

# Standard Practice for the Design and Operation of Supercooled Fog Dispersal Projects

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# **Standard Practice for the Design and Operation of Supercooled Fog Dispersal Projects**

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# STANDARDS

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The following standards have been issued:

ANSI/ASCE 1-82 N-725 Guideline for Design and Analysis of Nuclear Safety Related Earth Structures  
ASCE/EWRI 2-06 Measurement of Oxygen Transfer in Clean Water  
ANSI/ASCE 3-91 Standard for the Structural Design of Composite Slabs and ANSI/ASCE 9-91 Standard Practice for the Construction and Inspection of Composite Slabs  
ASCE 4-98 Seismic Analysis of Safety-Related Nuclear Structures  
Building Code Requirements for Masonry Structures (ACI 530-02/ASCE 5-02/TMS 402-02) and Specifications for Masonry Structures (ACI 530.1-02/ASCE 6-02/TMS 602-02)  
ASCE/SEI 7-10 Minimum Design Loads for Buildings and Other Structures  
SEI/ASCE 8-02 Standard Specification for the Design of Cold-Formed Stainless Steel Structural Members  
ANSI/ASCE 9-91 listed with ASCE 3-91  
ASCE 10-97 Design of Latticed Steel Transmission Structures  
SEI/ASCE 11-99 Guideline for Structural Condition Assessment of Existing Buildings  
ASCE/EWRI 12-13 Standard Guidelines for the Design of Urban Subsurface Drainage  
ASCE/EWRI 13-13 Standard Guidelines for the Installation of Urban Subsurface Drainage  
ASCE/EWRI 14-13 Standard Guidelines for the Operation and Maintenance of Urban Subsurface Drainage  
ASCE 15-98 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)  
ASCE 16-95 Standard for Load Resistance Factor Design (LRFD) of Engineered Wood Construction  
ASCE 17-96 Air-Supported Structures  
ASCE 18-96 Standard Guidelines for In-Process Oxygen Transfer Testing  
ASCE 19-10 Structural Applications of Steel Cables for Buildings  
ASCE 20-96 Standard Guidelines for the Design and Installation of Pile Foundations  
ANSI/ASCE/T&DI 21-13 Automated People Mover Standards  
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ASCE/SEI 24-05 Flood Resistant Design and Construction  
ASCE/SEI 25-06 Earthquake-Actuated Automatic Gas Shutoff Devices  
ASCE 26-97 Standard Practice for Design of Buried Precast Concrete Box Sections  
ASCE 27-00 Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction

ASCE 28-00 Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction  
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SEI/ASCE 37-02 Design Loads on Structures during Construction  
CI/ASCE 38-02 Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data  
EWRI/ASCE 39-03 Standard Practice for the Design and Operation of Hail Suppression Projects  
ASCE/EWRI 40-03 Regulated Riparian Model Water Code  
ASCE/SEI 41-06 Seismic Rehabilitation of Existing Buildings  
ASCE/EWRI 42-04 Standard Practice for the Design and Operation of Precipitation Enhancement Projects  
ASCE/SEI 43-05 Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities  
ASCE/EWRI 44-05 Standard Practice for the Design and Operation of Supercooled Fog Dispersal Projects  
ASCE/EWRI 45-05 Standard Guidelines for the Design of Urban Stormwater Systems  
ASCE/EWRI 46-05 Standard Guidelines for the Installation of Urban Stormwater Systems  
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ASCE/SEI 59-11 Blast Protection of Buildings  
ASCE/EWRI 60-12 Guidelines for Development of Effective Water Sharing Agreement

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## FOREWORD

The Board of Direction approved revisions to the ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed by ASCE. All such standards are developed by a consensus standards process managed by the ASCE Codes and Standards Committee. The consensus process includes balloting by a balanced standards committee and reviewing during a public comment period. All standards are updated or reaffirmed by the same process every five years if at all possible. Requests for formal interpretations shall be processed in accordance with Section 7 of ASCE Rules for Standards Committees, which are available at [www.asce.org](http://www.asce.org). Errata, addenda, supplements, and interpretations, if any, for this standard can also be found at [www.asce.org](http://www.asce.org).

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This standard, ASCE/EWRI 44-13, is a combination of ASCE/EWRI 44-05 and its supplement. The supplement covered

substantive content and some editorial changes to Sections 1.2.1 through 1.2.5, Section 5.0, and Section 7.0, alone; the content in the remaining ASCE/EWRI 44-05 sections was unchanged. The supplement was prepared and developed through the ASCE consensus standards process, the remainder was undertaken by the AWM SC, then the final consensus for the Revision of ASCE/EWRI 44 was conducted before trying to obtain acceptance by ANSI. ASCE/EWRI 44-13 has been prepared in accordance with the ASCE Standards Writing Manual, August 20, 2010, revision with recognized engineering principles and should not be used without the user's competent knowledge of the underlying principles for a given application.

