STUDY OF AIR POLLUTION IN CHILE USING BIOMONITORS

EDUARDO CORTÉS[1], NURI GRAS[1], GERARDO GUZMÁN[2], IRIS PEREIRA[3]

[1]Dept. of Nuclear Applications, La Reina Nuclear Centre, Chilean Nuclear Energy Commission, Santiago, Chile
[2]National Commission for the Environment, V Region, Valparaiso, Chile
[3]Inst. For Vegetal Biology and Biotechnology, University of Talca, Talca, Chile

Abstract

A project has been undertaken within the framework of a Co-ordinated Research Programme (CRP) supported by the International Atomic Energy Agency (IAEA) to carry out a long term study on atmospheric air pollution in Chile using biomonitors. The present project aims at the selection of appropriate plants and other indicators for monitoring of air pollution in several cities and rural areas in Chile. Nuclear analytical techniques, in particular neutron activation analysis (NAA) will be used complemented by AAS for the analysis of selected elements and to determine the sources of pollutants and the applicability of biomonitors to study air pollution in large areas, using indicators either naturally grown or artificially introduced to the region under examination.

1. INTRODUCTION

Chile in general and Santiago, its capital city, in particular have serious air pollution problems [1,2]. During winter time the air pollution in Santiago reaches dramatic levels producing dangerous health problems in children and adults. The problem has been studied by the local authorities from several sides, however, only recently it has been possible to identify the main sources and origins of the main pollutants [3,4]. The Metropolitan Commission for the Environment (COREMA) jointly with local research institutes (the Chilean Nuclear Energy Commission, CCHEN) and international organizations (The University of Sao Paulo, Brazil, USP) carried out intense campaigns in the winter of 1995, 1996 and 1997 to determine the main sources of the contamination. Sampling of airborne particulate matter was carried out by CCHEN using Gent type PM-10 samplers provided by the IAEA at selected sites and the determination of elements were carried put at USP and CCHEN. The data evaluation and interpretation were performed by staff of COREMA, CCHEN and USP [5-13]. The conclusions and recommendations of this task team were included in the so-called "Decontamination Program for the Santiago Metropolitan Area". Air pollution studies are also being carried out in others regions of the country and CCHEN has again played an important role contributing with the design of the study, sampling strategies and with sampling equipment.

In 1977 the CCHEN started a modest monitoring project on air pollution in Santiago to demonstrate the applicability of neutron activation analysis (NAA) to the determination of trace elements in airborne particulate matter [2]. From 1990 on CCHEN has been involved in several projects on Environmental Studies including air pollution. CCHEN has made important and relevant contributions to the development of such projects and, most important, to QA/QC of analytical laboratories at a national level.

On biomonitoring, CCHEN started in 1996 a project on the determination of baseline concentration of elements of environmental importance [14-16]. This project, being carried out jointly with the National Commission for the Environment (CONAMA), aims at establishing the "natural or background" concentration levels of some elements in given matrices for regulatory and control purposes. For this objective, CCHEN is using biomonitors, such as selected molluscs and plants. A sample preparation laboratory has been implemented for handling the samples in a contamination free environment. Available is a class 100 clean room and several laminar flow fume hoods.

Monitoring air pollution in large areas could be rather expensive if all the points of interest have to be equipped with expensive sampling equipment. On the other hand, not all the points of interest have the necessary utilities (i.e. electricity) or can be reached every day for changing filters. The use of biomonitors will greatly reduce the cost of equipment and manpower. Santiago, in particular, has implemented a decontamination plan of the atmosphere and it is necessary to follow closely the results of the recently enforced measurements. In addition, background information from known clean areas but which are far from the laboratories are needed for comparison purposes. The possibility of "planting" appropriate monitors in suspected areas or near sources of pollutants is quite interesting and can help to definitely detect the origin of contaminants for control and surveillance purposes.

The present project aims at the monitoring of air pollution using appropriate bioindicators to (i) study the applicability of biomonitors to monitor the pollution levels of the atmosphere, (ii) determine the concentration levels of toxic elements in the atmosphere of cities and rural areas using PM-10 samplers, (iii) to determine the concentration levels of those toxic elements on the membrane filters and in the selected biomonitors using NAA, complemented by AAS, (iv) to establish correlations, if any, between the concentration levels of toxic trace elements in airborne particulate matter and those in the biomonitors, (v) determine the sources of pollutants and (vi) to determine the applicability of biomonitors to study air pollution in large areas, using indicators either naturally grown or artificially introduced to the region under examination.

