Seeding Materials for Weather Modification

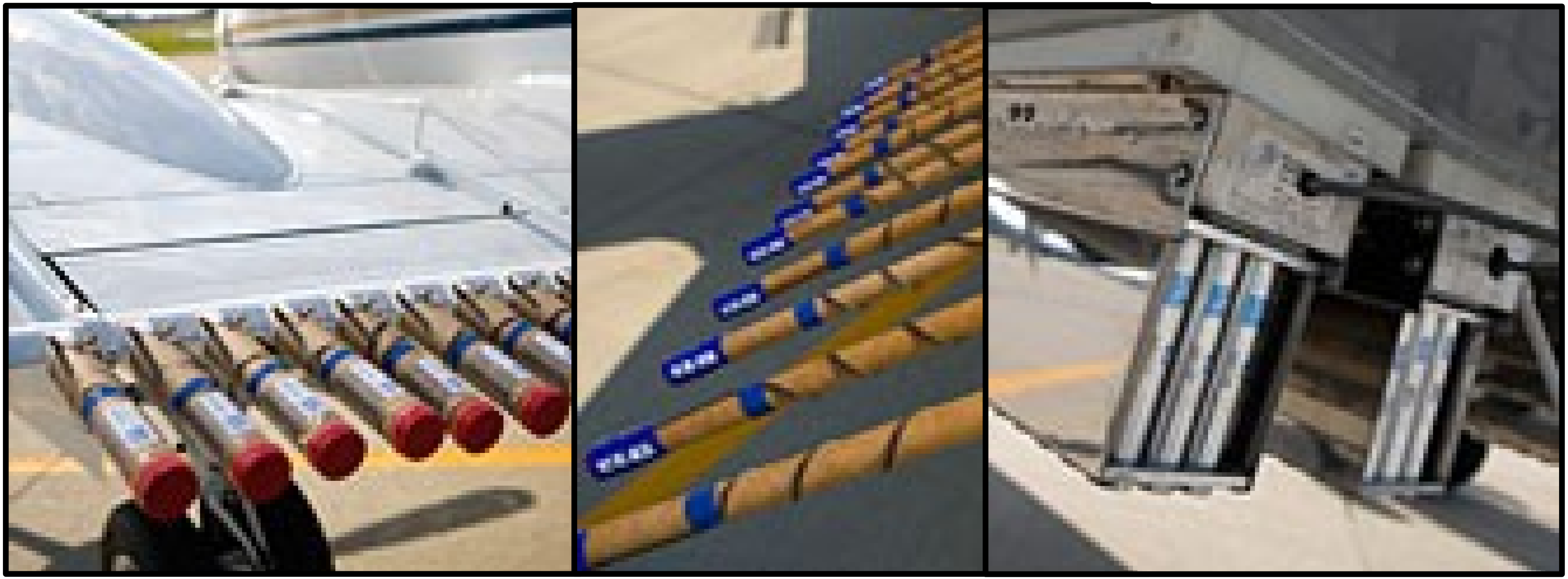


Image showing hygroscopic burn-in-place seeding flares (left), AgI burn-in-place seeding flares (middle), and AgI ejectable flares.

Goals for Applying Seeding Materials

- To produce large droplets (hygroscopic seeding) or ice crystals (glaciogenic seeding) in clouds.
- Need proper material / equipment.

Considerations

1. Program Objectives
2. Overall Cost
3. Production of Particles
4. Delivery of Material

Image showing ejectable flare racks on bottom of aircraft fuselage.

Generator Types

- Liquid
  - Uses acetone for hot flame.
  - Needs a carrier to put AgI into solution.
- Pyrotechnic
  - AgIO3, Al, Mg, binder.
  - Burn-in-place or ejectable.

Image showing end burners (top) and burning hygroscopic flare.

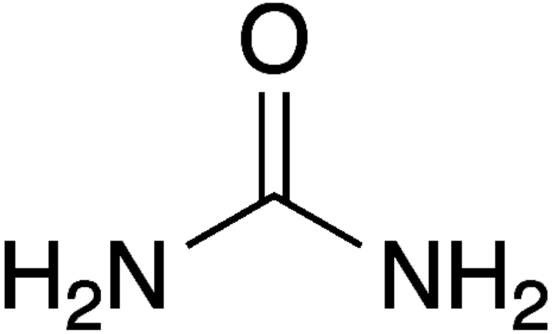
Hygroscopic Materials for Seeding

- What does hygroscopic mean?

