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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

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Dear Senator Schweiker:

This is in response to your request of September 22, 1971, for certain background information on cloud-seeding activities carried out in the United States under programs supported by the Federal agencies. Pursuant to the specific questions contained in your request, we directed our review toward developing information on cloud-seeding programs supported by Federal agencies, on the cost and purposes of such programs, on the impact of cloud seeding on precipitation and severe storms, and on the types of chemicals used for seeding and their effect on the environment. We also obtained data concerning the extent of cloud seeding conducted over Pennsylvania.

Our review was conducted at various Federal departments and agencies headquartered in Washington, D.C., and at certain of their field offices in Colorado and Montana. We interviewed cognizant agency officials and reviewed appropriate records and files of the agencies. In addition, we reviewed pertinent reports and documentation of the Federal Council for Science and Technology, the National Academy of Sciences, and the National Water Commission.

BACKGROUND AND COST DATA

Several Federal agencies support weather modification programs which involve cloud-seeding activities. Major research programs include precipitation modification, fog and cloud modification, hail suppression, and lightning and hurricane modification.

Statistics compiled by the Interdepartmental Committee for Atmospheric Sciences showed that costs for federally sponsored weather modification programs during fiscal years 1959 through 1970 totaled about $74 million; estimated costs for fiscal years 1971 and 1972 totaled about $35 million.

According to annual reports of the Committee, costs for Federal weather modification activities by research area and agency for fiscal years 1968 through 1972 are as follows:

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Research areas	1968 to 1970 actual	1971 to 1972 estimated	Total
	(000 omitted)		
Precipitation modification:			
Interior	$13,888	$12,000	$25,888
Commerce	1,983	1,888	3,871
National Science Foundation (NSF)	1,050	550	1,600
Total	16,921	14,438	31,359
Fog and cloud modification:			
Defense	4,215	2,806	7,021
Transportation	24	2,201	2,225
NSF	2,322	1,800	4,122
National Aeronautics and Space Administration (NASA)	545	230	775
Total	7,106	7,037	14,143
Hail suppression:			
NSF	3,300	4,400	7,700
Commerce	557	369	926
Total	3,857	4,769	8,626
Lightning modification:			
Agriculture	762	660	1,422
NSF	757	500	1,257
Commerce	369	342	711
Defense	230	69	299
Total	2,118	1,571	3,689
Hurricane modification:			
Commerce	725	2,428	3,153
Defense	325	125	450
Total	1,050	2,553	3,603
Total	$31,052	$30,368	$61,420

Other research involving weather modification supported by Federal agencies includes development of mathematical models of atmospheric conditions; studies of inadvertent modification; and studies of legal, economic, social, and ecological aspects of modifying the weather. Costs for such research for fiscal years 1971 and 1972 are estimated to total about $4.6 million.

Most weather modification efforts are based on the use of seeding agents to produce artificial nuclei on which water vapor and supercooled water can freeze or condense and alter the physical processes within clouds. The effects of seeding on a particular cloud depend on, among other things, the temperature of the cloud, the number of nuclei present, and the area of the cloud in which nuclei are added. In addition to being used for increasing and decreasing precipitation, seeding is used for influencing the type of precipitation and the electrical phenomena in the cloud. Such influence provides the basis for research on hail and lightning suppression.

Various methods are used to seed clouds from either the air or the ground. In aerial seeding flares containing silver iodide, the most commonly used seeding material in the United States, are ignited and dropped from a plane, or propane generators, attached to the wings of a plane, are used to burn acetone with silver iodide to produce nuclei which are delivered at controlled rates into the cloud. Propane generators are also used to seed clouds from the ground. Ground-based generators depend on prevailing winds to carry the nuclei to the clouds. Aerial seeding is considered to be more accurate than seeding from ground generators because aircraft can better deliver nuclei to those clouds or parts of clouds where the seeding material is desired.

Costs for cloud seeding, which is an integral part of a Federal agency's weather modification program, are generally commingled with other program costs and are not readily determinable as a separate cost activity. Seeding costs vary depending on the delivery system used. Aerial seeding, which makes extensive use of computers, radar, and aircraft, is generally recognized to be considerably more expensive than ground-based seeding. Air Force officials associated with the Air Force's weather modification program estimated that, exclusive of costs for personnel and capital investment, the hourly cost for seeding with ground-based generators was about $50 and for aerial seeding was about $647.50.