The American Society of Civil Engineers (ASCE) recognizes the work of the Atmospheric Water Management Standards Committee of the Environmental and Water Resources Institute (EWRI). The primary authors of this standard were the EWRI Atmospheric Water Management Standards Committee's Fog Dispersal Ad Hoc Subcommittee members: Thomas P. DeFelice (chair), Conrad G. Keyes, Jr., Darin Langerud, and Maurice Roos. We also acknowledge the many who contributed their comments, reviews, illustrations, and photographs.

Thomas P. DeFelice, PhD, ASCE Mem,  
WMA CO, PMP, Maryland

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## CHAPTER 1.0 INTRODUCTION

Fogs can pose a significant threat to public safety and quality of life in the air, on land, and at sea. For example, the luxury liner *Andrea Doria* collided with the *Stockholm* in fog off New York and sank on its 1956 maiden voyage. Fifty-one people died and millions of dollars in property were lost (Silverman and Weinstein 1974). An airliner (Flight VD8387) overran the runway in heavy fog after landing in Yichun, in northeastern China, killing 43 passengers on August 24, 2010. Extended periods of fog can have large economic impacts on the aviation, tourism, transportation, and mining industries (ASCE/EWRI 2005). For example, in the early 1970s one fog at one U.S. airport caused an estimated \$100,000 loss of revenue due to aircraft diversions, delays, and cancellations (Silverman and Weinstein 1974). The total annual weather impact on U.S. aviation is an estimated \$3 billion for accident damage and injuries, delays, and unexpected operating costs, and weather is a primary contributing factor in 23% of all aviation accidents (Kulsea 2002).

Although extended foggy periods can have negative impacts on agriculture and the mental health of the general public, there are some situations in which fog is beneficial, such as where fog water is collected for drinking water in arid regions (e.g., Schemenauer 1998), and where fog supplies some of the necessary moisture to vegetation. For example, fog supplies needed moisture to the northern California redwood trees during the summer dry season (e.g., Schemenauer 1998). Another example is the notorious winter fog in the San Joaquin Valley of California, which provides an important portion of the winter dormancy requirements of many deciduous orchard crops in the region. The San Joaquin valley fogs are also known as “tule” fogs and are in the category of “warm fogs” that are not normally supercooled, as their temperatures are often just above freezing (ASCE/EWRI 2005).

The harmful effects on transportation alone have been sufficient justification for attempts to modify or disperse fogs. Silverman and Weinstein (1974) note that fog was the subject of the first scientifically designed weather modification effort of any kind. This may partially explain why supercooled fog dispersal is perhaps the only weather-modification technology that does not require long experimentation and careful measurement to detect results, because results are both visible and nearly instantaneous. The most frequently cited goal of any supercooled fog dispersal project is to increase visibility. An increase in the local temperature can be a by-product of the clearing activities. Fog dispersal operations reduce the threat to public safety by increasing the visibility over highways and airport runways. Dispersing fog to increase visibility, especially at airports, has tremendous economic value—particularly at the local level—as transportation returns to normal levels. Additional sunshine resulting from fog dispersal operations can often improve the quality of life for specific

populations. Fog clearing in open-pit mines can allow the safe resumption of mining operations that were suspended due to decreased visibility (ASCE/EWRI 2005).

Ice fogs are a special case and are slower to dissipate than supercooled fogs because they are composed mostly of tiny ice crystals and they generally form at air temperatures below about 243°K (−30°C) (e.g., Huffman and Ohtake 1971). Ice fog dispersal is fundamentally different from the dispersal of supercooled fogs and may be more appropriately labeled *ice fog suppression*. Ice crystals predominate and form by *heterogeneous nucleation* and, in some instances, by *homogeneous nucleation*. Ice fogs are primarily caused by unnatural sources of water vapor, which may include automobile and aircraft exhaust, exhaust from utility plants, and open water, such as cooling ponds (ASCE/EWRI 2005). Benson (1969) indicated that decreasing the ambient temperature of these moisture sources did improve visibility. Most attempts to disperse ice fogs have included electric fields, dehydrators of various types (e.g., gas, furnace, automobile), air movement by helicopters, polyethylene rafts, plastic films (e.g., polyethylene), injection wells, cooling towers, and chemical films (e.g., hexadecanal, ethylene glycol monobutyl ether). Presently, the standard technique used to suppress ice fog caused by exposed water sources employs a thin ethylene glycol monobutyl ether film. This film is harmless to marine life (it is biodegradable) and lasts much longer than other films, but it is less effective in suppressing ice fog than hexadecanal film (ASCE/EWRI 2005). McFadden (1976) and McFadden and Collins (1978) provide details of these techniques. Ice fog suppression techniques will not be discussed in this document. The focus of this standard is on the dispersal of supercooled fog.