Image showing salt (left) and hygroscropic flares in a over-wing rack on a King Air 200 aircraft (right).

Hygroscopic Nuclei Chemistry

- Objective is to broaden the cloud droplet size distribution in order to promote the collision-coalescence mechanism.
- Commonly used materials (various mixtures):
  - NaCl - most common.
  - NH_4OH (Ammonium Hydroxide)
  - Urea (Also Called Carbamide) ->



Hygroscopic Seeding Requirements

- Must create many hygroscopic particles.
- Typically dispersed at cloud base.

Image showing unused hygroscropic flares (left) and a three hygroscopic flares installed, along with AgI flares, on an aircraft seeding rack (right).

Pyrotechnics: Hygroscopic Flares

- Flares burn hot (>2000 ºC).
- Solids are vaporized.
- Vapors quickly cool and form very small solid compounds in extremely large numbers.
- These particles coagulate (stick together) to form larger seeding particles.
- CCN concentrations ~20,000 cm^{-3}.

Initial Losses of Nuclei

Initial rate of decrease due to Brownian Coagulation in concentration of a monodispersed aerosols as a function of particle diameter (D) and Concentration (Na)

D (μm)	N (m^{-3})		
	$10^{13.5}$	10^{14}	$10^{14.5}$
10	1 %	3 %	10 %
1.0	1 %	3 %	10 %
0.1	2 %	7 %	20 %
0.01	3 %	9 %	30 %

Percent Decrease per Second

Glaciogenic Seeding Requirements

- Must generate AgI particles (small).
- Particles must nucleate ice crystals.
- Material/Crystals must be dispersed through cloud volume.

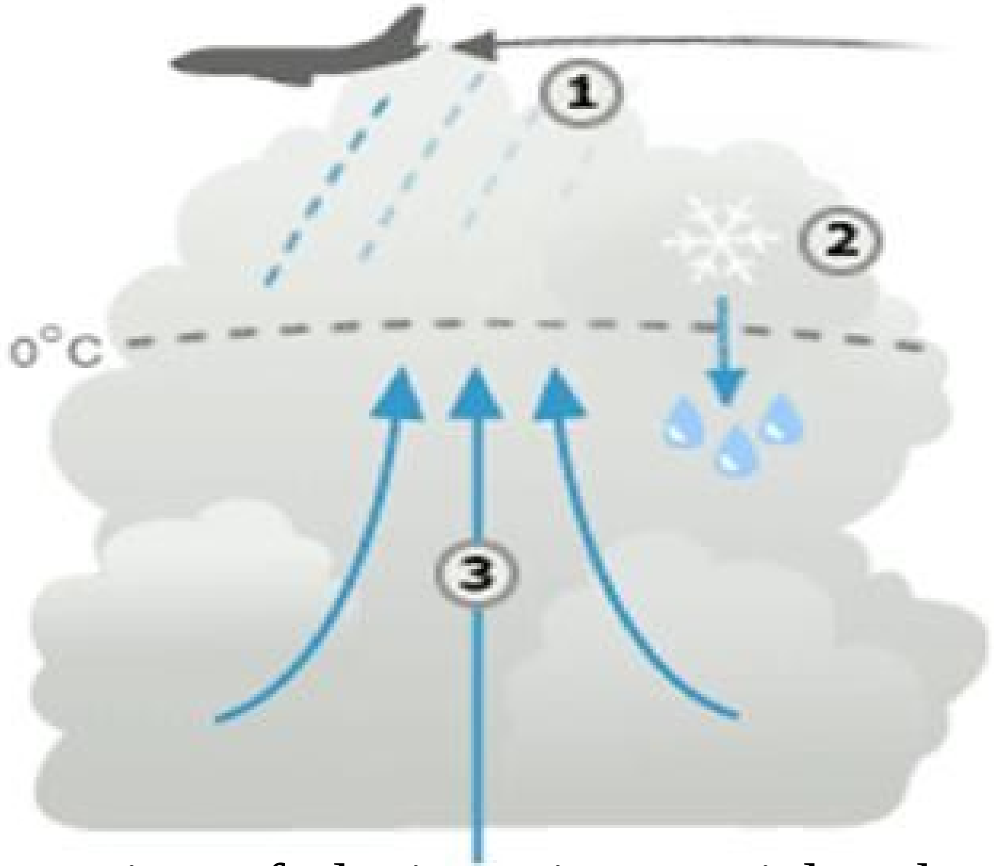


Image showing release points of glaciogenic material at the top of the cloud (1), within the cloud (2) and below the 0 °C.

