BIOMONITORING FOR THE EFFECTS OF AIR POLLUTION IN THE AOSERP STUDY AREA

REPORT OF A WORKSHOP

by

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Edmonton, Alberta

for

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
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We were extremely impressed by the constructive approach of the workshop participants (Appendix). We would specifically like to thank Dr. Allan Legge for his assistance in the organization of the workshop and in suggesting and contacting participants.

Drs. S.B. Smith, Allan Legge, Walter Heck, Jan Addison, Serge Malhotra, and Derek Bewley provided useful criticisms of an earlier draft of this report.

1. INTRODUCTION

This document is a summary of a workshop held on 7-8 June 1979 at the Mayfield Inn, Edmonton, Alberta, in order to provide guidance to the Alberta Oil Sands Environmental Research Program (AOSERP) concerning the establishment of a system to biologically monitor the effects of air pollution in the AOSERP study area.

The workshop was a preliminary step in the development of a biomonitoring program for the AOSERP study area. It resolved some important issues that will permit AOSERP to proceed with that development. Where important issues were not resolved, we have "flagged" them for consideration in subsequent planning.

2. PROJECT HISTORY

In January 1979, LGL Limited was approached by AOSERP to "conduct a review of biomonitoring techniques appropriate to the terrestrial ecosystem of the AOSERP study area." In response to this request, it was determined that the best approach was likely to be to:

1. limit the subject area to biomonitoring for the effects of aerial emissions;
2. prepare a brief background paper on the subject of biomonitoring for the effects of aerial emissions;
3. conduct a 2-3 day workshop of air pollution effects "experts"; and
4. prepare a report that summarizes the opinions of the workshop participants.

This approach was accepted and LGL proceeded to select workshop participants (with suggestions from AOSERP and from Dr. Allan Legge) and to prepare the background document. The purpose of the background document was to familiarize the workshop organizers with previous research and to outline some of the issues prior to the workshop.

The workshop participants who were not familiar with the oil sands area were sent the following documents prior to the workshop

1. Stringer, P.W. 1976. A preliminary vegetation survey of the Alberta Oil Sands Environmental Research Program study area. Prep. for the Alberta Oil Sands Environmental Research Program by Intraverda Plant Systems Ltd. AOSERP Report 4. 108 p.;
2. Smith, S.B. (ed.) 1979. Alberta Oil Sands Environmental Research Program Interim Report covering the period April 1975 to November 1978. Prep. by A.S. Mann, R.A. Hursey, R.T. Seidner, and B. Kasinska-Banas. Edmonton, Alberta.; and

3. Peterson, W.L. and G.W. Douglas. 1977. Air quality monitoring with a lichen network: baseline data. Syncrude Canada Ltd. Environmental Research Monograph 1977-5. 79 p.

These documents were sent to provide workshop participants with an understanding of the chemical composition and amount of aerial emissions by existing oil sands plants, the temporal and spatial distribution of terrestrial deposition of airborne pollutants, and the ecosystems that are potentially influenced by that pollution.

After the workshop, LGL prepared a draft report of the workshop and sent it to the workshop participants and to AOSERP (26 July 1979). Following the receipt of comments, the draft was extensively revised and this report was submitted to AOSERP on 1 October 1979.

3. BACKGROUND INFORMATION

As discussed above, a brief background document was prepared by LGL so that the workshop organizers would be familiar with the issues prior to the workshop. The following information is a further condensation of that document which will serve as an introduction to the discussion of the workshop results.

This short review is presented here to provide an idea of the breadth of potential biomonitoring tools. For more detailed and technical reviews, the reader is referred to a number of excellent publications (e.g., Stern 1962, Nriagu 1978).

3.1 THE STUDY AREA

The surface mineable oil sands of Alberta are confined to the northern region of the province. Within this region, two oil extraction plants are operating and more are planned for the next ten years. Emissions from these plants are complex mixtures but are predominantly sulphur dioxide and carbon monoxide with smaller quantities of nitrous oxides, particulates with metal oxides, and water vapour.

The mining and extractive operations are being carried out in the Boreal Forest Region of Alberta with the majority of the land in the Mixedwood Section (Rowe 1972). Vegetation is a mosaic of open sphagnum and sedge wetlands, black spruce, black spruce and tamarack, sedge and shrub fen, willow-alder scrub, willow scrub, balsam poplar forest, upland white spruce-aspen forest, and jack pine forest (Stringer 1976).

The Athabasca and Clearwater Rivers drain the area, in valleys incised 200-300 feet into the interior muskeg-covered plains. Forested areas are concentrated along the river valleys and on upland areas, particularly the Birch Mountains (2700 feet ASL) to the west, Stony Mountain (2500 feet ASL) to the south, and Muskeg Mountain (1900 feet ASL) to the east. The Thickwood Hills (1600 feet ASL) rise to the southwest of the area.

Glacial till deposits of varying thickness cover the upland areas, while glacio-fluvial outwash deposits cover much of the lowland areas. Some post-glacial sand dunes stabilized by vegetation occur in the interior plain.

Drainage is poor in most areas with numerous depressional lakes and perennially saturated areas of bog vegetation.

Climate of the area is cool temperate with long, cold winters and short, hot summers. Mean maximum temperature from 30-year records is 74°F in August and the mean minimum -12°F in February, with maximum precipitation during August.