Biomonitoring, in a general sense, is the use of properties of an organism or a part of it to obtain information on a certain quantity in a certain part of the biosphere. The relevant information in biomonitoring programmes using plants or animals is commonly deduced from either changes in the behaviour of the monitor organism or from the concentrations of specific substances in the monitor tissues [17]. The concentrations of trace elements in tissues of suitable biomonitors give information on the response of organisms to air pollution and are used as a measure of the concentrations of air particulate matter in the atmosphere.

To be suitable for application as monitor for air particulate matter, specific requirements have to be met by a biological tissue or monitor [18Sloof thesis]. General criteria of primary importance are:

a) the response of the organism to the quantity of the elements to be monitored should be known
b) the organisms should be common in the area of interest
c) availability is required at any time or season
d) the monitor should be tolerant to pollutants at relevant levels.

Additional requirements specific for monitoring atmospheric trace elements are:

e) the element uptake should be independent of local conditions other than the levels of the elements to be monitored

f) the element uptake should not be influenced by regulating biological mechanisms or antagonistic or synergistic effects
g) the biomonitor should average the element concentrations over a suitable time period
h) the organism should not take up appreciable amounts of elements from sources other than atmosphere
i) the organisms should have low background concentrations
j) the sampling and sample preparation should be easy and quick
k) the accumulation should reach to concentration levels which are accessible by routine analytical techniques.

2. BIOMONITORING AIR POLLUTION

Various monitor materials have been used in trace-element air monitoring programmes, including lichens, mosses, ferns, grass, tree bark, tree rings, tree leaves and pine needles [19-21]. Evaluation of the criteria mentioned above for the various biomonitor materials, leads to lichens and mosses as the best suitable monitors. For all biomonitors used, the mechanisms of trace element uptake and retention are still not sufficiently known. For monitors other than lichens and mosses, the contribution from sources other than atmospheric, such as soil have to be taken into account. Where comparisons have been made, lichens and mosses show consistently higher metal levels than higher plants which simplifies the analytical process for the determination of trace-element. According to some authors differences between element concentrations in bark on different trees are often significant to the trace elements levels in lichens. Some lichen species exist in large geographical areas, occurring in rural as well as in urban and industrial areas. The morphology of lichens and mosses does not vary with seasons, thus accumulation can occur throughout the year. Lichens and mosses usually have considerable longevity, which led to their use as long-term integrators of atmospheric deposition.

3. SELECTION OF STUDY SITES

Chile is a long country (4500 km) with a variety of climates, geological and population environments (Fig. 1). Ideally, the study of air pollution should covers all mayor cities and industrial areas as well as rural zones. Air pollution in large cities is becoming a major hazard problem.

Santiago city, the capital, is the one at more risk and its habitants are already suffering the consequences (Fig. 2). Unfortunately for Santiago, the quality of the air depends largely on the climatic conditions which are not favourable during large periods of the year. The city covers an area of 144 km^2, has a population of ever five million inhabitants and about 600.000 vehicles. The mean rain falls is about 380 mm. The wind regime is also adverse. The highest wind velocity, with a value of about 5 m/s is produced in summer, while the lowest, with values as low as 0.6 m/s, occurs during the winter season. The mean yearly value could be between 1.0 to 1.2 m/s.

Valparaiso is the main port of Chile (Fig. 2). Although it has a favourable wind regime, lower population and much less traffic than Santiago, it has been selected as the site for installation of a number of industries and power plants. It would be rather appropriate to start now an air pollution monitoring programme to establish present concentration levels of trace elements in the air to be used as reference data for future studies. On the other hand, there are a number of Natural Parks which might be at risk with these new activities. One such parks is La Campana, which is a hill of about 2200 m of altitude. This mountain has the influence of the city on the south side, the industrial area on the north and receives the fumes from a copper smelter. A new thermoelectric power plant is going into operation in the near future and will also impact this park. The present study will allow the evaluation of the impact of this new power plant on the park.

Talca is a city at about 300 km south of Santiago (Fig. 2). It has a rather low industrial activity and good climatic conditions. This area has been extensively studied as regards their natural resources, its fauna and flora including native forests. The group of the Institute for Vegetal Biology and Biotechnology of the University of Talca has made extensive studies on lichens and other botanical species in the city itself and the mountainous areas around it, including Los Andeans Mountains, and have experience in these matters.

These three places, namely Santiago, Valparaiso and Talca, and their surrounding areas have been selected as the first sites were this project will be focused. In addition, in Valparaiso and Talca are the most experienced people in lichens in the country and they will support the development of this project with their expertise. Nevertheless, the general objective of this project is to establish a database on lichen species in the country with the help of local universities or institutes related to the environment, to select the most appropriate species for biomonitoring air pollution and applied the knowledge gained in this pilot phase to other places in the country.