Generation of Ice Nuclei Requirements

- Want to get maximum number of effective ice nuclei per mass of AgI.
  - Cost efficiency.
  - Operations efficiency (i.e., weight, time of operations, etc.).

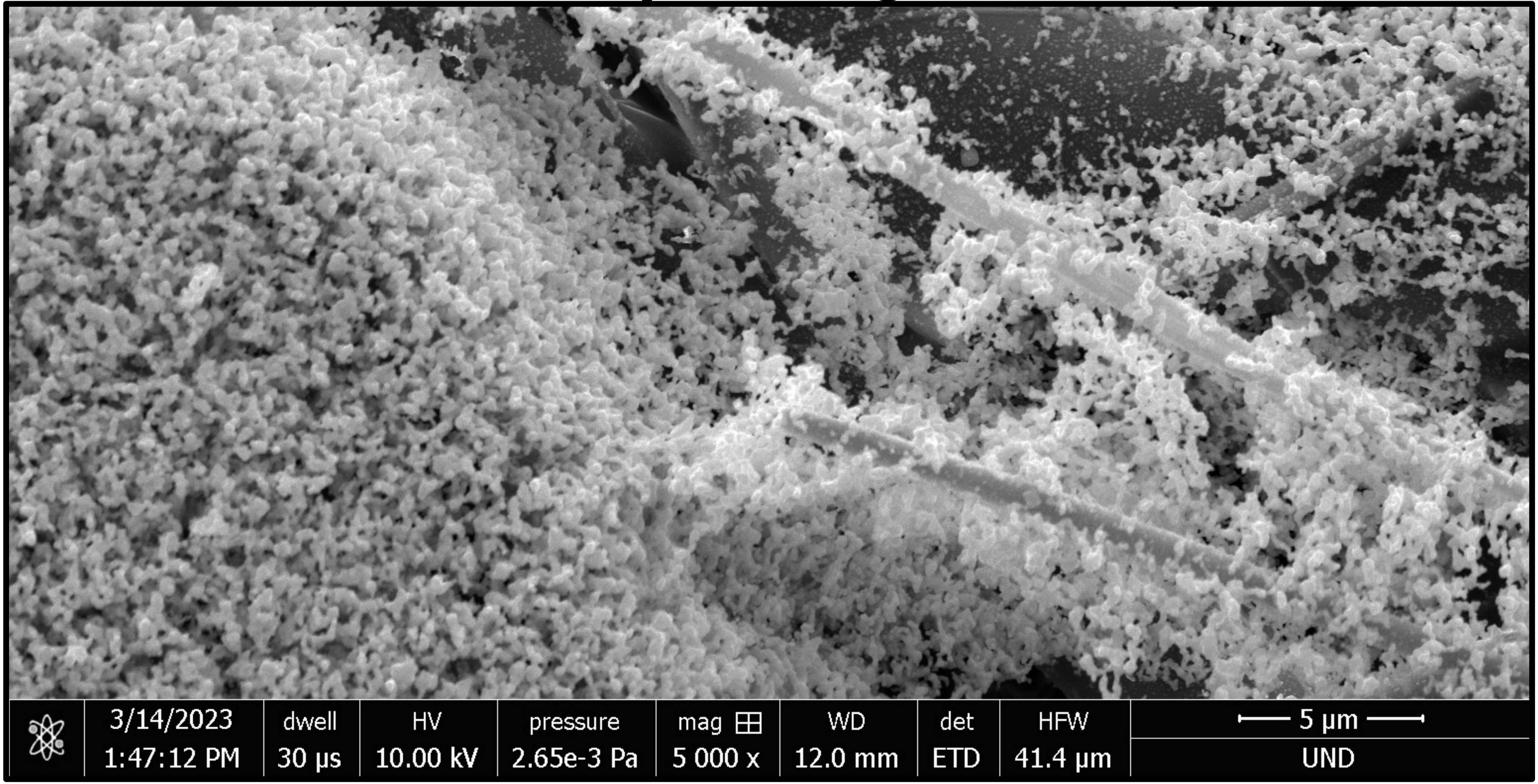
Image showing particle filer.