A detailed atmospheric study conducted during 1974 and 1975 demonstrated that:

1. A nocturnal inversion was common and lasted longer during fall and winter mornings;
2. During summer and fall, wind was predominantly from the southwest, but in spring, northerly or southerly winds predominated with the latter reinforced by drainage valleys;
3. Valley air temperatures were consistently higher than plains air temperatures; and
4. A limited number of inversion breakups with ground level fumigation at SO_2 concentrations greater than 0.2 ppm are predicted for spring and summer.

Although no agricultural development has taken place in the oil sands area, a number of agronomic and non-indigenous plants have been introduced on reclaimed land.

3.2 CHOICE OF A MONITOR

An ideal system to detect and measure the effects of atmospheric pollution does not exist. Researchers have advocated the measurement of health or survival of many animal and plant species, the measurement of ecosystem processes such as photosynthesis or decomposition, and the measurement of specific cellular processes that may be related to the potential for future effects of air pollution. Some of the research on potential biomonitors is summarized in the following sections.

3.2.1 Vegetation

3.2.1.1 Vascular plants. Two major pollution episodes in the past provided stimulus in North America to investigate sulphur dioxide damage to vegetation. The rapid increase in industrial activity during the past decade has added impetus to the SO_2 pollution research. Since 1888, nickel ore has been smelted in the Sudbury basin resulting in severe damage to forests and crops that are only recently showing signs of recovery. In western Canada during 1930, local residents of Trail, British Columbia, made formal objections to the government regarding damage to forests and crops as a result of smelter fumes. When SO_2 was identified as the major cause of damage, a large number of reports were generated in an attempt to determine the effects of SO_2 on forests and crops in the area.

The results of past and recent investigations related to the effects on plants of sulphur dioxide emissions throughout North America fall into three categories. These are:

1. Diversity, productivity, and regeneration;
2. Tree growth; and
3. Plant physiology and sulphur content.

3.2.1.1.1 Diversity, productivity, and regeneration. The observation that sulphur dioxide fumes deplete natural vegetation cover has led to identification of a number of vascular species being more or less susceptible to continued exposure. Gorham and Gordon (1960) found *Pinus strobus* and *Vaccinium myrtilloides* to be particularly sensitive to SO_2, while Dreisinger and McGovern (1970) showed buckwheat and trembling aspen to be strongly affected. In decreasing order of SO_2 susceptibility, Katz and McCallum (1939a) listed larch, Douglas fir, Englemann spruce, white pine, yellow pine, cedar, lodgepole pine, silver and white fir. In Britain, Bell and Mudd (1976) showed that a grass, *Lolium perenne*, exposed for many years to low levels of SO_2 had evolved a resistance to the gas, not evident in genotypes collected in non-polluted areas.

Plant productivity can be adversely affected by SO_2 exposure, evidence of which was presented by Katz and Ledingham (1939), and Katz and McCallum (1939b). Results of many field and laboratory experiments showed that rye, barley, and alfalfa productivity was seriously affected depending upon the level of SO_2 fumigation, the degree of leaf damage, and the phenological condition of the plant when the fumigation occurred. A complex interplay of light intensity, temperature, and humidity also affected the plant response. The fumigation of Douglas fir and yellow pine resulted in severe injury during the spring, but susceptibility was much less in winter months. Considerable loss of foliage and consequently reduced growth were noted up to three years after the fumigation (Katz and McCallum 1939b). As might be expected, young seedlings of plants were found much more susceptible to SO_2 exposure; transplanted seedling conifers were found to be damaged more readily by SO_2 during summer months than trees in their natural surroundings (Katz and McCallum 1939c). Smelter fumes in the vicinity of Sudbury were found to reduce white pine reproduction by 50% (Linzon 1958). The susceptibility of mature plants to SO_2 was found to parallel the physiological activity of the plant leaves (Katz and McCallum 1952). The more rapid physiological processes in young plants (respiration, carbon assimilation) render the juvenile material more susceptible to fumigation.

3.2.1.1.2 Tree growth. The measurement of tree growth relies upon counting of annual rings and analysis of ring width to determine rate of growth. The factors influencing tree ring width are climate, tree species, soil, available moisture, disease, and pollution. Earlier work listed in Laboratory of Tree Ring Research (1970) has emphasized the characteristics of tree rings for use to determine the dates of climatological events (drought, flood), insect infestations, and anthropogenic events (fire, habitat alteration).

More recently, studies of tree rings have shown that pollution can influence growth. Linzon (1958) found that white pine diameter growth decreased as smelter pollution levels increased and that sooty smoke (presumably with a higher SO_2 content) near a locomotive works suppressed jack pine growth. Ring width in Scots pine decreased with increasing SO_2 near a chemical plant (Havas and Hultenen 1972), and Lathe and McCallum (1939) observed a 50% decrease in Douglas fir growth during the peak of emissions from the Trail smelter. They noted that lodgepole pine was less sensitive.

In the Tucson Laboratory for Tree Ring Research, elaborate techniques have been developed by Fritts and his co-workers to use tree rings as diagnostic tools of environmental change. Their methods are based upon large numbers of samples from which ring widths are measured and then 'adjusted' to allow for known climatic effects. Tree core samples from the vicinity of smelters in Arizona and New Mexico were used to determine the effect of sulphur, copper, lead, and zinc effluents on tree growth. Very narrow rings were attributed to smelter effluents, but the lack of detailed information on site factors (e.g. drought, insect infestation) made it difficult to be conclusive on the relationship of pollution and ring width (Nash *et al.* 1976).