4. LICHENS INVENTORY

There are approximately 20,000 lichen species, consisting of several groups of fungi and algae. Lichens have a life span of tens to hundreds of years. In Santiago, the information about the species available is shown in Table I. Table II indicates the different lichens species and the substrate where they have been found and, eventually, collected for taxonomic purposes and botanical studies.

Figure 3 represents the Santiago metropolitan area. On this map the location of the Air Pollution Control Network and the districts were the lichens have been found are indicated.

In the area of Valparaiso, and more specifically in the Natural Park Cerro La Campana, a number of lichens species have also been identified and subject to botanical studies. A list of these species is given en Table III.

In the zone of Talca the species of lichens found in the city and the pre-Andean mountains are listed in Table IV.

At present, a selection of the species common to all sites of interest is being carry out. Ideally, a number of species appropriated for biomonitoring air pollution will be selected and a systematic collection would start. It has been indicated in the literature that the lichens such as *Parmelia Acharius* are the most used ones for this purposes. In the inventory of lichens from the three sites of interest this specie has been found.

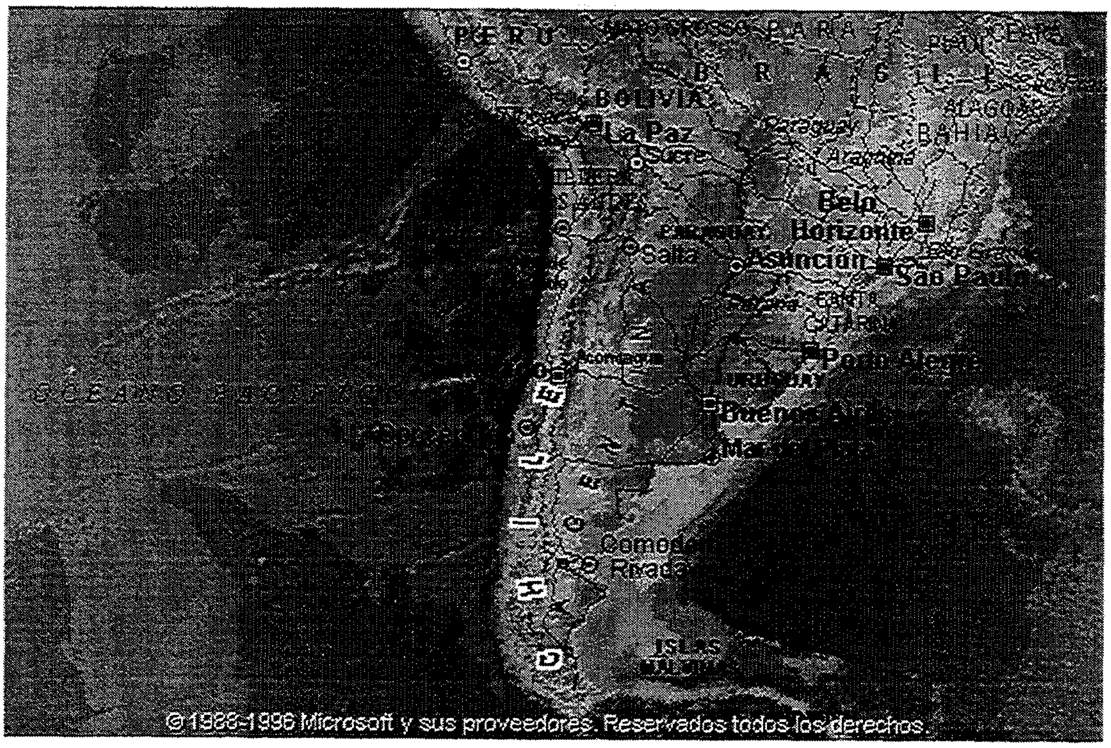

FIGURE 1: LOCATION OF CHILE IN SOUTH AMERICA

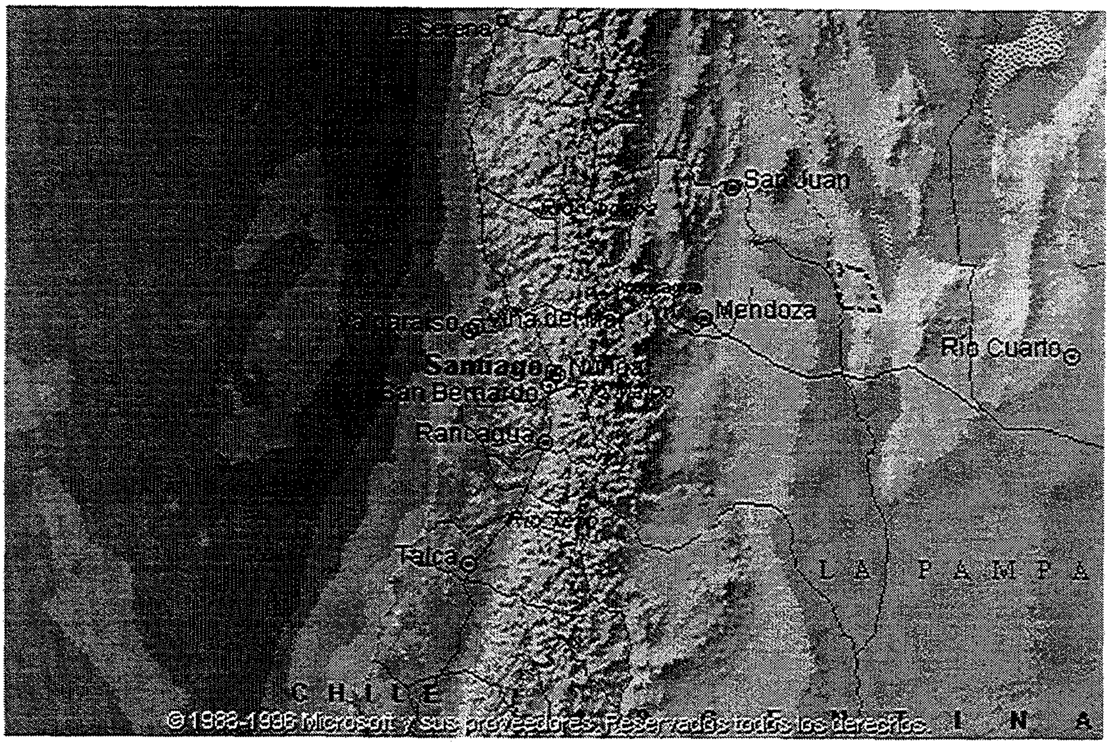

FIGURE 2. LOCATION OF THE THREE AREAS SELECTED FOR THE STUDY

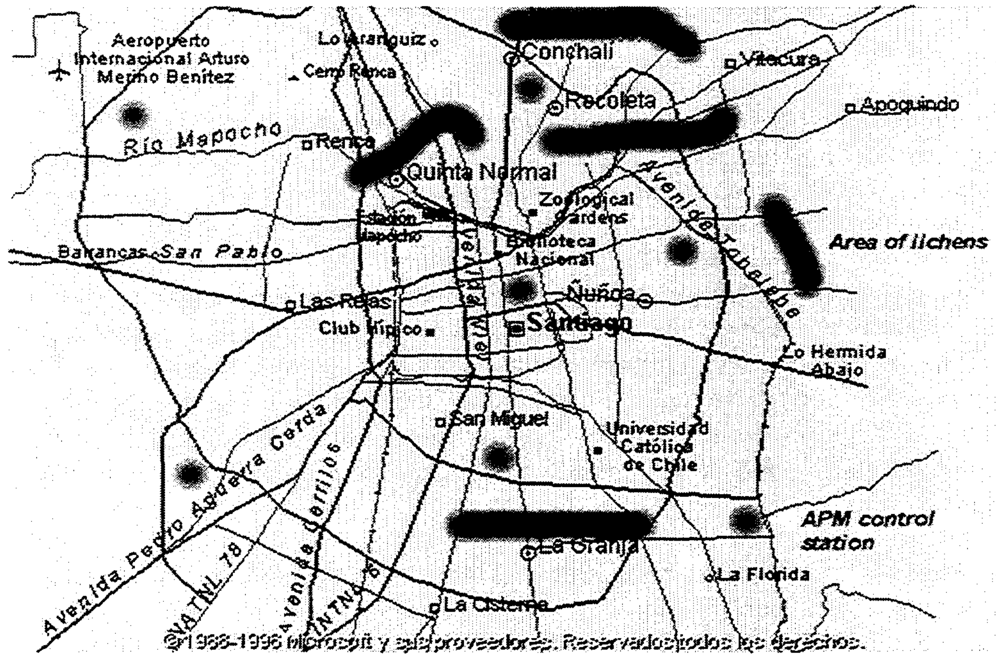

FIGURE 3. SANTIAGO METROPOLITAN AREA AND THE LOCATION OF APM NETWORK SAMPLERS AND LICHENS

5. SAMPLING AND SAMPLE PREPARATION

Once the specific specie(s) has been selected, they will be collected according to procedures described in the literature and which have been adequated to our facilities [18]. The samples will be collected with plastic materials (tweezers and spatulas) and stored also in clean plastic containers.

At the laboratory the samples will be cleaned, using only clean plastic materials, washed with distilled water, milled at liquid nitrogen temperature and freeze dried. The solid will then be homogenized and stored at low temperature.

