.1 (n = 4) and 2.8 ± 1.0 (n = 4) ppb, respectively.

Figure 5 shows the chromatogram run of second-day urine extract of rats administered TBTC. Several peaks observed were assigned to MBTC, DBTC, D3OH, D3CO, TBTC, D4OH, and DCOOH, respectively, as shown in Figure 5. These metabolites were also determined previously (Matsuda et al., 1993). In addition to these metabolites, several other unknown peaks were reported. Analysis by GC/MIP/AED also showed the presence of at least nine unknown peaks (Figure 5). GC/MIP/AED incorporates a photodiode array coupled to a monochrometer that provides a very good selectivity for tin.

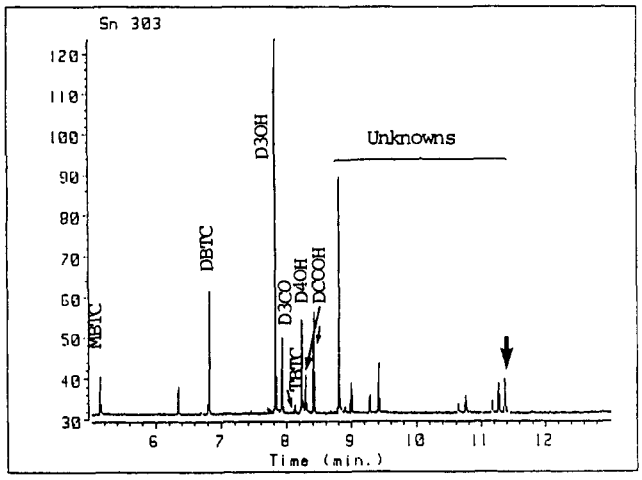

Figure 5. GC/MIP/AED chromatogram of alkylated urine extract obtained from rat administered tri-*n*-butyltin chloride (TBTC).

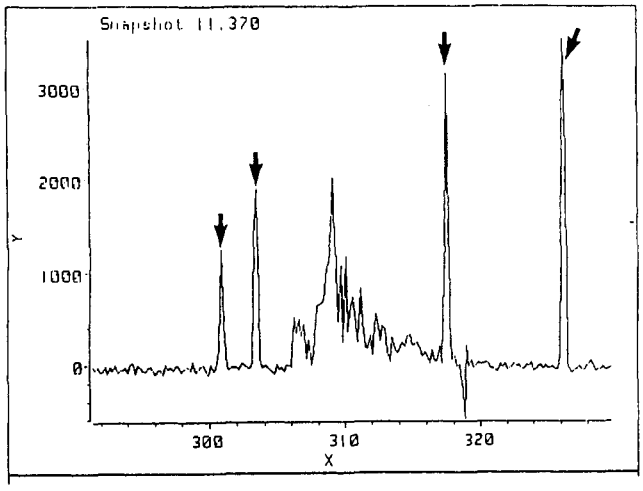

Figure 6. Snapshot at 11.370 min on GC/MIP/AED chromatogram of alkylated urine extract (Figure 5) obtained from rat administered tri-*n*-butyltin chloride (TBTC).

Thus, the characterization of the tin peak can be performed by taking the emission spectrum at the peak and comparing it with the tin emission pattern (Łobiński et al., 1992). Figure 6 shows the emission spectrum of one of the unknown peaks indicated by an arrow in Figure 5, which was measured in the 290–330-nm range after subtraction of helium background noise. The presence of lines at 300.914, 303.419, 317.505, and 326.234 nm clearly indicate that this peak derives from a tin compound. The other eight unknown peaks observed on the chromatogram were also characterized as organotin compounds by the presence of the characteristic four lines.

Conclusion. This paper deals with the application of the gas chromatography/helium atmospheric pressure microwave-induced plasma/atomic emission detection system for analysis of organotin compounds in biological samples. The system was shown to be very effective for the analysis of organotin species in the samples having high matrices such as fish organs, animal organs, and urine. It showed high separation potential due to no tailing, high specificity for tin, and high sensitivity. This made it possible to determine metabolites which were not separated or detected by GC/FPD and to overview the entire picture, which could not be done by GC/MS/SIM.