3.2.1.1.3 Plant physiology and sulphur content. Although the determination of pollution by wild vascular plants can be effective using macro-features (e.g., leaf colouration, tree ring widths, reduced regeneration), the use of wild plants poses different problems than cultivated material. Wild plants vary widely in sensitivity, have non-specific injury symptoms, and are irregularly distributed (Heck and Heagle 1970). To overcome these problems, cultivars of pinto bean, maize, soybean, and tabacco have been used in field and laboratory work. The results of this work, which has concentrated upon photochemical pollutants (ozone), show that pollution indices can be generated based upon the level of damage to exposed plants. The indices give an indication of pollution distribution in the field. Under laboratory conditions, the cumulative and synergistic effects of pollutants (ozone, SO_2, NO_2, metals) can be determined (Heck and Heagle 1970, Dunning and Heck 1973, Larsen and Heck 1976).

Prior to air pollution effects becoming evident on the external surfaces of plants, internal or ultra-structural injury can be anticipated. Ultra-structural studies of pine needles subjected to aqueous SO_2 have been undertaken by Malhotra (1976). SO_2 in aqueous form is required before biochemical or physical damage occurs (Saunders and Wood 1973, cited by Malhotra 1976). The results of Malhotra's work showed that sulphur dioxide injury to older mature tissue was much more severe than that of young tissue. Chloroplasts became dislocated in the leaf, with attendant disruption of the chloroplast structure. He also found the effect of SO_2 was significantly more important than the acidity of the aqueous solution and that metabolism of the young tissue was least affected by the SO_2 exposure. The work of Brandt and Heck (1968) and Wellburn *et al.* (1972) is cited as having demonstrated similar responses to SO_2, suggesting that cytology combined with biochemical analyses may be used as an indicator of plant damage in the field.

Measuring the accumulation of sulphur in plants may not be the most appropriate technique to identify SO_2 levels in the atmosphere, since sulphur is a major component of all plants. In healthy leaves, sulphur levels range from 500 to 14,000 ppm, depending upon plant species (Malhotra and Hocking 1976).

In a single study in Wales, Pyatt (1973) analysed tissues from a large number of species (mainly lichens) but included ferns and tree leaves in his sample. He found a linear relation between plant sulphur content and atmospheric sulphur levels.

The bark from trees has been used to evaluate atmospheric SO_2 (Skye 1968, Newberry 1974, Hornvedt 1975), but results have been equivocal. Bark pH varies between tree species, and sulphur content can be significantly affected by epiphytes (Pyatt 1973).

Katz and Pasternack (1939) found that sulphur continued to accumulate in barley leaves fumigated with SO_2, without change in protein content as long as the leaves remained free of visible injury. As a result of the Trail smelter investigation, Katz and McCallum (1939a) found sulphur accumulation in shrub foliage may reach three or four times normal levels without visible injury and may go even higher in conifers without growth inhibition.

3.2.1.1.4 Metals in vascular plants. The ionic form of metals, primarily iron, zinc, molybdenum, copper, and selenium, are essential to plant growth in small amounts. Excess of these and other metals in the environment are toxic to plants and repress growth. In the Sudbury area, Hutchinson (1971) found levels of lead ten times lower in plants than soils near major highways. Hutchinson and Whitby (1974) found nickel and copper concentrations in *Vaccinium angustifolium* close to smelter emission points to be considerably higher than in plants at greater distances. Metal accumulation by plants from soil has been demonstrated in the course of experiments to evaluate metal tolerant varieties (Smith and Bradshaw 1972). The source of metals in plants (air or soil) must therefore be determined for this to be an effective monitoring technique. The modifying effect of large vegetated areas on metal uptake from the atmosphere by plants was demonstrated by Czarnowska (1974). Plants collected from urban parks revealed much lower iron, zinc, lead, and copper content than plants collected from roadsides. In all cases, metal content was lower in plant tissue than surrounding soil.

3.2.1.2 Non-vascular plants.

3.2.1.2.1 Lichens. The effect of urban atmospheric pollution on lichens was first identified by Grindon (1859) who noted the decline in species in Manchester, England. Similar observations were made by Nylander (1866) in Paris, and his published material was the first to directly relate lichen species diversity and visual condition to air quality. A number of other naturalists made similar observations during the late 1800's (cited in Hawksworth 1971). It was not until 1926 that Sernander developed the concept of lichen zones around cities, with a lichen desert toward the centre, an intermediate tension zone, and a 'normal' zone. As more sophisticated methods were developed to measure environmental parameters, warm, dry urban air was suggested as the principal causative agent in depleting lichen diversity. Not until 1960 was pollution satisfactorily identified as the major influence on lichen distribution in cities, and urban dessication was recognized as a subsidiary factor (Barkman 1958).

In order to assess the effects of pollution on lichens, three approaches have been adopted

1. Based upon frequency, sensitivity, and number of each lichen species, indices of atmospheric purity can be derived (De Sloover and LeBlanc 1968). Maps of the indices have been correlated with absolute sulphur dioxide levels in the air.
2. The second technique entails transplanting lichen specimens, attached to their substrate, from rural unpolluted areas to urban or industrial sites (LeBlanc, Robitaille and Rao 1975; Kauppi 1976).

The rapidity with which the transplanted lichens change in size, appearance, or internal physiology is an indication of pollution levels. Macroscopic changes (colour changes, waxy secretions) in lichens exposed to SO_2 correlate well with changes in chlorophyll, death of algal cells, and development of vegetative reproductive features (LeBlanc and Rao 1973).