### 1.1 HISTORICAL REVIEW OF SUPERCOOLED FOG DISPERSAL OPERATIONS

Supercooled fog is colloidally stable but is otherwise in a thermodynamically metastable state (e.g., Silverman and Weinstein 1974). Thus, supercooled fog can be dissipated by growth and sedimentation of ice crystals. Seeding supercooled fog with ice-forming particles (*nuclei*) may yield visibility improvements of at least 1.6 km (1 mi) within 15 min following seeding (Fig. 1-1). The results are so repeatable that randomized statistical verification is generally considered unnecessary. As a result, supercooled fog dispersal has been operational since 1950 in the United States and since 1952 in Russia. The most frequent locations of these operations are at airports. Suitable seeding techniques are primarily dependent upon wind, temperature, and the supercooled liquid water amount. Some involve the introduction of artificial ice nuclei into the air from either ground-based or airborne delivery systems. Other techniques employ liquid carbon dioxide, nitrogen, or propane to disperse fogs. Liquid

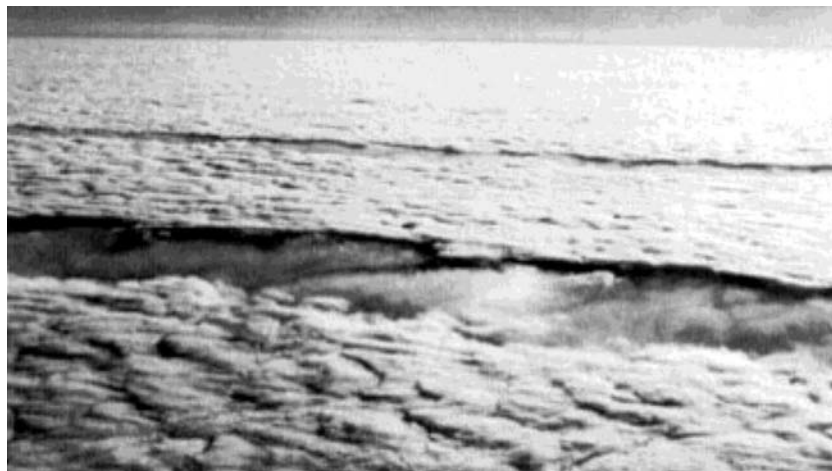


FIG. 1-1. Long rectangular hole cut through a stratus cloud using crushed dry ice at the rate of about 1 kg/km (Schaefer, 1948, 1953; WMA 1997).

nitrogen is used in ground-based systems at a few airports in some countries.

Fog-clearing operations are required under U.S. law to be reported to the National Oceanic and Atmospheric Administration (NOAA). However, it would appear that some supercooled fog dispersal projects may not be reported to NOAA. For example, there were nine fog dispersal activities reported during 1973 (Charak 1981), whereas there were three each year between 1991 and 1993 according to Blackmore (1992, 1994), and no fog activities were reported to NOAA during 1998. These numbers do not necessarily reflect a sharp reduction of fog dispersal activities. Sponsors should periodically publish the results of these activities, because knowing about them could improve our understanding of fogs and their impacts on society and the environment.

The remainder of this document includes capability statements for fog dispersal and an abridged version of the physics of supercooled fog formation and dispersal, as well as recommendations for planning, organizing, conducting, and evaluating a supercooled fog dispersal operation.

## 1.2 THE STATUS OF SUPERCOOLED FOG DISPERSAL TECHNOLOGY

In 1964 the National Science Board appointed a Special Commission of Weather Modification, chaired by Dr. A. R. Chamberlain, which found that "Supercooled fog on the ground can be dissipated" (NRC 2003). Since then, several policy and/or capability statements on the subject of supercooled fog dispersal have been created. The following sections summarize the present perspectives of the scientific establishment on the subject of supercooled fog dispersal.