Airborne particulate matter (APM) is collected using the Gent type PM-10 sample collectors provided by the IAEA within the frame work of a CRP on air pollution studies. The collection devices are SFU-PM10 samplers with a stacked filter unit (SFU) for both membranes, i.e. a coarse (10 - 2.5 μm) and a fine (< 2.5 μm) stage. These samplers are located at selected places in the area of study: in Santiago in the district of Huechuraba, in Valparaiso at La Campana Natural Park and in Talca at the University of Talca Campus. The sampling period is different for each site, depending on the load of the filters. In Santiago, the most contaminated of all three zones, the samples are collected during 24 h per day and during one day per week. In Valparaiso and Talca the samples are collected during 48 h per week. Analysis of these samples will indicate the appropriateness of the sampling period and would be modified if necessary.

6. ANALYSIS AND QA/QC

The samples will be analyzed by INAA and a few samples will be analyzed using radiochemical NAA. The elements to be determine and the number of samples which will follow this procedure will be determine later.

Great emphasis will be placed in quality control and quality assurance of the analyses. This will be performed using reference materials such as the IAEA-336, trace Elements in Lichen.

In addition, a lichen control material has been prepared for analytical quality control purposes within this project. About 2 kg of Rocella sp. were collected from the delta of the Bio Bio river. The lichen was found on rocks close to the sea side. The collection was done manually, using polyethylene gloves and plastic materials. The sample was cleaned in the laboratory, under a laminar flow fume hood, to eliminate all rests of rocks and external materials. The sample was then freeze dried for 48 hours in the Sample Preparation Laboratory at La Reina Nuclear Centre. When dried, the material was milled in a Retsch mill, model RMO with and agate mortar. It was finally homogeneized and sieved through a 125 μm Teflon sieve. Presently, a preliminary characterization of this material is being done by instrumental NAA. This will be followed by homogeneity tests and final determination of the elemental composition and concentration levels.

The analysis of the APM collected on filters will be analyzed by INAA. Although enough experience has been gained in the analysis of this type of samples, QA/QC procedures will also be enforced. APM samples collected from previous campaigns carried out in Santiago, have been cut in four pieces; one piece was analyzed by proton induced X-ray emission (PIXE) and another by NAA. The remaining two quarters will be used for QA/QC purposes.

TABLE I. SPECIES OF LICHENS IN SANTIAGO CITY DISTRIBUTED ACCORDING TO THE DISTRICT OF OCCURRENCE

Lichen Specie	***District***
Buella Fuscula (Nyl.) Zahlbr.	- Huechuraba - Recoleta - La Granja
Caloplaca Cerina (Ehrh. ex Hedw.) Th. Fr.	- Huechuraba - La Cisterna
Candelariella Vitellina (Hoffn.) Mull.- Arg.	- Huechuraba - La Cisterna
Gasparrinia Microphylla (Hue) Dodge	- Huechuraba - Recoleta - Quinta Normal - Santiago - Providencia - Las Condes - YuZoa - La Reina - Lo Espejo - La Cisterna
Lecania Chilena Dodge	- La Cisterna
Lecanora Dispersa (Pers.) Sommerf	- Huechuraba - Quinta Normal
Lempholemma sp.	- Huechuraba - Quinta Normal
Parmelia sp.	- Huechuraba - Quinta Normal
Physcia Adscendens (Th. Fr.) Oliv.	- Huechuraba - Quinta Normal - Santiago - YuZoa - La Reina - La Cisterna
Ramalina Ecklonii (Spreng.)	- Recoleta - La Reina
Teloschistes Chrysophthalmus	- La Reina
Usnea Igniaria Mot.....	- La Reina
Xanthoria Parietina	- Santiago - La Reina
Xanthoria Polycarpa (Hoffm.) Oliv.	- Huechuraba - Recoleta - YuZoa - La Reina - La Cisterna

TABLE II. LICHENS AND THEIR SUBSTRATE

LICHENS \ PHOROPHYTES	Acacia caven	Acer negundo	Acer pseudoplatanus	Araucaria angustifolle	Cedrus deodara	Citrus sinensis	Cryptocarya alba	Erythrina crista-galli	Fraxinus americana	Grevillea robusta	Gymnocladus dioica	Ligustrum lucidum	Magnolia grandiflora	Phoenix canarienaRs	Platanus orientalis	Populus nigra	Prunus armeniaca	Prunus avium	Robinia pseudo-acacia	Schinus molle	Ulmus americana	Vitis vinifera	Washingtonia filifera	Washingtonia robusta	Tortula muralle	MadPre de Nothofagus	Mortier
1.- Buellia fuscula																			*							*	
2.- Caloplaca cerina																			*							*	
3.- Candelariella vitellina																			*							*	
4.- Gasparrinia microphylla	*								*		*				*		*	*	*		*				*	*	
5.- Lecania chilena																											*
6.- Lecanora dispersa	*	*		*	*	*	*	*		*		*	*	*	*	*			*	*	*		*	*			*
7.- Lempholemma sp.			*																*							*	*
8.- Parmelia sp.		*													*				*								

TABLE II. (Cont.)