FEDERALLY SUPPORTED WEATHER MODIFICATION ACTIVITIES

Information concerning federally supported weather modification programs involving cloud-seeding activities to control precipitation, fog, hail, lightning, and hurricanes and any evidence of the impact that seeding has had on precipitation and severe storms are presented below.

Precipitation modification

The general purpose of precipitation modification research is to study and develop techniques to manage and control rain or snow. Federal support for precipitation modification research has been provided principally by three agencies--the Departments of the Interior and Commerce and NSF.

Department of the Interior 33

The Department of the Interior supports precipitation modification research under its Project Skywater, which was initiated in 1962. The project is administered by Interior's Bureau of Reclamation, and the research is carried out, in large part, by universities under contracts with Interior. Costs for Project Skywater from its inception through fiscal year 1972 are estimated to total about $28 million.

The primary objective of Project Skywater is to learn how to manage precipitation in water-deficient areas by seeding orographic (mountain-produced) clouds. Initially such seeding involved winter storm clouds only. Since 1963, 10 field experiments on winter-storm-cloud seeding have been conducted under the project at various locations in the western United States. Under these experiments winter storm clouds were seeded with silver iodide mainly by ground generators in an attempt to increase snowfall. According to Interior the experiments indicated that seeding orographic winter storm clouds would increase snowfall when the temperature of the cloud tops was approximately between -12°C. and -22°C. and would decrease snowfall when the temperature was outside these limits. On the basis of these experiments, Interior has estimated that seasonal snowfall in the western United States can be increased by 10 to 30 percent.

Experiments involving seeding summer cumulus clouds under Project Skywater started in 1965. These experiments involved aerial seeding of cumulus clouds with silver iodide, salt, dry ice, or urea to induce additional rainfall. Such

experiments included cloud seeding over Arizona, Oklahoma, and Texas in 1971 to alleviate drought conditions in those States. According to Interior, in some cases the summer-cumulus-cloud-seeding experiments resulted in increased precipitation and in other cases it resulted in decreased precipitation. Therefore Interior considers experiment results to date to be inconclusive.

2 Department of Commerce 74

The Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) supports precipitation modification research on summer cumulus clouds and winter storm clouds under its National Cumulus Modification Project and its Great Lakes Snow Redistribution Project, respectively. In contrast with Interior's Project Skywater, which involves orographic clouds, these projects concern tropical cumulus clouds and winter stratus clouds, which are produced by the interactions of water and air over lakes.

The National Cumulus Modification Project is aimed at increasing rainfall from tropical cumulus clouds. Experimental seedings of such clouds with silver iodide were conducted initially over the Carribbean Sea in 1963 and 1965. Since 1968 such experiments have been conducted over Florida. Seeding under the project is done with silver iodide flares which are dropped directly into suitable clouds from airplanes. Project costs for fiscal years 1968 through 1972 are estimated to total about $2.1 million.

The results of these experiments, according to NOAA, indicate that seeded clouds, on the average, yield more than three times as much rain as unseeded clouds. NOAA has estimated that seeding individual clouds yields 100 to 250 acre-feet of additional water for each cloud and that seeding two single clouds which merge can yield approximately 20 times as much water as two singly seeded clouds which do not merge. However, it has not been determined whether the seeding techniques developed for tropical cumulus clouds in Florida would be applicable in other parts of the country.

The primary objective of the Great Lakes Snow Redistribution Project is to alleviate the heavy snowfalls which annually hamper Buffalo, New York, and other cities located along the shoreline of Lake Erie. In 1968 and 1969 snowstorms occurring early in the winter were seeded with silver iodide and dry ice in an attempt to redistribute snow further inland from the normal heavy accumulations along the southeastern shore of

Lake Erie. Significant redistribution has not been accomplished to date through these experiments. Similar seeding experiments were planned to be continued through 1972. Costs under this project for fiscal years 1968 through 1972 are estimated to total about $1.7 million.