LITERATURE CITED

Fish, R. H.; Kimmel, E. C.; Casida, J. E. Bioorganotin Chemistry: Reactions of Tributyltin Derivatives with a Cytochrome P-450 Dependent Monooxygenase Enzyme System. *J. Organomet. Chem.* **1976**, *118*, 41–54.

Hattori, Y.; Kobayashi, A.; Takemoto, S.; Takami, K.; Kuge, Y.; Sugimae, A.; Nakamoto, M. Determination of Trialkyltin, Dialkyltin, and Triphenyltin Compounds in Environmental Water and Sediments. *J. Chromatogr.* **1984**, *315*, 341–349.

Huang, Y.; Ou, Q.; Yu, W. Study of Gas Chromatography-Microwave-induced Plasma Atomic Emission Spectrometry. Part 1. Effect of the Structure of a Compound on the Determination of Its Empirical Formula. *J. Anal. At. Spectrom.* **1990**, *5*, 115–120.

Ishizaka, T.; Suzuki, T.; Saito, Y. Metabolism of Dibutyltin Dichloride in Male Rats. *J. Agric. Food Chem.* **1989a**, *37*, 1096–1101.

Ishizaka, T.; Nemoto, S.; Sasaki, K.; Suzuki, T.; Saito, Y. Simultaneous Determination of Tri-*n*-butyltin, Di-*n*-butyltin, and Triphenyltin Compounds in Marine Products. *J. Agric. Food Chem.* **1989b**, *37*, 1523–1527.

Kimmel, E. C.; Fish, R. H.; Casida, J. E. Bioorganotin Chemistry. Metabolism of Organotin Compounds in Microsomal Monooxygenase Systems and in Mammals. *J. Agric. Food Chem.* **1977**, *25*, 1–9.

Lafuente, M. T.; Tadeo, J. L. GLC multiresidue analysis of post harvest fungicides in citrus fruit. *Fresenius' Z. Anal. Chem.* **1987**, *328*, 105–107.

Łobiński, R.; Dirkx, W. M. R.; Ceulemans, M.; Adams, F. C. Optimization of Comprehensive Speciation of Organotin Compounds in Environmental Samples by Capillary Gas Chromatography Helium Microwave-Induced Plasma Emission Spectrometry. *Anal. Chem.* **1992**, *64*, 159–116.

Maguire, R. J.; Huneault, H. Determination of butyltin species in water by gas chromatography with flame photometric detection. *J. Chromatogr.* **1981**, *209*, 458–462.

Maguire, R. J.; Tkacz, R. J. Degradation of the Tri-*n*-butyltin species in Water and Sediment from Tront Harbor. *J. Agric. Food Chem.* **1985**, *33*, 947–953.

Matsuda, R.; Suzuki, T.; Saito, Y. Metabolism of Tri-*n*-butyltin Chloride in Male Rat. *J. Agric. Food Chem.* **1993**, *41*, 489–495.

Mueller, M. D. Tributyltin Detection at Trace Levels in Water and Sediments Using GC with Flame-Photometric Detection and GC-MS. *Fresenius' Z. Anal. Chem.* **1984**, *317*, 32–36.

Scott, B. F.; Chau, Y. K.; Rais-Frirouz, A. Determination of butyltin species by GC/atomic emission spectroscopy. *Appl. Organomet. Chem.* **1991**, *5*, 151–157.

Suzuki, T.; Matsuda, R.; Saito, Y. Molecular Species of Tri-*n*-butyltin Compounds in Marine Products. *J. Agric. Food Chem.* **1992**, *40*, 1437–1443.

Takami, K.; Yamamoto, H.; Okumura, T.; Sugimae, A.; Nakamoto, M. Application of "Clean-up" Cartridge for Gas Chromatographic Determination of Di- and Tri-*n*-butyltin in Fish. *Anal. Sci.* **1987**, *3*, 63–67.

Ting, K.; Kho, P. GC/MIP/AED Method for Pesticide Residue Determination in Fruits and Vegetables. *J. Assoc. Off. Anal. Chem.* **1991**, *74*, 991–998.

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