LICHENS \ PHOROPHYTES	Acacia caven	Acer negundo	Acer pseudoplatanus	Araucaria angustifolle	Cedrus deodara	Citrus sinensis	Cryptocarya alba	Erythrina crista-galli	Fraxinus americana	Grevillea robusta	Gymnocladus dioica	Ligustrum lucidum	Magnolia grandiflora	Phoenix canarienaRs	Platanus orientalis	Populus nigra	Prunus armeniaca	Prunus avium	Robinia pesudo-acacia	Schinus molle	Ulmus americana	Vitis vinifera	Washingtonia filifera	Washingtonia robusta	Tortula muralle	MadPre de Nothofagus	Mortier
9.- Physcia adscendens	*	*							*		*				*			*	*			*				*	
10.- Ramalina ecklonii																			*							*	
11.- Teloschistes chrysophthalmus																			*								
12.-Usnea igniaria																			*								
13.- Xanthoria parietina		*																	*								
14.- Xanthoria polycarpa		*															*	*	*								

TABLE III. LIQUENS FOUND AT LA CAMPANA NATURAL PARK

Class	Subclass	Order	Suborder	Family	Genus	Specie
Ascomycetes	*Ascomycetidae*	*Caliciales*		*Caliciaceae*	*CONIOCYBE* Acharius	*Coniocybe furfuracea* (L.) Ach.
		Lecanorales	*Lecanorineao*	*Collemataceae*	*COLLEMA* Wiggers.	*Collema cf. santesonii* Degel
					LEPTOGIUM S. Gray	*Leptogium azureum.* (Sw.) Mont.
						Leptogium hildenbrandii (Garov.) Nyl,
				Parmeliaceae.	*ALECTORIA* Acharius	*Alectoria cf. crispa* Mot.
					CORNICULARIA Acharius	*Cornicularia epiphorella* (Nyl) DR
					OMPHALODIUM Meyer et Flotow	*Omphalodium arboriculum* Räs
					PARMELIA Acharius	*Parmelia panniformis* (Nyl) Wain.
						Parmelia perlata (Huds.) Ach.
						Parmelia saxatilis (L.) Ach.
						Parmelia squamans Stizb.
						Parmelia stictica (Del.) Nyl.
					PARMOTREMA Massalongo emend. Hale	*Parmotrema arnoldii* (DR) Hale
					PSEUSOPARMELIA Lynge	*Pseudoparmelia caperata* (L.) Hale
						Pseudoparmelia rutidota (Hook. et Tay].) Hale
					USNEA Wiggers emend. Acharius	*Usnea chilensis* Mot.
						Usnea pusilla (Räas.) Räs
					XANTHOPARMELIA Hale	*Xanthoparmelia conspersa* (Ach.) Hale

TABLE III. (Cont.)

Class	Subclass	Order	Suborder	Family	Genus	Specie
				Lecanoraceae	*HAEMATOMMA* Massalongo	*Haematomma canipanacnsis*
						Haematomma puniceum (Swans) Mass.
					LECANORA (Acharius) Th. Fries	*Lecanora atra* (Huds.) Ach
						Lecanora muralis (Schreb.)
						Lecanora subfusca (L.) Ach.
						Lecanora subradiosa Nyl.
					OMPHALODINA Choisy	*Omphalodina milanophthalma* (Rain.) Follyn. et Redon
				Candelariaceae	*CANDELARIA* Massalongo	*Candelaria concolor* (Dicks.) Arn
					CANDELARIELLA Mülller, Argoviensis	*Candelariella Vitellina* (Ehrht.) Müll. Arg.
				Umbilicariaceae	*UMBILICARIA* Hoffmann	*Umbilicaria phaea* Tuck.
						Umbilicaria polyphylla (L.) Baurng.
				Ramalinaceae	*RAMALINA* Acharius	*Ramalina ecklonii* (Spreng.) Mey. et Flot.
						Ramalina cf. pollinaria (Westr.) Ach.
			Peltigerineae	*Peltigeraceae*	*MASSALONGIA* Körber	*Massalongia carnosa* (Dicks.) Körb.
					NEPHROMA Acharius	*Nephroma gyelnikii* (Räs.) Lamb
					PELTIGERA Willdenow	*Peltigera Polydactyla* (Neck.) Hoffm.
				Stictaceae	*PSEUDOCYPHELLARIA* Walnio	*Pseudocyphellaria crocata* (L.) Wain

TABLE III. (Cont.)