Cloud Seeding Generators

- May create either liquid or solid particles.
- Normally used to create glaciogenic particles, but can work for certain hygroscopic particles.
- Works by vaporizing the seeding material, such as AgI in acetone.
- Requires temperatures greater Than 1000 °C.

Cloud Seeding Generator outside of Clifford Hall in March of 2022.

Electron Microscope Images from Generator



Particle Yields of AgI Flares

- Particles created by cooling of vapor.
- Need good airflow.
- Particles coagulate.
- Maximum yield about 10^{15} particles per m^3.
- Approximately 10^{14} Ice Nuclei per gram AgI are produced by efficient seeding compounds.

AgI Cloud Seeding Efficiency

- Definition: Number of particles per gram of AgI producing ice crystals at a given Temperature.
- May vary as a function of Temperature.
- Difficult to test.

Image showing burn-in-place AgI seeding flares install on aircraft rack.

Sliver Iodide Efficiency (Activity)

- Ice Nucleation efficiency of silver iodide at -20 °C on a particle count basis.

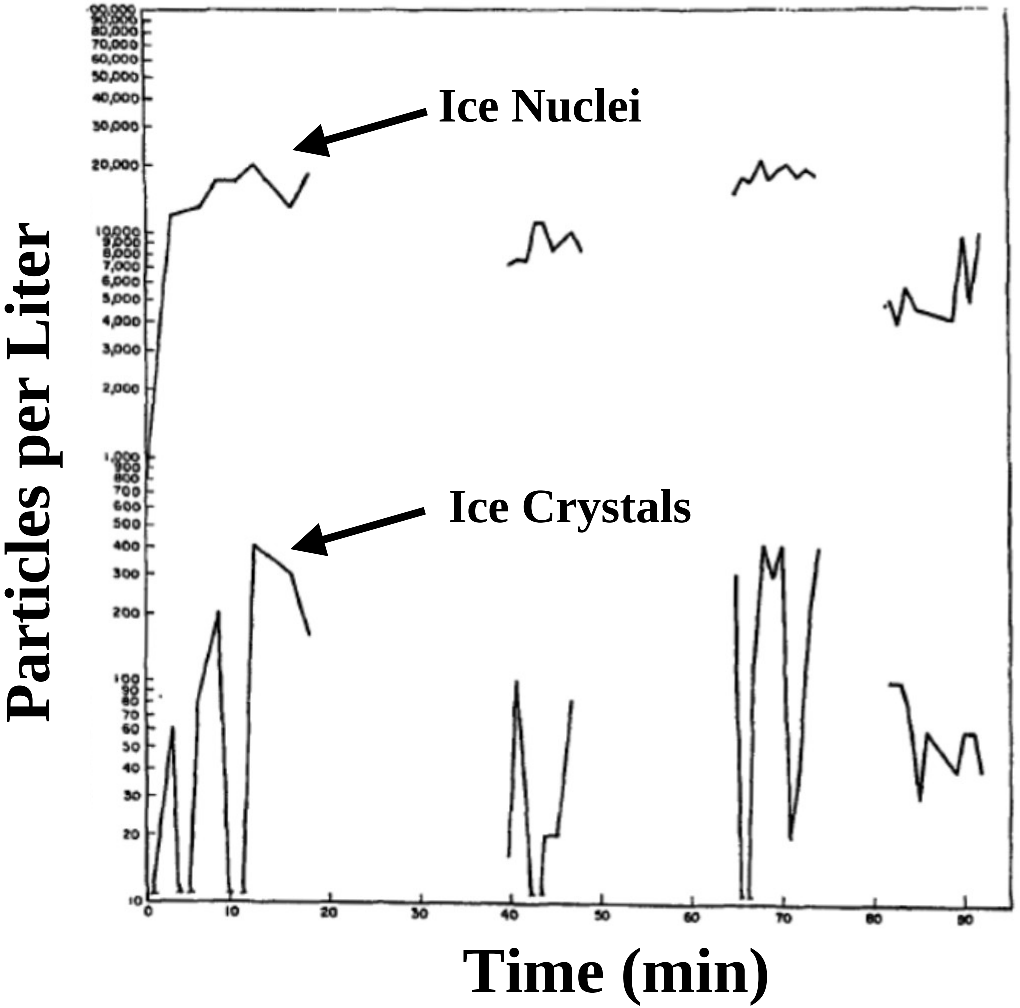


Figure 4 from Langer, et al., 1967, J. Appl. Meteor., 6, 963-965 showing that ice nuclei are two orders of magnitude larger than ice crystal concentration.

