ECOLOGICAL IMPACTS OF NUCLEATING AGENTS USED IN WEATHER MODIFICATION PROGRAMS: AN INTERDISCIPLINARY ASSESSMENT

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INTRODUCTION

Weather modification has been carried out since the late 1940 period (Brown, 1971) with silver iodide used as the nucleating agent in most United States programs. Together with other aspects of weather modification programs, the question of the possible ecological impacts of nucleating agents has been raised, both by scientific workers and the lay public. Cooper and Jolly (1969, 1970) completed an environmental assessment of weather modification programs, and possible environmental impacts of nucleating agents were considered. Their analysis, based mainly on a review of the available medical and toxicological literature on silver, suggested that possible effects of these agents upon aquatic microorganisms (especially in anaerobic environments) and fish populations could be points of concern.

Carson and Smith (1975) completed a general appraisal of environmental exposure to silver, in which the contributions of weather modification programs were considered. Based upon the relatively small amounts of silver used in these programs, the environmental exposure to silver from this source was considered to be of minor importance. As a general conclusion, the possible effects of silver in the environment were felt to be more important in regard to aquatic lower life forms, as compared with possible impact on humans or other higher life forms.

To assess potential environmental impacts of nucleating agents as used specifically in weather modification programs, and to provide recommendations for policy making groups, program administrators, environmentalists and the public, a group of 18 scientists met during November, 1976. The possible environmental impacts of nucleating agents were discussed, and information currently available related to this subject was evaluated.

The general conclusions and recommendations of the workshop participants for each of the areas felt to be of concern can be summarized as noted below:

CHEMICAL EQUILIBRIA, DISPOSITION AND ANALYSIS OF SILVER IN THE ENVIRONMENT

One of the major problems which will require additional emphasis

is to be able to monitor atmospheric transport processes and the final disposition of seeding agents used in weather modification programs with greater certainty. Differences between winter versus summer seeding programs can lead to major variations in disposition patterns and localized concentrations of nucleating agents, and on the subsequent impact they might have on impact ecosystems. For winter orographic seeding, the nucleating agents were felt to be bound predominantly in surface soils after snow melt, and would not be released to any great extent to surface waters or impact directly on growing crops, as might occur with summer seeding programs in agricultural areas.

With the low concentrations which are present in soil, rain, snow, and water samples, it will be necessary to have increased emphasis placed on sampling techniques, sample storage procedures and analytical methodology. The possibility of tracer use to allow differentiation between water derived from seeded versus unseeded precipitation should be given greater emphasis.

EFFECTS UPON HUMANS, DOMESTIC AND SPORTS ANIMALS

Direct evidence for significant detrimental effects of silver on higher organisms has not been shown, and based on research completed to date, it is not expected that the presence of nucleating agents in or on food materials ingested by ruminants, as a specific point of possible concern, should have disernable effects or lead to significant bioconcentration, as observed with lead or mercury. The direct impacts of silver-containing food materials on endangered species could not be assessed as being uniquely associated with possible nucleating agent presence.

BIOCHEMICAL EQUILIBRIA AND POTENTIATION OF OTHER METALS AND AGENTS IN THE ENVIRONMENT

This is an area where it is felt that potentially interactive effects of silver-derived nucleating agents with other materials (such as other metals, pesticides, etc.) could be of concern. If such effects might occur, these would be extremely subtle and would not be directly evident to the public. Silver, together with some other metals, is unique in that at lower concentrations it also can lead to stimulation of some types of biochemical processes, instead of leading to inhibition as usually observed at higher concentrations. Thus, continued attention should be given to possible more subtle effects of this metal in the environment, and research in this area appears to be warranted, although this is not a major item of public concern.

AQUATIC BIOLOGICAL PROCESSES, INCLUDING AQUATIC INVERTEBRATES AND FISH POPULATIONS

General information available indicates that lakes will serve as

reservoirs for silver and other metals which tend to accumulate in bottom sediments. Although a large body of information is not available on the effects of nucleating agents on aquatic insects and algae, the transient presence of this metal in waters, and the adsorption of silver by surface soils through which most precipitation would pass will lead to the retention of silver compounds in surface soils before the moisture is released to surface waters. Even when present in surface waters, silver compounds will tend to be bound rapidly by stream-bottom organic materials. With the wide-spread efforts to inhibit algal growth in reservoirs and other bodies of water, primarily by using copper salts, any possible negative effects of silver from weather modification sources, if this were to occur, would tend to support these efforts. In regard to cold water sport fish populations, no evidence was felt to be available which would indicate that silver in natural environments would have significant effects, in spite of evidence for effects of free silver ion being observed in the laboratory. As most work to date had been carried out with cold water fish, additional studies with warm-water fish appear to be warranted.

