WEATHER MODIFICATION ASSOCIATION (WMA) POSITION STATEMENT ON THE ENVIRONMENTAL IMPACT OF USING SILVER IODIDE AS A CLOUD SEEDING AGENT
JULY 2009

The Weather Modification Association (WMA) is occasionally asked to comment on questions regarding the environmental effects of silver iodide aerosols used in cloud seeding, which include silver iodide aerosol complexes such as silver iodide-silver chloride. Silver iodide is the primary component of silver iodide-based ice-nucleating complexes used in cloud seeding, and all these complexes will be referred to as silver iodide (**AgI**) in this statement. The published scientific literature clearly shows ***no environmentally harmful effects*** arising from cloud seeding with silver iodide aerosols have been observed; nor would they be expected to occur. Based on this work, the WMA finds that silver iodide is environmentally safe as it is currently being dispensed during cloud seeding programs.

Background

Silver and chemical compounds containing silver are used by various industries and small portions of this silver are emitted into the environment as a process waste product. Industrial sources were much larger in the past than they are today; notable sources include silver emissions from the photographic and electrochemical plating industries, urban refuse, sewage treatment plants, specialty metal alloy production and electrical components. In 1978 an estimated 2,740 metric tons (metric ton = 1,000 kg) of silver were released into the US environment. This led the US Health Services and EPA to conduct studies regarding the potential for environmental and human health hazards related to silver. These agencies and other state agencies applied the Clean Water Act of 1977 and 1987 to establish regulations on this type of pollution. Standards were established for industry and laboratory disposal practices of drain water into sewer systems, safe silver limits in the public water supply, and thresholds of adverse effects of silver on the biosphere. In 1978 cloud seeding activities were the source of about three metric tons of silver (as silver iodide) released into the environment, or about 0.1 per cent of the total (Eisler 1996). About the same amount of silver iodide is being used annually for cloud seeding activities in the U.S. and Canada today. Cloud seeding activities release silver iodide to the atmosphere over specific areas of the western states of the U.S., Canada and some other areas around the globe to augment rainfall, augment snowfall or reduce hail damage. Environmental impact studies related to silver iodide usage in cloud seeding were conducted starting in the 1960s and continue to be conducted today; all findings to date indicate no adverse environmental and human health impacts (ASCE 2004, 2006; WMA 2005; WMO 2007).

How much silver is released into the environment by cloud seeding?

Silver iodide is usually sold by commercial chemical company distributors in granular or powder form. It is used in combination with various other chemicals, most often salts, and has been used for half a century as a glaciogenic agent (microscopic sized particles, referred to as ice nuclei, ice forming nuclei, or occasionally freezing nuclei, that spawn ice crystal formation). Silver Iodide is considered water insoluble (solubility constant at $<10^{-9}$ g[of Ag] g^{-1} [of solvent-water]; see units note), which means that if one gram of the chemical is added to one gram of water, roughly one billionth of that gram of silver iodide would dissolve in to the water; the remainder will stay in the water undissolved. This property allows the silver iodide particles to maintain their structure prior to contact with supercooled (colder than freezing) cloud droplets. Silver iodide, as used in cloud seeding, is either dissolved in a flammable solution or combined with other flammable solids to produce seeding flares or other devices, which are burned to release submicron-sized, virtually invisible, silver iodide aerosol complexes into the atmosphere. These complexes are plentiful in number and increase the probability of ice crystals forming when they reach cloud environments at temperatures near or colder than the AgI ice nucleation (or crystallization) temperature threshold (about -5°C). This is significantly warmer than the threshold of most naturally occurring ice-forming nuclei, which commonly have thresholds near -15°C and colder.

Only small quantities of seeding material are released from individual cloud seeding generators typically in the range of 5-25 grams of silver iodide per hour from ground generators and up to a few kilograms per hour from aircraft depending on the size of the target area. Moreover, this is being done only during certain periods and locations of precipitation-producing weather systems. The reason that such small quantities can be used is that AgI dispensing systems generally produce up to 10^{15} (see power of 10's note) ice forming nuclei per gram of AgI expended (e.g., ASCE 2004, 2006). This means small amounts of AgI seeding material can produce tremendous numbers of ice crystal seeds that can create ice crystals, which can grow into snowflakes. The insolubility of AgI is a crucial factor for such small particles that allows them to maintain their identity (structure) intact and not condense water (and thus lose their structure) inside a cloud droplet. Without this property there would be no cloud seeding effect.

As a metric of cloud seeding chemicals, silver concentrations have been measured in the snowpack of several cloud seeding target areas in the western U. S. The average concentrations throughout the snowpack have generally ranged from 4-20 x 10^{-12} g[of Ag] g^{-1}[of solvent-water], rarely exceeding 100.0 x 10^{-12} g g^{-1} (Warburton *et al.* 1995a,b, 1996; McGurty 1999). Since seeding clouds could lead to rain (if snowflakes melt during their fall to earth) measurements of seeding chemical concentrations in the rainwater have also been done and found to be in similarly low concentrations (e.g., Sanchez *et al.* 1999).

Why is there concern about using silver iodide in cloud seeding?