Yields and Efficiency for Cloud Seeding

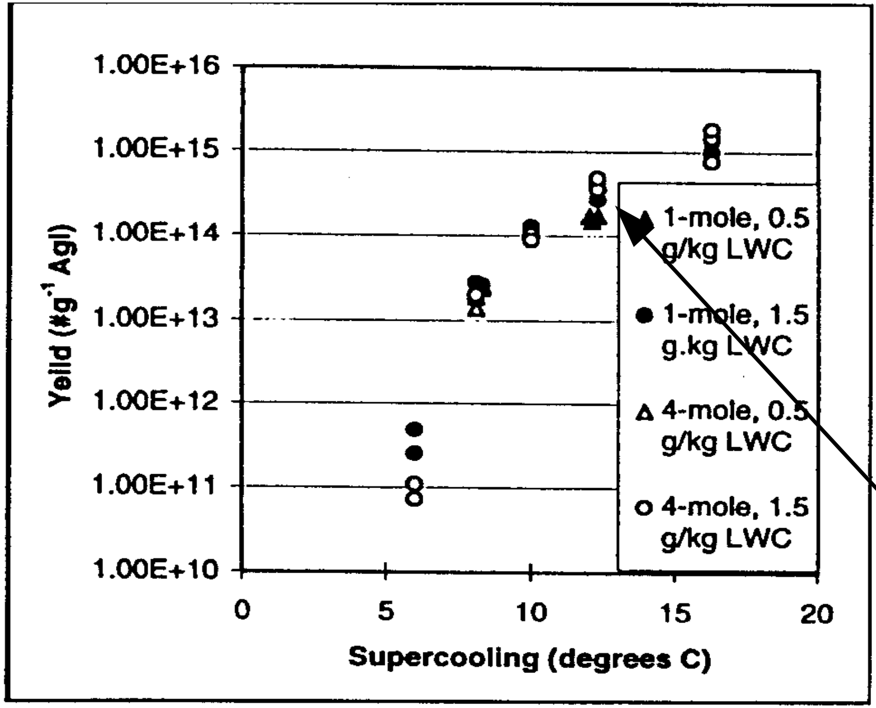


Figure 32. *Effectiveness for $AgI_{0.8}Cl_{0.2}$-NaCl and $AgI_{0.8}Cl_{0.2}$-4NaCl nuclei (DeMott 1997).*

5.3 ACTIVITY OF SILVER IODIDE PARTICLES 111

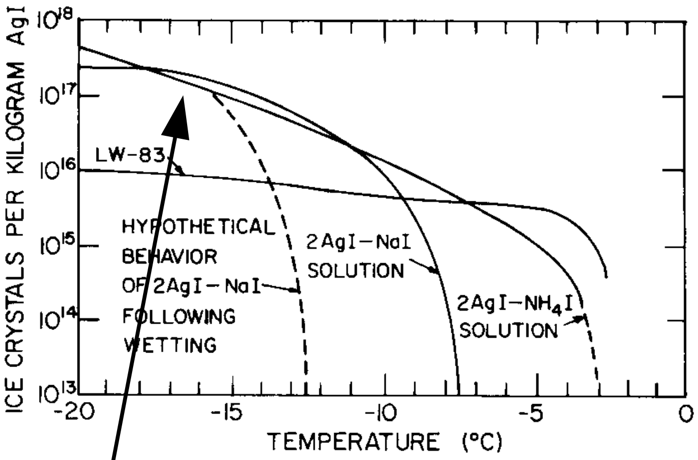


Fig. 5.5. Activity curves for AgI generator products measured in wind tunnel/cloud chamber facility at South Dakota School of Mines and Technology by J. A. Donnan. [After P. St.-Amand *et al.* (1971b). *J. Weather Modification* **3**, 31, by permission of Weather Modification Association and senior author.]