THE SOIL-PLANT ENVIRONMENT

Available data suggest that with 100-fold-higher silver levels in surface soils, that decreases in rates of organic matter decomposition may be observable over time periods of perhaps four-five years, as a minimum. With the ability of plants to accumulate metals in the root environment and at other points up to 100-200 times higher than background levels, the possibility exists of silver (and other metals, possibly) accumulating at concentrations where microbial decomposition processes could be influenced. If slight changes in decomposition rates were to occur in specific microsites in soils, the effects on the functioning of decomposer components of ecosystems could be expected to be negligible, and could have some positive benefits related to organic matter retention in surface soils. Again, the more subtle aspects of possible metal accumulation in plants may justify additional monitoring efforts, especially in relation to agronomic crops.

Research results for direct effects of silver-based nucleating agents on plant growth processes (possible effects on phenological development, flowering, pollen tube germination, etc.) indicate that both stimulation and inhibition have been observed using silver ion, however, little information is available on possible silver using iodide or nucleating agent burn complex effects carried out under carefully controlled laboratory conditions. In localized areas surrounding previously-used seeding generator sites where silver has accumulated in surface soils at markedly higher than background levels, no effects on plant growth or vigor have been observed, although silver transport into above-ground plant parts has been noted. The possibility of silver influencing ethylene production (by plants and microbes) which serves as a plant growth-controlling agent was considered as a possible more subtle aspect of metal-plant interactions which might require further investigation.

SEWAGE TREATMENT PROCESSES AND ANAEROBIC ENVIRONMENTS

Available information suggests that silver in various forms will have lesser effects on anaerobic processes in comparison with aerobic microbiological processes. However, as sewage treatment generally leads to concentration of metals in sewage sludges, the possibility of combined metal effects should be given further attention. This is of importance when related to re-use of sewage sludges as fertilizers, and is an area where additional research and monitoring should be considered.

EFFECTS ON BIRDS

The possible effects of silver-based nucleating agents on avian populations depends on the food source of the particular species (insects, grains, etc.). No bioconcentration of silver from plants to lower consumer levels has been shown to date in work with grasshoppers, suggesting that movement into higher consumer trophic levels would not be a significant point of concern. For grain-eating bird species, the higher silver concentrations found in seeds might tend to lead to a greater silver burden, however, no direct evidence for effects of such higher silver burdens have been found. Additional studies may be warranted which are more directly related to weather modification concerns, in which nucleating agents would be used instead of silver ion, the silver form used in most previous studies.

MONITORING STRATEGIES FOR SILVER AND SILVER-BASED SEEDING AGENT CONCENTRATIONS AND BIOLOGICAL EFFECTS

The development of new strategies for monitoring disposition, accumulation and potential biological effects of seeding agents were felt to be points of major importance in the future. The possibility of monitoring metal concentrations in surface mud microlayers, the monitoring of possible seeding agent accumulation effects on the epiphytic microbial flora of leaves, the selection of more specific bioconcentration indicator plants, and the use of the root zone of plants as specific sites for measurement of silver in the environment were suggested. For longer term measurement of silver disposition, the possibility of measuring silver accumulation in specific rings of tree growth as related to seeding activity has been demonstrated. This is one of the more difficult areas to develop meaningful strategies, as the inherent seasonal and spatial variabilities in silver concentrations make it costly and experimentally difficult to sample with sufficient intensity over the extended areas which might be influenced by such programs.

NON-SILVER-BASED NUCLEATING AGENTS

The use of dry ice was felt to be environmentally acceptable, assuming that toxic amines of various types were not present as

by-products in the commercial materials which would be used for seeding. For some of the other non-silver nucleating agents, the potential environmental effects were not considered to be minimal, as some workers have suggested. The workshop members felt that until a real possibility existed that these materials would be used on an operational basis in weather modification programs, that further work on ecological impacts of these materials would not be justified.

CONCLUSIONS

In summary, the members of the workshop felt that the points of major public concern regarding nucleating agents (effects on plant growth, game animals and fish, as points of special public interest) represented negligible environmental hazards. The more subtle potential effects of silver-based nucleating agents, such as a possible ability to potentiate the movement or effects of other materials of environmental concern (other metals, pesticides, etc.) or their ability to influence the activity of microorganisms in soils and aquatic environments, particularly after localized bioconcentration by plants, warrant continued research and monitoring activities, although any effects, if they might occur, are not expected to involve unacceptable risks. The long term use of silver iodide, together with the confidence which the weather modification profession has in delivery systems and the efficacy of this material, make it unlikely that other agents will be used on a large-scale basis in the future, unless improvements in delivery systems and major changes in the economics of silver availability might occur.

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