It is well established that silver in some forms can be toxic to lower organisms without being toxic to higher animals (Kotrba 1968). Numerous controlled laboratory studies have shown that silver, silver nitrate and even silver iodide when added to laboratory aquariums, even at trace levels, can be toxic to some fish and other aquatic life when exposed over long time periods; the toxicity is related to specific compounds, concentrations and other factors such as water hardness, etc (e.g., Davies & Goettl 1978). However, these laboratory conditions bear little resemblance to outdoor freshwater bodies where the mobility of any of these silver compounds is essentially zero and these compounds are rapidly converted to less toxic compounds by the presence of other chemicals found in nature. Hence, they are not freely bio-available to the environment. Laboratory results derived from biological studies cannot be taken to imply any meaningful information about silver iodide used in cloud seeding because its insoluble nature makes it nearly impossible to dissociate sufficiently or rapidly enough to ever achieve toxic levels. Meaningful evaluation must include the specifics of the chemical form of silver (i.e., ionic silver, silver nitrate, silver iodide), the quantities involved, and the chemical, even physical, nature of the environment. Hence, care must be taken when comparing the potential impact of silver iodide on the environment as used in cloud seeding programs with the impact of silver or soluble silver in laboratory settings, which are not representative of the natural environment where cloud seeding is conducted.

Basis for asserting that cloud seeding using silver iodide has negligible environmental impact.

The potential environmental impacts of cloud seeding programs using silver iodide have been studied since the 1960s. These studies have all concluded that ice-nucleating agents, specifically silver iodide as used in cloud seeding, represent a negligible environmental hazard, (i.e., findings of no significant effects on plants and animals), (e.g., Cooper & Jolly 1970; Howell 1977; Klein 1978; Dennis 1980; Harris 1981; Todd & Howell 1985; Berg 1988; Reinking *et al.* 1995; Eliopoulos & Mourelatos 1998; Ouzounidou & Constantinidou 1999; Di Toro *et al*. 2001; Bianchini *et al*. 2002; Tsiouris *et al.* 2002a; Tsiouris *et al.* 2002b; Christodoulou *et al.* 2004; Edwards *et al.* 2005; Keyes *et al.* 2006; Williams & Denholm 2009).

The U.S. Public Health Service established a concentration limit of 50 micrograms of silver per liter of water in public water supply to protect human health (e.g., Erdreich *et al.* 1985). The concentrations of silver potentially introduced by modern cloud seeding efforts are significantly less than this level. The literature embodies tens of thousands of samples collected from cloud seeding program areas over a thirty-year period showing the average concentration of silver in rainwater, snow and surface water samples is typically less than 0.01 micrograms per liter. More importantly, these measurements represent the total amount of silver contained in any given sample and are not specific to the form of silver present in a sample. Nevertheless, these measurements show that silver is virtually undetectable in any form in the vast majority of the tens of thousands of samples collected from these areas.

More than 100 Sierra Nevada lakes and rivers have been studied since the 1980's (e.g., Stone 1986); no detectable silver above the natural background was found in seeded target area water bodies, precipitation and lake sediment samples, nor any evidence of silver accumulation after more than fifty years of continuous seeding operations (Stone 1995; Stone 2006). Many of these alpine lakes have virtually no buffering capacity, making them extremely susceptible to the effects of acidification and sensitive to changes in trace metal chemistry. Therefore studies were conducted as part of environmental monitoring efforts to determine if cloud seeding was impacting these lakes. No evidence was found that silver from seeding operations was detectable above the background level. There was also no evidence of an impact on lake water chemistry, which is consistent with the insoluble nature and long times required to mobilize any silver iodide released over these watersheds. Comparisons of silver with other naturally occurring trace metals measured in lake and sediment samples collected from the Mokelumne watershed in the Sierra Nevada indicate that the silver was of natural origin (Stone 2006). Similarly, Sanchez *et al.* (1999) analyzed the chemistry of water bodies and rainwater from samples collected during a summer cloud seeding program in Spain, and determined the silver input from cloud seeding to be indistinguishable from natural inputs. Greek scientists studying the effects on soils, plants and their physiology, atmospheric precipitation, plankton, animals and man, as well as the impact of irrigation and organic matter to AgI leaching from the Greek cloud seeding activities found similar results following the analyses of 2500 soil samples (e.g., Tsiouris *et al.* 2002a; Tsiouris *et al.* 2002b).

Summary

The published scientific literature clearly shows ***no environmentally harmful effects*** arising from cloud seeding with silver iodide aerosols have been observed, nor would be expected to occur. Based on this work, the WMA finds that silver iodide is environmentally safe as it is currently being used in the conduct of cloud seeding programs.

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NOTES:

Following are intended to help non-technically trained readers understand information provided above.

Power of 10's note: Very large and very small numbers are often expressed in scientific or powers of 10 notation. The 10^{15} stated in the WMA statement means that 1 is 10 multiplied by 10, 15 times and it equals 1,000,000,000,000,000. When 10 is raised to a negative power it means 1 divided by 10 the power number of times; for example, 1×10^{-1} equals 0.1.

Units note: $g\ g^{-1}$ as used here means grams of chemical divided by grams of water in the sample, so that $1 \times 10^{-12}\ g\ g^{-1}$ means 0.000000000001 grams of silver per 1.0 grams of water.