3. Thirdly, extensive laboratory studies of lichens in simulated pollution conditions have been conducted. Studies by Pearson and Skye (1965) were carried out with unrealistically high SO_2 concentrations, although more recent studies (Nash 1973) with low levels of SO_2 have substantiated earlier findings. Results showed that chlorophyll levels are reduced with increasing SO_2 exposure and that the limit of sensitivity to SO_2 is 0.5 ppm for 12 hours. Margot (1973) found that algae cultured 'in vitro' were not substantially affected by SO_2 under dry conditions, but under increasing humidity with fixed SO_2 levels, greater numbers of soredia (sexual reproductive bodies) were killed. Elaborate experiments by Lange (Turk *et al.* 1974) showed that lichen assimilation rates decreased and respiration rates increased when the thallus was exposed to SO_2 and then placed in the dark. Nieboer *et al.* (1976), evaluating carbon fixation, metabolite loss, and pigment transformation of lichens in contact with SO_2, found that less carbon fixation occurred in the more sensitive species exposed to SO_2, cellular potassium ion leakage from lichen material increased with SO_2 exposure, and chlorophyll transformation by bleaching and phaeophytinisation (a shift to the blue spectrum took place in thalli exposed to SO_2).

3.2.2 Soil

The major emphasis in studies of soil alteration due to atmospheric emissions has been soil acidification from sulphur dioxide. This has been summarized by Nyborg and Walker (1977). The rate of acidification is not well defined, but absolute values of pH can change by 1 to 3 pH units depending upon the proximity of the SO_2 source to the soil tested and the length of time SO_2 emissions have been prevalent. Due to snow cover in winter months, soil in northern climates may not be as strongly influenced due to rapid spring melt runoff without penetration of water into the soil profile. Container experiments in which soil is set out both in exposed situations as well as protected from particulates and rainfall give quick and accurate results if conditions other than SO_2 are kept under control.

The incidence of metal contamination of soils has increased, particularly due to the use of leaded gasoline and metal-containing insecticides and the smelting of ores containing cadmium, lead, nickel, copper, iron, and vanadium. In the majority of cases, soil contaminants have been found to be concentrated in the upper horizons (Chisholm and Bishop 1967, Hutchinson 1971, Hutchinson and Whitby 1974).

In addition to direct soil analyses for metal content, water extracts of the soils provide a liquid bioassay medium in which inhibition of root elongation can be evaluated (Hutchinson and Whitby 1974).

The use of soil micro-organisms as sulphur dioxide monitors has not been encouraging, due mainly to the rapid fluctuations in soil flora as a result of many variables including SO_2. Elaborate experiments with low level infusion of soils with SO_2 in permeation tubes did not provide any unequivocal measure of the effects of the gas on soil microflora or fauna (J. Crepin, pers. comm.).

3.2.3 Animals

3.2.3.1 Vertebrates. The relevant research on sulphur dioxide effects on domesticated animals is summarized by Stockinger (1962). In essence, very high concentrations of SO_2, as much as 835 ppm, affected the heartbeat, respiratory rate, and mucus formation of the experimental animals. Although such high concentrations of SO_2 are rather unrealistic for ambient conditions, general conclusions arising out of research on effects of SO_2 on domestic animals are that:

1. Under most exposure conditions, SO_2 acts as an upper respiratory tract irritant, with accute but no chronic or cummulative effects having been observed;
2. Animal species vary greatly in susceptibility to SO_2, rats being most resistant, guinea pigs most sensitive; and
3. Resistance to infection was lowered in animals repeatedly exposed to high SO_2.

Autopsy of animals exposed to SO_2 showed that retention of SO_2 in blood up to 11 days depended on the level of SO_2 inhaled, and that the distribution of sulphur in various organs was not uniform, although principal concentration occurred in the lungs.

Mammalian hair has long been a useful diagnostic tool for detection of arsenic (Sherlock Holmes n.d.), but determination of other metals such as lead, cadmium, and mercury in hair can be used to assess the degree of exposure. Mention is made by Maugh (1978) that rodent hair is being collected from sites near a proposed coal-fired power plant before operation begins. After startup of the plant, more hair will be collected in the hope that it will provide a monitor of aerial pollutants from the plant.

3.2.3.2 Insects. The measurement of air pollution using insects has not been extensively undertaken, although insects may respond indirectly to the effects of SO_2 on vegetation. Much of the topical information is summarized by Hilchie and Ryan (1978).

Trees weakened by disease and gaseous effluents may be predisposed to attack by bark beetles. If the bark beetle population continues to grow on diseased wood, neighbouring healthy trees may be attacked. Work in California showed that atmospheric pollution (mainly ozone) caused chlorotic decline in ponderosa pine and subsequent heavy attack of the trees by pine beetles. Although more recent studies of ponderosa pine show that the trees continue to be affected by aerial pollutants, bark beetle populations were not increasing at the expected rate. It was suggested that the nutritive value of the diseased tress was insufficient to support the bark beetle population (citations in Hilchie and Ryan 1978).

Studies have been conducted in Poland on the effects of SO_2 on arthropods in wheat fields and grassland. In the two habitats, certain groups of arthropods were found to be more or less prevalent at varying distances from the SO_2 emission point. The conclusion was reached that aphids are least sensitive to SO_2 and the natural predators of insects are most sensitive to SO_2 (Przybylski 1974, cited in Hilchie and Ryan 1978).

During the winter of 1970-71 and the summer of 1971, ground beetle populations were studied in the vicinity of an Ontario kraft paper mill. Measurements of sulphate sulphur fallout at increasing distances form the mill were also monitored. It was concluded that ground beetle population size was directly influenced by SO_2 (Freitag *et al.* 1973).