Class	Subclass	Order	Suborder	Family	Genus	Specie
						Pseudocyphellaria hirsuta (Mont.) Wain
			Teloschistineae	*Teloschistaceae*	*CALOPLACA* Th. Fries	*Caloplaca pulverulenta* (Müll. Arg.) Zahlbr.
					TELOSCHISTES Norman	*Teloschistes chrysophthalmus* (L.) Beltr.
						Teloschistes flavicans (Sw.) Ach.
					XANTHOPELTIS Santesson	*Xanthopeltis rupicola* Sant.
					XANTHORIA (E. Fries) Th. Pries	*Xanthoria elegans* (Link) Th. Fr.
						Xanthoria fallax (Hepp.) Arn.
						Xanthoria parietina (L.) Th. Fr.
						Xanthoria substellaris Wain.
		Gyalectales		*Gyalectaceae*	*DIMERELLA* Trevisan	*Dimerella lutea* (Dicks.) Trev.
					LEPRARIA Acharius	*Lepraria aeruginosa* (Wigg.) Sm.
				Chrysothrichaceae	*CHRYSOTHRIX*	*Chrysothrix noli-tangere* Mont.

TABLE IV. LICHENS AND THEIR PHOROPHYTES AS FOUND IN TALCA AND PRE-ANDEAN ZONES

Specie	Phorophytes
Physcia aipolia (Ehrh. ex Humb.)	Acacia caven
Ramalina chilensis Bert. ex Nyl.	Acacia caven
Teloschistes chrysophthalmus (L.)Th.Fr.	Acacia caven
Buellia fuscula (Nyl.) Zahlbr.	Acer negundo
Caloplaca cerina (Ehrht. ex Hedw.) Th.Fr.	Acer negundo
Candelariella vitellina (Ehrht.) Müll. Arg.	-Acer negundo -Melia azedarach -Populus alba -Robinia pseudo-acacia -Ulmus procera
Lecanora dispersa (Pers.) Sommerf.	-Acer negundo
Lecanora muralis (Schreb.) Rabenh.	-Acer negundo -Platanus orientalis
Lepraria incana (L.) Ach.	-Robinia hispida -Ulmus procera
Parmelia arnoldii Du Rietz	-Melia azedarach
Parmelia flaventior Stirt.	-Acer negundo -Melia azedarach -Prunus domestica
Phaeophyscia orbicularis (Neck.) Moberg	-Acer negundo -Melia azedarach -Robinia psedo-acacia
Ramalina striatula Nees & Flot. (Syn: R. celastri (Spreng.) Krog & Swinsc.)	-Acer negundo -Melia azedarach
Teloschistes chrysophthalmus (L.) Th. Fr.	-Acer negundo -Melia azedarach
Usnea igniaria Not.	-Melia azedarach
Xanthoria parietina (L.) Th.Fr.	-Acer negundo -Robinia pseudo-acacia
Usnea florida (L.) Web. ex Wigg. em. Clerc	Acacia caven

7. FUTURE ACTIVITIES

For the next year, the activities will continue as planned. A systematic collection of lichens will begin. The specie(s) to be collected will be selected according to the occurrence of them in the zones of interest and their presence in the rest of the country. In addition, the experience of the participants in this CRP could help us in the selection of the most appropriate material. In addition, the collection of airborne particulate matter using Gent type PM-10 samplers at the same location where the biomonitor(s) will be sampled will continue and the preparation of analytical quality control materials will be proceed to assure reliable and useful data.

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REFERENCES

[1] UNIVERSIDAD DE CHILE, Study on the physical and chemical characterization of airborne particulate matter in the Metropolitan Area, Report, University of Chile, Santiago, Chile (1985)

[2] ANDONIE, O., ORTIZ, J., Analysis of atmospheric aerosols of Santiago using neutron activation analysis, Thesis, University of Chile, Santiago, Chile (1977)

[3] TORO, P., CORTÉS, E., Air pollution in Santiago (Chile) as studied by nuclear and other techniques, Report on the First Research Coordination Meeting for the Coordinated Research Programme on Applied Research on Air Pollution Using Nuclear-Related Analytical Techniques, IAEA, Vienna, Austria (1993)

[4] TORO, P., CORTÉS, E., Caracterización del material atmosférico en suspensión en Santiago de Chile: Parte I. Diseño, muestreo y análisis para una campaña experimental, Proceedings III Simposio Centroamericano y del Caribe en Química Analítica Ambiental y Sanitaria, San José, Costa Rica (1995) and in Nucleotécnica **15** (1995) 21-47

[5] HOPKE, P.K., Receptor modeling in environmental chemistry, John Wiley, New York (1985)