Images showing approximately 10^{14} Ice Nuclei per gram AgI.

Particle Activity

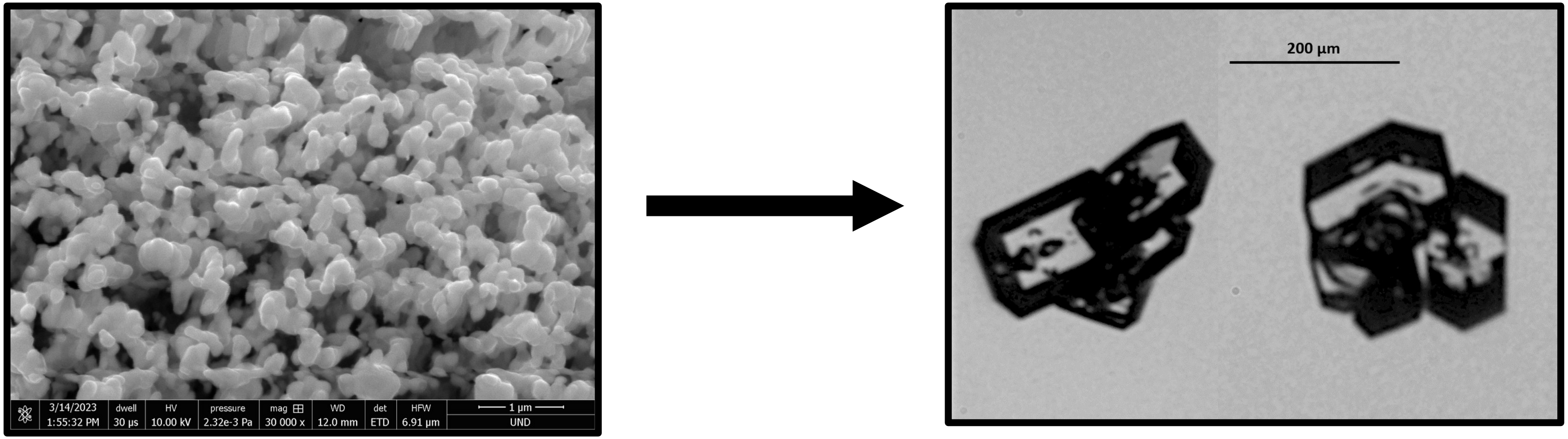
- Activation: Formation of an ice crystal on a nucleus.
- Modes of Activation: Deposition, condensation freezing, contact, and bulk freezing.
  - Ideally, would produce many crystals at warm temps (-5° C), none at cold.

Types of Particle Activation

- Deposition – Requires larger nuclei and is effective only at colder temperatures.
- **Condensation Freezing – Relatively effective.**
- **Contact – Requires high concentrations to act very quickly.**
- Bulk Freezing – Nucleus may dissolve.

Activation Rate

- Speed of ice nucleation is critical.
- Rate is a function of formulation, temperature, liquid water content.
- The condensation/freezing activate type is fastest.



Ice nuclei image (left) that are critical to ice formation (right).