With sufficient time for exposure of trees to pollutants, evolutionary trends in moths have been observed. Under conditions of heavy smoke emissions in conjunction with SO_2, a blackening of tree bark has taken place with concurrent loss of ephiphytic plants (Kettlewell 1955). The tree bark was progressively blackened by soot and also became darker as light coloured lichens died. Since the early nineteenth century, a melanic phase of moth has evolved in areas where reflectance of resting surfaces of the ordinarily pale coloured moth have decreased. Lees *et al.* (1973) showed that the melanic frequency of the moth *Biston betularia* was highly correlated with sulphur dioxide level.

The use of scale insects for pollution monitoring has been shown to have potential, since scale insect populations consist of sessile populations that increase under polluted conditions. The increase in numbers is thought to be in response to a reduction of scale insect predators (Carlson and Dewey 1973).

Honey and honey bees have been used in an attempt to determine levels of sulphur dioxide pollution. No conclusive results have been presented to show that bees are responsive to SO_2.

Lead is considered to be the most common heavy metal toxicant in the environment (Hilchie and Ryan 1979), probably due to automotive exhaust, but other sources may be important depending upon the industrial process involved. Studies have demonstrated that levels of lead accumulating in insects are directly proportional to the proximity of the insect collections to highway traffic. Variations in levels of lead varied within groups of insects, plant sucking insects having the lowest levels and predatory insects having the high levels (Price *et al.* 1974).

Stockinger (1962) notes that honey bees in Saxony, Germany, suffered severe mortality due to arsenic poisoning at concentrations much lower than those that were subsequently detected in wild deer and fox.

4. THE WORKSHOP RESULTS

We have not limited this summary of workshop results to the actual proceedings during the two days, nor have we attempted to provide a 'transcript' of the workshop. Instead, we have distilled material provided by participants before and after the workshop as well as detailed notes taken during the workshop to produce a summary that does not discuss detailed aspects of biomonitoring unless those details are important to the understanding of unresolved issues.

4.1 THE PROBLEM

Current air emission standards cannot be related to biological impacts or to the natural assimilative capacity of the environment. Existing air pollution monitoring systems are designed to measure the air quality (i.e., the amount of pollutants in the air); they are not designed to detect the effects of air pollution on living organisms.

The following steps are necessary in order to ensure that air emission standards are related in a meaningful way to environmental protection:

1. The quantities of air pollutants must be measured at the source in order to recognize the specific source that must be regulated;
2. The quantities of air pollutants that reach the biological receptors must be measured in order to describe the dose-effect relationship; and
3. The actual effects of the air pollution on the biological receptors must be measured in order to complete the dose-response relationship and to determine whether current emission standards are appropriate.

The measurements described in 1 and 2 above are currently conducted over a limited area within the AOSERP study area. The third measurement is not being conducted. Continued failure to relate the specific levels of air pollution to specific biological effects will have many consequences, which include:

1. The risk of undetected environmental damage at current emission levels, especially from the effects of long-term accumulation; and
2. The risk of unreasonable expense to industry, because of the insistence on unjustifiably low emission standards.

The definition of a method to measure the effects of air pollution on biological receptors was the primary focus of the workshop.

4.2 OBJECTIVES

The specific objectives of the workshop were the following:

1. To define the spatial, temporal, physical, and biological considerations of importance in the design of a biomonitoring program to detect the effects of aerial emissions in the AOSERP study area;
2. To design (if possible) a biomonitoring program; and
3. To evaluate the inadequacy of the information upon which such a recommended biomonitoring program must be based, and to recommend research that will address the major information gaps.

None of these objectives was fully completed during the workshop. The conceptual basis for a biomonitoring program was fully discussed, however, and a concensus was reached.

4.3 PURPOSE OF BIOMONITORING

A considerable portion of the workshop time was spent in discussion of research topics that did not appear to be related to the specific problem of designing a biomonitoring program. One reason for this problem was that there were two different views of the purpose of a biomonitoring program:

1. Biomonitoring is conducted to measure the amount of pollutants in organisms as an indicator of the amount of pollutants that enter the ecosystem (i.e., the measurement of the amounts of pollutants in organisms serves as a partial replacement for a direct physical measurement system); and
2. Biomonitoring is conducted to measure the state of health of organisms, populations, or ecosystems (i.e., the measurement of the effects of pollutants rather than the amounts of pollutants).

It was generally agreed that the measurements described in the latter statement were of prime importance to the workshop. The former is usually a necessary part of biomonitoring (e.g., the concentrations of pollutants must be measured to determine the dose-response relationship in a plant). However, some types of biomonitoring may involve measurements that are not related to the concentrations of pollutants through changes in species diversity , and concurrent pollutant concentration measurement may be meaningless in those types.

4.4 CHOICE OF MONITORING SYSTEMS

Throughout the workshop, participants frequently discussed the difficult problem of choosing one or more monitors. A wide variety of biological materials was suggested (e.g., micro-organisms, plants, insects, soil).

Participants discussed approaches using single and multiple monitors. It was proposed that a single, very sensitive monitor would provide adequate warning of environmental impact due to impaired air quality. However, no single suitable monitor was suggested. Multiple monitoring techniques that were suggested included analyses of changes in metabolic pathways, physiological responses of lichens and mosses, metal accumulation in soil organic material, soil leaching, and insect emergence. It was agreed that, when the final choice of monitors is made, it must take into account the year-round deposition of pollutants. Users of the monitoring system must also recognize the inability of any one monitor to respond under all climatic conditions. Participants further noted that there is inherent ecological 'noise' as a result of natural processes that are unrelated to pollution effects; control monitoring sites are thus essential in order to take this 'noise' into consideration.