3 National Science Foundation 95

NSF has supported precipitation modification research through grants, principally to Colorado State University. Since 1961 the NSF has supported a cloud-seeding project which was initiated by Colorado State University near Climax, Colorado, in 1959. The objective of the research was to determine the effects of seeding winter orographic clouds with silver iodide delivered from the ground. Through fiscal year 1972 NSF grants for winter-cloud seeding to Colorado State University totaled about $1.3 million.

The National Water Commission report entitled "Precipitation Modification," dated July 1971, stated that the NSF-supported experiments at Climax "offered conclusive evidence that under certain meteorological conditions precipitation can be substantially increased or decreased." The results of these experiments have provided, in large part, the basis for Interior's winter orographic seeding research conducted under Project Skywater in Colorado.

Fog modification

The principal objective of fog modification research has been to study and develop methods for dissipating fog. The 4 Department of Defense has been the principal Federal supporter 5 of research concerning warm- and cold-fog dissipation. For fiscal years 1968 through 1972 Defense has estimated that costs for such research will total about $7 million.

Defense's modification program for warm fog (temperature above 0°C.) has focused on the development of three techniques to promote the dissipation of fog. Only one of these involves seeding with chemicals. The other techniques are based on mixing fog with drier, warmer air from above by using the downwash created by helicopters or with warm air produced by ground-based burners.

Cloud-seeding experiments to dissipate warm fog were conducted by Defense in northern California in October 1968 and October 1969. Other seeding experiments were conducted at

McClellan Air Force Base, California, during January 1971. In these experiments fog was seeded with salt or urea. Defense has had only limited success in developing techniques to dissipate warm fog.

To dissipate cold fog (temperature below 0°C.), however, Defense has successfully developed techniques for aerial and ground-based cloud seeding with dry ice and propane, respectively. Defense intends to develop an operational cold-fog-modification program for use, when necessary, at military installations.

Other Federal agencies which have supported fog modification research are the Department of Transportation, NSF, and NASA. Much of the research supported by these agencies has been laboratory related and has not involved cloud-seeding activities.

Hail suppression

Hail suppression research seeks to develop modification techniques that will restrict the size of hailstones and that will thus reduce their damage potential. NSF has been the lead agency for Federal support of hail suppression research, and the NSF's cost for such research for fiscal years 1966 through 1972 is estimated to total about $7.9 million.

In 1966 NSF funded a 1-year pilot field experiment--Project Hailswath--in which hailstorms over South Dakota and Colorado were seeded with silver iodide and dry ice. Similar experiments were conducted during the period 1968 through 1970 under a project called Joint Hail Project.

In 1971 the NSF initiated a new research program called the National Hail Research Experiment to study hailstorms over a target area in Colorado by using ground meteorological networks, instrumented aircraft, ground and airborne radar, and other techniques. From these observations, mathematical models of representative hailstorms will be developed and a number of hail suppression techniques will be tested by computer simulation. NSF's National Center for Atmospheric Research at Boulder, Colorado, has primary responsibility for management of the experiment in which other Federal agencies, several universities, and private institutions will participate. Under the experiment exploratory seeding with silver iodide over northeastern Colorado is planned during five summer seasons beginning in 1972.

Lightning modification

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5/ The Department of Agriculture is the major Federal supporter of lightning modification research. Agriculture supports such research under its Project Skyfire which is administered by the Forest Service. Project Skyfire was initiated to test various cloud-seeding techniques for their effects on the lightning characteristics of thunderstorms and to develop methods to prevent forest fires caused by lightning. Project costs for fiscal years 1968 through 1972 are estimated to total about $1.4 million. Project costs prior to 1968 were not available.

Experimental seeding with silver iodide was conducted under Project Skyfire in western Montana during 1960, 1961, and 1965 through 1967. Although research under the project continues, no seeding has been conducted since 1967. Agriculture has noted that the electrical process in clouds is not fully understood; however, research results have indicated that seeding can reduce the number of lightning strokes and the duration of the strokes associated with a single storm and thus can lessen the chance that the lightning will cause a forest fire. Additional research is necessary to determine more specifically the predictable effects of seeding lightning.

Other Federal agencies have provided limited support for lightning modification research. In 1966 Defense supported aerial seeding of lightning storms with metallic nylon chaff over Flagstaff, Arizona. These experiments indicated the possibility that electrical fields in storms could be discharged by chaff seeding before they reached the strength necessary to generate lightning.