Activation Rate

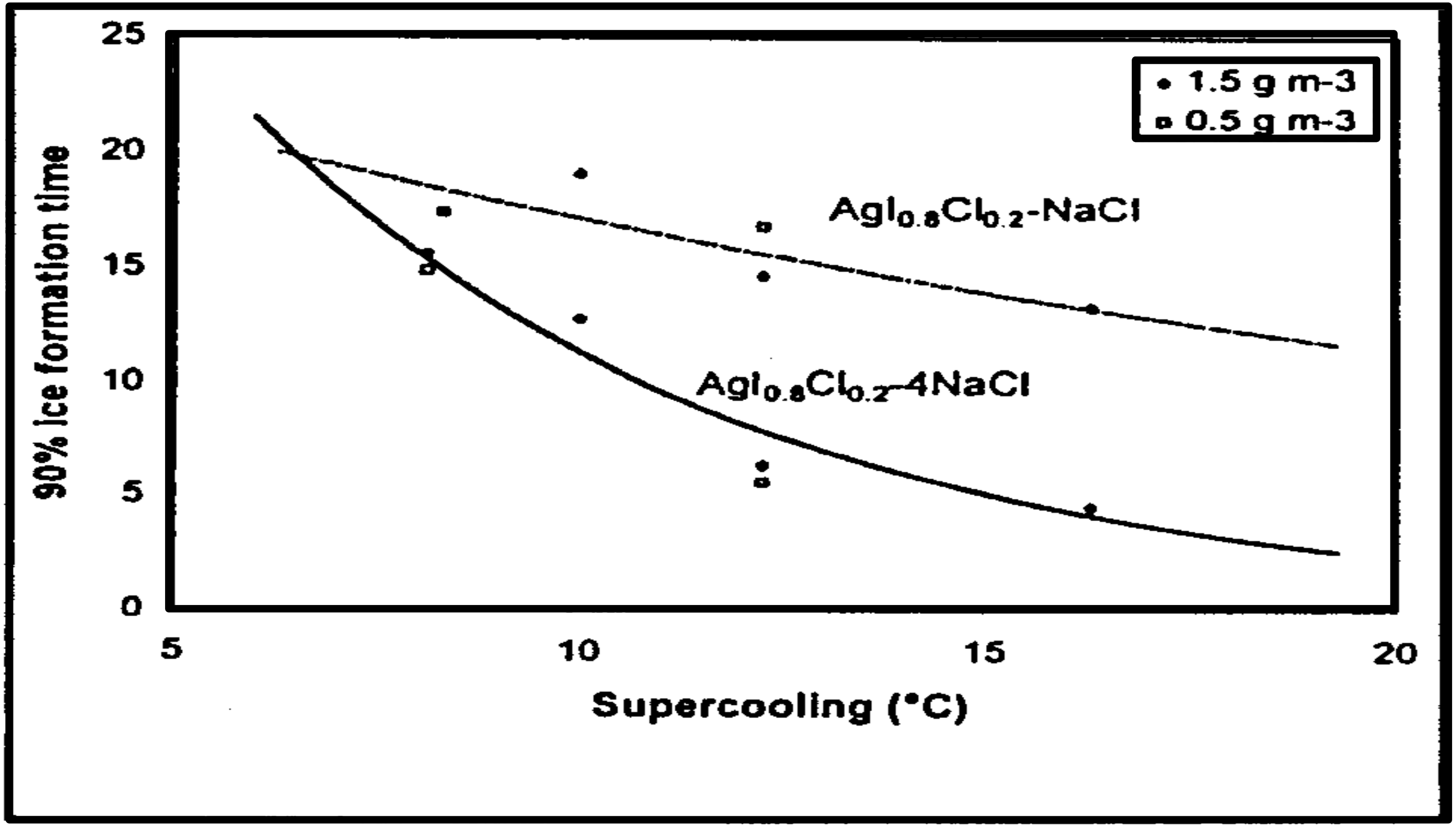


Figure 33 from DeMott 1997 showing activation times of of AgI containing particles used in the North Dakota Cloud Modification Program.

Deactivation (Lose of Activation Ability)

- By UV rays: loss of nucleation ability, up to 90% in one hours.
- By solution.

Image of the Sun

Photodeactivation of AgI

- When exposed to UV radiation, the iodine is dissociated from the silver and will go off as a gas.
- The silver remains on the outside of the particle, leaving a coating of silver.
- Pure silver is not an effective ice nuclei.