Several issues were addressed in specific terms and were not resolved during the workshop:

1. Native or introduced species? Some participants felt that the use of introduced species as monitors in the oil sands area would not be useful, even though the responses to air pollution of some non-native species are much better understood. Others felt that the use of introduced species to the types of air pollution occurring in the oil sands area would be a good first step, at least until the responses to pollution of a variety of native species have been established
2. Individual pollutants or a mixture of pollutants? It was frequently pointed out that the aerial emissions from the oil sands plants are complex and variable mixtures and the components of the mixtures and their interactions must be considered when choosing a biomonitoring system. However, some participants felt that it is impossible to consider the effects of all individual pollutants and combinations of pollutants (especially considering that it is impossible at this time to design a biomonitoring system that will respond to even two or three pollutants individually and in combination). This latter viewpoint suggests that a biomonitoring program will have to be designed without adequate dose-response information and that such information

will never be available (within the foreseeable future).

3. A species or ecosystem approach? There were some participants that felt that chronic low-level air pollution may cause changes in ecosystem processes that are best measured directly rather than detected through the eventual effects of those changes on individual species. Soil litter decomposition was mentioned as one process that may be affected by terrestrial deposition of air pollutants. This discussion led to the suggestion that there may be a number of ecosystem processes that should be monitored in case there are general ecosystem changes that are not quickly recognized through a change in health of individuals of a sensitive species.

4.4.1 Specific Proposals

At the end of the first day of the workshop, two sub-groups were formed (led by Dr. V. Runeckles and Dr. A. Legge) to continue definition of a biomonitoring program. Dr. Runeckles and Dr. Legge agreed to take different approaches; Dr. Runeckles' group dealt with the technical details of specific approaches, and Dr. Legge's group wrestled with a more conceptual approach. The sub-groups met informally during the evening and reported to the workshop the following morning.

4.4.1.1 Group 1. The group led by Dr. V. Runeckles presented their version of the most promising system(s). The following is the text of their report (with a few minor changes):

The group considered two topics:

1. *The most promising monitoring system(s) that could be put into place immediately at selected sample sites; and*

2. *The research that is needed to improve upon any existing data base for the monitor(s) chosen.*

1. *Biomonitoring System*

Sites. *The group agreed that certain natural indicators of pollution are available and that permanent sites should be selected to provide continuous monitoring and control locations for these indicators. Criteria for selection of sample locations include:*
(a) That the locations be secure from future destruction;
(b) That the locations be representative of major vegetation types;
(c) That the system be able to respond to future development by the addition of new and comparable sites; and
(d) Concentration and frequency of pollution impingment, from air quality models of ground level concentrations.
The group considered that the following basic information is required from each sample site chosen: a detailed vegetation description (e.g., species, cover, diversity), an inventory of insects and passerine birds, and a photographic record of sites. Sample sites should be 1 ha in size.

Monitors. *The monitoring program that could be set up immediately places most emphasis on jack pine trees and forest. This species has been chosen because it is a dominant coniferous species that permits annual productivity measurements, that provides useful foliage chemical analysis, and that has valuable associations with insects, fungi and vascular parasites. Every effort should be made to select monitoring material that can be 'banked' as a reference material. Non-indigenous indicator species should also be included in sample sites in order to provide an indication of acute injury. Alfalfa, buckwheat, and blackberry are suggested.*

Processes. *Particular emphasis should be placed on observations of growth, diversity, and chemical content of lichens and mosses. We suggest that some measure of litter decay be developed for each site. (Low levels of SO_2 have been shown to affect litter decomposition.) The group could not identify any one technique as being particularly valuable for 'early warning' of the impacts of air pollution; however, biochemical and physiological changes in lichens and other plants should be considered.*

2. *Biomonitoring Research*

Improvement of the existing data base for the monitors chosen could be achieved through research into the following topics:
(a) Insect/predator relationships;
(b) Component processes of litter decomposition;
(c) Pollinators as accumulators of pollutants; and
(d) leaching studies of soil.

4.4.1.2 Group 2. The group led by Dr. A. Legge primarily addressed the research necessary to develop a biomonitoring system. In addition to the 'early warning' and 'integrative system function' aspects of biomonitoring (which could be established without much further research), they proposed that research be aimed at identifying the critical system processes that might be affected by air pollution. This ecosystem approach would entail the selection of a portfolio of system processes (with high sensitivity and high risk of missing the effects of pollution) as well as higher level system processes (with lower sensitivity and lower risk of missing important system effects). An ecosystem modelling approach would probably be necessary in order to objectively evaluate the choices among system process measurements.

Dr. Legge's group pointed out that most of the specific suggestions made by Group 1 will fit into this conceptual approach, with the following exceptions and additions:

1. sites should be in one vegetation type (rather than "be representative of major vegetation types") (probably jack pine stands);
2. sites chosen should be similar with respect to soil type, meteorological and microclimatic conditions, etc.; and
3. reference sites should be included to account for natural ecological variability.

4.5 THE CONSENSUS

The workshop arrived at the following consensus:

1. A biomonitoring system using one or more sensitive organisms can be established immediately. The survival and health of these organisms can provide 'early warning' of the impacts of air pollution.
2. A research and development effort to refine biomonitoring techniques should proceed along the following two closely co-ordinated lines:

(a) Annual measurements of an integrative measure of system health (e.g., net productivity, decomposition) should be made to provide an index of the change associated with chronic low-grade air pollution.