**1.2.1 American Society of Civil Engineers.** The ASCE Policy Statement 275 (ASCE 2012) on atmospheric water resources management reads:

*The American Society of Civil Engineers (ASCE) supports and encourages:*

- *The protection and prudent development of atmospheric water (also known as "weather modification" or "cloud seeding") for beneficial uses.*
- *Sustained support for atmospheric water data collection, research and operational programs, and the careful*

*evaluations of such efforts, including the assessment of extra-area and long-term environmental effects.*

- *Freely disseminating the results and findings of all atmospheric water-management programs and projects to the professional community, appropriate water managers and to the public.*

The ASCE Manual of Professional Practice No. 81, *Guidelines for Cloud Seeding to Augment Precipitation* (ASCE/EWRI 2006) offers guidelines that cover general cloud-seeding projects and techniques.

**1.2.2 Weather Modification Association.** The most recent excerpts relating to supercooled fog dispersal from the capability statement adopted by the Weather Modification Association (WMA 2011) read:

*The dispersal of shallow, supercooled (colder than 0°C) fog or stratus cloud decks is an established operational technology. The effects from dispersing supercooled fog and stratus are easily measured and the results highly predictable. Hence, randomized statistical verification has generally been considered unnecessary.*

*Dispensing ice phase seeding agents, such as dry ice, liquid nitrogen, liquid propane, or silver iodide into supercooled fog and stratus is effective in improving visibility. Clearings established in cloud decks embedded in strong wind fields fill in quickly, unless seeding is nearly continuous. Selection of a suitable technique is dependent upon wind, temperature, and other factors. Dry ice has commonly been used in airborne delivery systems. Liquid carbon dioxide, liquid nitrogen, and liquid propane have been used in ground-based delivery systems at some airports.*

**1.2.3 American Meteorological Society.** Excerpts relating to fog clearing from the most recent capability statement adopted by the American Meteorological Society, *Planned Weather Modification through Cloud Seeding* (AMS 2010), read:

*In its most common form, specially formulated aerosols or very cold materials are dispersed in targeted locations within clouds to achieve precipitation enhancement, hail damage mitigation, fog clearing, and other intentional effects. Cloud seeding techniques have been developed over nearly 70 years through experimentation and trials. ...*

*Planned weather modification programs benefit from a comprehensive understanding of the physical processes responsible for desired modification effects. Recent improvements in the composition and techniques for dispersion of seeding agents, observational technology, numerical cloud models, and in physical understanding of cloud processes permit ever more detailed design and targeting of planned weather modification effects, and more accurate specification of the range of anticipated responses. ...*

*Affects are often immediately evident in simple situations, such as when cloud seeding is used to clear supercooled fog and low stratus cloud decks. ...*

*This statement is considered in force until November 2013 unless superseded by a new statement issued by the AMS Council before this date.*

**1.2.4 World Meteorological Organization.** Excerpts from the WMO capability statement on supercooled fog dispersal (WMO 2010) read as follows:

*The ability to influence cloud microstructures has been demonstrated in the laboratory, simulated in numerical models, and verified through physical measurements in some natural systems such as fogs, layer clouds and cumulus clouds. ...*

*In principle, all types of fog can be dispersed by sufficient heating or mechanical mixing, though such methods are often impractical and expensive. ... Dispersal of supercooled fogs using glaciogenic materials or coolants is well established as a reliable technique feasible in certain meteorological conditions. ...*

*The relative occurrence of cold fogs is geographically and seasonally dependent.*

*Cold (supercooled) fog can be dissipated by growth and sedimentation of ice crystals. This may be induced with high reliability by seeding the fog with artificial ice nuclei from ground-based or airborne systems. This technique is in operational use at several airports and highways where there is a relatively high incidence of supercooled fog. Suitable techniques are dependent upon wind, temperature and other factors. Dry ice has commonly been used in airborne systems. Other systems employ rapid expansion of compressed gas to cool the air enough to form ice crystals. For example, at a few airports and highway locations, liquid nitrogen or carbon dioxide is being used in ground-based systems. A new technique, which has been demonstrated in limited trials, makes use of dry ice blasting to create ice crystals and promote rapid mixing within the fog. ...*

*Because the effects of glaciogenic cloud seeding are easily measured and the results are highly predictable, randomized statistical verification generally has been considered unnecessary.*

*Weather modification is sometimes considered by countries when there is a need to improve the economy in a particular branch of activity (for example, increase in water supply for agriculture or power generation) or to reduce the risks that may be associated with dangerous events (frosts, fogs, etc.). Besides the present uncertainties associated with the capability to reach such goals, it is necessary to consider the impacts on other activities or population groups.*