[6] HARMAN, H.H., Modern factor analysis, Third Ed. Revised, University of Chicago Press, Chicago (1976)

[7] TORO, P., CORTÉS, E., MORALES, R., DINATOR, M.I., Material particulado en la atmósfera de Santiago: contribución del carbón negro y balance de masa elemental, Actas XXII Congreso Latinoamericano de Química, Concepción, Chile, Enero 1996

[8] DINATOR, M.I., MORALES, R., ROMO, C., TORO, P., CORTÉS, E., KLOCKOW, D., A multiparametric study of suspended particulate matter in the atmosphere of Santiago, Chile, Procedings of 10th World Clean Air Congress, Helsinki, Finland, 1995

[9] TORO, P., CORTÉS, E., ARTAXO, P., Caracterización química elemental del material particulado en la atmósfera de Santiago y su interpretación estadística, Actas II Seminario Internacional en Contaminación Atmosférica, Santiago, Chile, Noviembre 1995

[10] TORO, P., CORTÉS, E., ARTAXO, P., Size distribution of atmospheric aerosol in Santiago, Chile, Proceedings of the International Colloquium on Process Related Analytical Chemistry in Environmental Investigations, Gramado, Brazil, May 1996

[11] TORO, P., CORTÉS, E., Air pollution in Santiago (Chile) as studied by nuclear and other techniques, in Report on the Second Research Coordination Meeting for the International Atomic Energy Agency Coordinated Research programme on Applied Research on Air Pollution using Nuclear-Related Analytical Techniques, University of West Indies, Kingston, Jamaica, 21-25 October 1996

[12] CORTÉS, E., TORO, P., ARTAXO, P., Chemical characterization and source identification of airborne particulate matter in Santiago, Chile. Proceedings of the International Symposium on Harmonization of Health Related Environmental Measurements Using Nuclear and Isotopic Techniques, Hyderabad, India, 4-7 November 1996

[13] TORO, P., CORTÉS, E., Assessment of the chemical characteristics and sources of airborne particulate matter in Santiago, Chile, J. Radioanal. Nucl. Chem. **221**(1-2) (1997) 127-136

[14] CORTÉS, E., GRAS, N., Biomonitors for the determination of baseline concentrations of environmentally important elements and their use as reference materials, IV Simposio Centroamericano y del Caribe de Química Analítica Ambiental y Sanitaria, Ciudad de Panamá, Panamá, 22-26 de septiembre de 1997

[15] CORTÉS, E., GRAS, N., Utilización de biomonitores para la determinación de una línea base de concentraciones de elementos de importancia para el medio ambiente y su uso como material de referencia, Primer Congreso Iberoamericano de Química Ambiental y Primeras Jornadas Chilenas de Física y Química Ambiental, Jahuel, Chile, 19-22 de octubre 1997

[16] GRAS, N., CORTÉS, E., Determinación de línea base de concentración de elementos de importancia ambiental usando biomonitores, XXII Jornadas Chilenas de Química, Osorno, Chile, 12-15 de noviembre de 1997

[17] SLOOF, J.E., de BRUIN, M., WOLTERBEEK, H.TH., Critical evaluation of some commonly used biological monitors for heavy metal air pollution, Proc. Of the Int. Conf. On Environmental Contamination, Venice, September 1988, 296-298

[18] SLOOF, J.E., Environmental lichenology: Biomonitoring Trace Element Air Pollution, Thesis, Interfacultair Reactor Instituut, Technische Universiteit Delft, September 1993

[19] LOPPI, S., NELLI, L., ANCORA, S., BARGAGLI, R., Passive monitoring of trace elements by means of tree leaves, epiphytic lichens and bark substrate, Environ. Monit. Assess., **45**(1) (1997) 81-88

[20] FREITAS, M.C., REIS, M.A., ALVES, L.C., WOLTERBEEK, H.T., VERBUG, T., GOUVEIA, M.A., Biomonitoring of trace elements air pollution in Portugal. Qualitative survey, J. Radioanal. Nucl. Chem., **217**(1) (1997) 21-30

[21] KOVACS, M., PENKSZA, K., TURCSANYI, G., SILLER, I., KASZAB, L., Multielement analysis of a montane beech forest in Hungary, Verh. Ges. Oekol., **25** (1996) 147-152

[22] MAENHAUT, W., FRANCOIS, F., CAFMEYER, J., The Gent Stacked Filter Unit (SFU) sampler for the collection of atmospheric aerosols in two size fractions: description and instructions for installation and use, Report on the First Research Coordination Meeting for the Coordinated Research Programme on Applied Research on Air Pollution Using Nuclear-Related Analytical Techniques, IAEA, Vienna, Austria (1993)