(b) A series of research projects should be initiated to evaluate the cause-effect relationships that are implicit between the 'early warning' response or organisms and their 'health.' Research should also investigate the potential for developing other more sensitive measures of the effects of air pollution on the ecosystem.

(c) The overall objective should be to provide government with an operating biomonitoring program, requiring a low level of ongoing research, at the end of five years.

5. LITERATURE CITED

Barkman, J.J. 1968. The influence of air pollution on bryophytes and lichens. Pages 197-210 *in* Air pollution: proc. 1st European congress on influence of air pollution on plants and animals.

Bell, J.N.B. and C.H. Mudd. 1976. Sulphur dioxide resistance in plants: a case study of *Lolium perenne*. Pages 87-105 *in* T.A. Mansfield, ed. Effects of air pollutants on plants.

Brandt, C.S. and W.W. Heck. 1968. Effects of air pollutants on vegetation. A.C. Stern, ed. Air pollution.

Carlson, C.E. and J.E. Dewey. 1971. Environmental pollution by flourides in Flathead National Forest and Glacier National Park. U.S. Forest Service, Forest Insect and Disease Branch, Missoula, Montana.

Chisholm, D. and R.F. Bishop. 1967. Lead accumulation in Nova Scotia orchard soils. Phytoprotect. 48:78-81.

Czarnowska, K. 1974. The accumulation of heavy metals in soils and plants in Warsaw area (exemplified by grasses and mosses). Polish J. Soil Sci. 7:117-122.

De Sloover, J. and F. LeBlanc. 1968. Mapping of atmospheric pollution on the basis of lichen sensitivity. Pages 42-56 *in* R. Misra and B. Gopal, ed. Proc. Symposium, on recent advances in trophic ecology.

Dreisinger, B.R. and P.C. McGovern. 1970. Monitoring atmospheric sulphur dioxide and correlating its effects on crops and forests in the Sudbury area. *In:* Conference on Impact of Air Pollution on Vegetation. 23 pp.

Dunning, J.A. and W.W. Heck. 1973. Response of pinto bean and tobacco to ozone as conditioned by light intensity and/or humidity. Environ. Sci. and Technol. 7:824-826.

Freitag, R., L. Hastings, W.R. Mercer and A. Smith. 1973. Ground beetle populations near a Kraft Mill. Can. Entomol. 105: 299-310.

Gorham, E. and A.G. Gordon. 1960. Some effects of smelter pollution northeast of Falconbridge, Ontario. Can. J. Bot. 38:307-312.

Grindon, L.H. 1859. The Manchester Flora. W. White, London.

Havas, P. and S. Hultenen. 1972. The effect of air pollution on the radial growth of Scots Pine. Biol. Conserv. 4:

Hawksworth, D.L. 1971. Lichens as litmus for air pollution: a historical review. Inter. J. Environ. Studies 1:281-296.

Heck, W.W. and A.S. Heagle. 1970. Measurement of photochemical air pollution with a sensitive monitoring plant. J. Air Poll. Control Ass. 20:97-99.

Hilchie, G.J. and J.K. Ryan. 1979. Approaches to the design of a biomonitoring program using arthropods as bioindicators at the AOSERP study area. Prep. for Alberta Oil Sands Environmental Research Program by McCourt Management Ltd. 39 pp.

Hornvedt, R. 1975. Epiphytic macrolichens on Scots pine related to air pollution. Meddelelser Norsk Inst. Skogforskning 31:584-604.

Hutchinson, T.C. 1971. Lead, cadmium and vanadium levels in soils and vegetation in metropolitan Toronto. Indicative of airborne contamination. Interdisciplinary Meeting of Can. Bot. Ass., Bot. Soc. Amer. 1971 (Abst.).

Hutchinson, T.C. and L.M. Whitby. 1974. A study of airborne contamination of vegetation and soils by heavy metals from the Sudbury, Ontario copper/nickel smelters. Pages 179-189 *in* D.D. Hemphill, ed. Trace substances in environmental health VII.

Katz, M. and G.A. Ledingham. 1939. Experiments on yield of barley and alfalfa. Pages 332-368 *in* Effect of sulphur dioxide on vegetation. Nat. Res. Council Can., Publ. 815.

Katz, M. and A.W. McCallum. 1939a. The sulphur content of trees and shrubs in relation to sulphur dioxide in the atmosphere. Pages 104-130 *in* Effect of sulphur dioxide on vegetation. Nat. Res. Council Can., Publ. 815.

Katz, M. and A.W. McCallum. 1939b. Fumigation experiments on conifers in their natural habitat. Pages 218-243 *in* Effect of sulphur dioxide on vegetation. Nat. Res. Council Can., Publ. 815.

Katz, M. and A.W. McCallum. 1939c. Fumigation experiments on transplanted conifers. Pages 218-243 *in* Effect of sulphur dioxide on vegetation. Nat. Res. Council Can., Publ. 815.

Katz, M. and A.W. McCallum. 1952. The effect of sulphur dioxide on conifers. Pages 84-96 *in* L.C. McCabe, ed. Air pollution.

Katz, M. and D.S. Pasternack. 1939. Effect of fumigation on some chemical constituents of barley, wheat and alfalfa. Pages 369-392 *in* Effect of sulphur dioxide on vegetation. Nat. Res. Council Can., Publ. 815.

Kauppi, M. 1976. Fruticose lichen transplant technique for air pollution experiments. Flora Bd. 165:407-414.