Photodeactivation of AgI

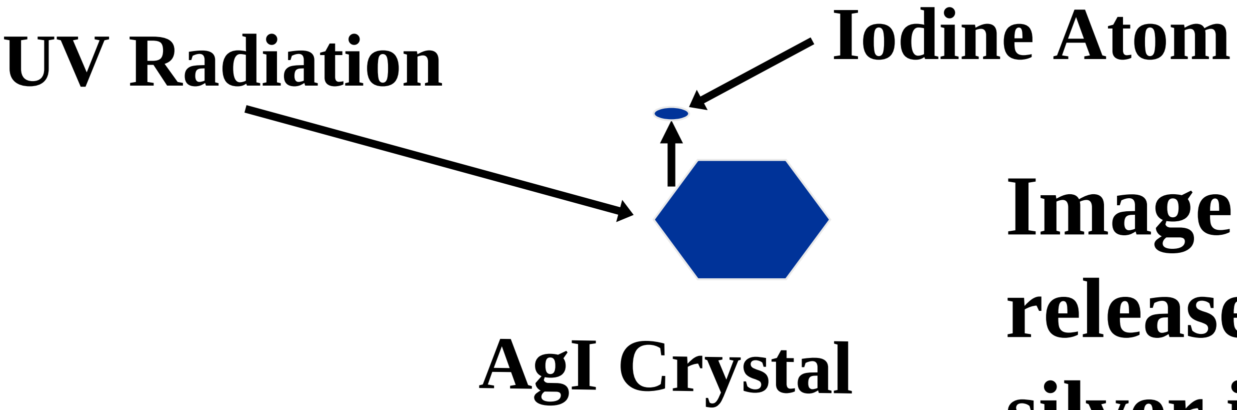


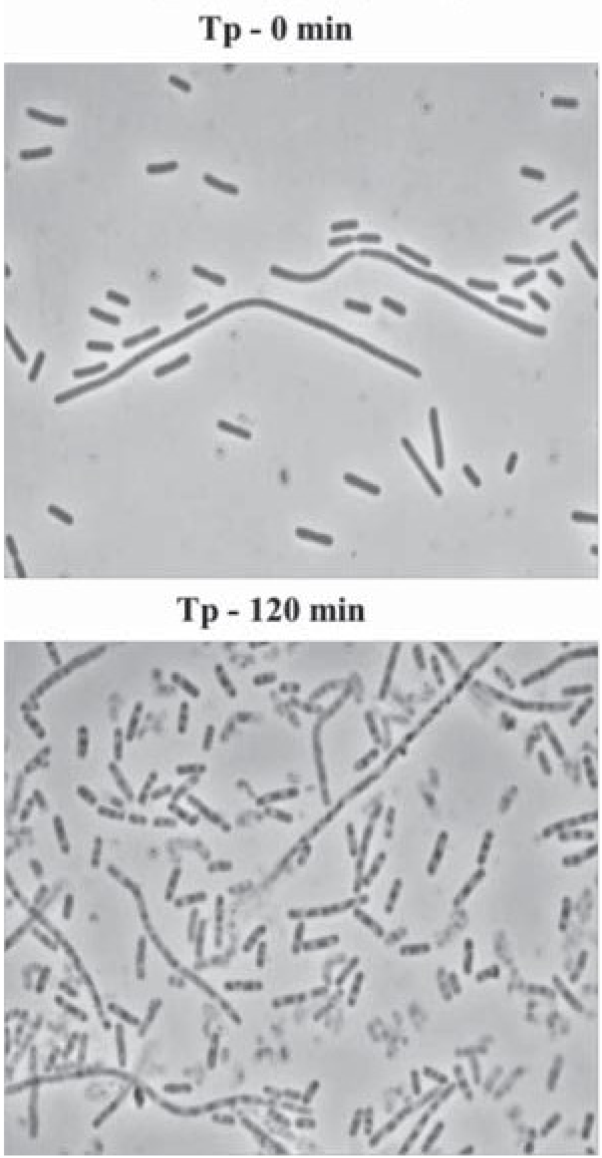
Image showing that the release of iodine from the silver iodide leaves silver behind as a coating on the AgI crystal.

Summary of Key Attributes

- Particle Efficiency
  - Number of active ice nuclei per gram of seeding agent.
- Particle Activity
  - Number of active ice nuclei as a function of temperature.
- Activation Rate
  - Speed of activation.

Other Materials

- Pseudomonas syringae (solid baterial) is a rod-shaped, Gram-negative bacterium with polar flagella. (Wikipedia, 2015).
- Naturally occurring.
- Causes water to freeze on plants.



Images showing the E. Coli C41 fabricated organic ice nuclei (OIN).

Pseudomonas Syringae

- These proteins serve as effective nuclei to initiate the formation of ice crystals at relatively high temperatures, so that the droplets will turn into ice before falling to the ground.

Images showing snow generator.

Liquid Propane

- Release of liquid propane as a gas from a dispenser chills the air to as cold as -100 °C.
- Because of the tremendous local chilling, LP release can generate ice crystals at temperatures as warm as -0.5 °C.
- Rate is approximately

  4 oz/min.

Images showing an instrument to measure snow depth.