Commerce has supported research directed toward developing lightning detection techniques and toward exploring techniques for artificially triggering lightning. NSF has supported laboratory research to examine the relationship between cloud electricity and precipitation and to explore the possibility of inducing rainfall by injecting electrical charges into clouds.

Hurricane modification

The earliest cloud-seeding experiment to modify a hurricane was conducted in 1947 under Project Cirrus, which was

sponsored by Defense. The results of the experiment could not be assessed because, at the time, the dynamics of hurricanes were not sufficiently understood.

To better understand hurricanes the National Hurricane Research Project, more commonly referred to as Project Stormfury, was initiated in 1956. This project was jointly funded by Commerce and Defense. Project Stormfury was designed to explore the structure and dynamics of hurricanes and to develop a seeding technology to reduce the maximum surface winds associated with hurricanes. Costs to be incurred under the project during fiscal years 1968 through 1972 by Commerce and Defense are estimated to total about $3.1 million and $450,000, respectively. Cost information for the project prior to 1968 was not available.

Under Project Stormfury, four hurricanes--all on the Atlantic Coast--were seeded with silver iodide. In 1961 Hurricane Esther was seeded, and in 1963, 1969, and 1971 Hurricanes Beulah, Debbie, and Ginger, respectively, were seeded. According to Commerce, decreases in the wind velocity of seeded hurricanes were noted in these experiments, but the level of the decreases were within the range of natural variability of hurricane winds. Therefore additional research was necessary before a definite determination could be made as to the degree to which hurricanes could be modified by seeding.

ECOLOGICAL EFFECTS OF CLOUD-SEEDING AGENTS

As noted earlier, silver iodide has been the most commonly used chemical in weather modification experiments. Other seeding agents which have been used by public and private seeders include salt, urea, dry ice, propane, and metallic nylon chaff.

Regarding the use of silver iodide for seeding, a report entitled "Ecological Effects of Modification: A Problem Analysis," dated May 1969 and sponsored by Interior, states that "all available evidence indicates little likelihood of environmental effects" from the iodine in silver iodide. However, the report notes that the possible consequences of silver, which, in some respects, is one of the most toxic of heavy metals, are not so easily resolved. The report indicates that the use of silver iodide as a seeding agent presents no direct hazard to humans because the immediate concentrations of silver and iodine in the air and rainfall

will be exceedingly small. The report points out that, with rare exceptions, there is substantially less silver in precipitation from seeded storms than is allowed by the U.S. Public Health Service standard for drinking water. Thus the report states that:

> "*** Preliminary indications are that it will not concentrate to harmful levels through either terrestorial or aquatic food chains. The threat of environmental contamination from silver iodide does not seem great enough to preclude its use at this time. Close attention should be given to the problem, however."

According to Defense reports on fog modification projects, salt is corrosive to metals and detrimental to plant life and therefore is not practical for seeding in populated areas or over airport runways. These reports also indicated that urea is nontoxic and noncorrosive to metals, protected surfaces, and animal tissue and that it is highly beneficial to plant life.

Dry ice and liquid propane, according to the Program Manager for NSF's weather modification program, have no known adverse ecological effects when used as seeding agents. Concerning metallic nylon chaff, the Program Manager said that chaff is aluminized nylon threads which are inert and which have no known adverse ecological effects.

CLOUD SEEDING OVER PENNSYLVANIA

In 1967 the State of Pennsylvania enacted legislation requiring State licensing and regulation of weather modification activities carried out in Pennsylvania. We interviewed cognizant officials of various Federal agencies that sponsor weather modification research, and they advised us that their respective agencies had not supported cloud-seeding experiments over Pennsylvania from enactment of the legislation. Also, an official of the Pennsylvania Department of Agriculture, which is responsible for administering the requirements of the law, told us that the State had not issued any licenses for cloud seeding.

We trust that the above information is responsive to your needs. We have previously returned the material on cloud

seeding that your office made available for our use in this review.

Sincerely yours,

Comptroller General
of the United States

cc+R
The Honorable Richard S. Schweiker
United States Senate