Kettlewell, H.B.D. 1955. Recognition of appropriate backgrounds by the pale and black phases of Lepidoptera. Nature (Lond.) 212:323-342.

Larsen, R.I. and W.W. Heck. 1976. An air quality data analysis system for interrelating effects, standards and needed source reductions: Part 3. Vegetation: injury. J. Air Poll. Control Ass. 26:325-333.

Lathe, F.E. and A.W. McCallum. 1939. The effect of sulphur dioxide on the diameter increments of conifers. Pages 174-206 *in* Effect of Sulphur dioxide on vegetation. Nat. Res. Council Can., Publ. 815.

LeBlanc, F. and D.N. Rao. 1973. Effects of sulphur dioxide on lichen and moss transplants. Ecology 54:612-617.

LeBlanc, F., G. Robitaille, and D.N. Rao. 1974. Biological response of lichens and bryophytes to environmental pollution in the Murdochville copper mine area, Quebec. J. Hattori Bot. Lab. 38:405-433.

Lees, D.R., E.R. Creed, and J.G. Duckett. 1973. Atmospheric pollution and industrial melanism. Heredity 30:227-232.

Linzon, S.N. 1950. The influence of smelter fumes on the growth of White Pine in the Sudbury region. Dept. Agric. Forest Biol. Div., Ottawa. 45 pp.

Malholtra, S.S. 1976. Effects of sulphur dioxide on biochemical activity and ultrastructural organization of pine needle chloroplasts. New Phytol. 76:239-245.

Malhotra, S.S. and D. Hocking. 1976. Biochemical and cytological effects of sulphur dioxide on plant metabolism. New Phytol. 76:227-237.

Margot, J. 1973. Experimental study of the effects of sulphur dioxide on the soredia of *Hypogymnia physodes*. Pages 314-329 *in* B.W. Ferry, M.S. Baddeley, D.L. Hawksworth, ed. Air pollution and lichens.

Nash, T.H., H.C. Fritts, and M.A. Stokes. 1976. A technique for examining non-climatic variation in widths of annual tree rings with special reference to air pollution. Tree Ring Bull. 35:15-24.

Newberry, G. 1974. The influence of a sulphate-process paper mill on corticolous lichens. Bryologist 77:561-576.

Nieboer, E., D.H.S. Richardson, K.J. Puckett, and F.D. Tomassini. 1976. The phytotoxicity of sulphur dioxide in relation to measurable responses in lichens. Pages 61-85 *in* T.A. Mansfield, ed. Effects of air pollutants on plants.

Nriagu, J.O. (ed.). 1978. Sulphur in the environment: Part II. Ecological impacts. J. Wiley and Sons Inc.

Nyborg, M. and D.R. Walker. 1977. An overview - the effects of sulphur dioxide emissions on the acidity and sulphur content of soils. *In:* Proceedings of Alberta Sulphur Gas Research Workshop III. Alberta Institute of Pedology and Alberta Environment. 335 pp.

Nylander, W. 1866. Les lichens du jardin du Luxembourg. Bull. Soc. Bot. France 13:364-372.

Pearson, L. and E. Skye. 1965. Air pollution affects pattern of photosynthesis in *Parmelia sulcata* a corticolous lichen. Science 148:1600-1602.

Price, P.W., B.J. Rathcke, and D.A. Gentry. 1974. Lead in terrestrial arthropods; evidence for biological concentration. Environ. Entomol. 3:370-372.

Przbylski, Z. 1974. Resultats d'observations relatives a l'influence des gaz et vapeurs de soufre sur les arbres fruitiers, arbustes et arthropodes aux alentours des usines et mines de soufre dans la region de Tarnobrzeg. Environ. Poll. 6:67-74.

Laboratory of Tree Ring Research. 1969. Publications in Dendrochronology Since 1950. Prep. by Staff at the Laboratory of Tree Ring Research, Tucson, Arizona. 13 pp.

Pyatt, F.B. 1973. Plant sulphur content as an air pollution gauge in the vicinity of a steelworks. Environ. Poll. 5:103-115.

Rowe, J.S. 1972. Forest regions of Canada. Canadian Forestry Service. Publ. 1300. 172 pp.

Saunders, P.J.W. and C.M. Wood. 1973. SO_2 in the Environment, its production, dispersal and fate. *In:* Air Pollution and Lichens, B.W. Ferry, M.S. Baddeley, D.L. Hawksworth (Eds.).

Smith, R.A.H. and A.D. Bradshaw. 1972. Stabilization of toxic mine wastes by the use of tolerant plant populations. Trans. Inst. Mining Metal. 81:230-238.

Stern, A.C. (ed.). 1962. Air Pollution. Volume 1. Academic Press.

Stokinger, H.E. 1962. Effects of air pollution on animals. Air Pollution, Volume 1. Pages 282-334 *in* A.C. Stern, ed.

Stringer, P.W. 1976. A preliminary vegetation survey of the Alberta Oil Sands Environmental Research Program Study Area. Prep. for Alberta Oil Sands Environmental Research Program by Intraverda Plant Systems Ltd. AOSERP Report 4. 108 pp.

Turk, R., V. Wirth, and O.L. Lange. 1974. Carbon dioxide exchange measurements for determination of sulphur dioxide resistance of lichens. Oecologia. 15:33-64.

Wellburn, A.R., O. Majernik, and F.A.M. Wellburn. 1972. Effects of SO_2 and NO_2 polluted air upon the ultrastructure of chloroplasts. Environ. Poll. 3:

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