PRELIMINARY INVESTIGATION
of
A NEW GENERATOR FOR SILVER IODIDE

USING ISOPROPYLAMINE AS THE CARRIER

by

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Introduction

Silver iodide has been dispersed to supercooled clouds from a complex of silver iodide and sodium or potassium iodide in acetone by various combustion processes. Work with dispersion systems using anhydrous ammonia as the carrier has been reported by the author (1) (2). Both thermal and non-thermal systems were investigated with the former showing the most promise. However, the logistics of processing the anhydrous ammonia in the thermal system are complex. The ammonia will not support its own combustion so a supporting fuel is required. This led to considerations of other substances which would have similar characteristics in regard to their behavior as AgI carriers, but would have higher boiling points and heating values. A boiling point of greater than 25C at 760mm Hg would avoid pressurized storage and flashing in the fluid handling system. A reasonably high heating value would avoid the use of a supporting fuel.

Substances which have all these desirable characteristics are amines, hydrocarbon-ammonia compounds. The concept of using amines was first suggested by Dr. W. B. Finnegan of the Naval Ordnance Test Station, China Lake, California. This led to investigation in the laboratory where several were found to have the desired characteristics. Of these, the most promising to date is isopropylamine, $(CH_3)_2CHNH_2$, although several others may be applicable. Isopropylamine hereinafter referred to as IPA boils at 31C at 760mm pressure. It has a heating value of approximately 18000 Btu/lbm. The material complexes readily with AgI at concentrations to as high as 60% IPA by mass.

Advantages of IPA

One can well ask, is there really an advantage of IPA as compared to the conventional system? There are several advantages which may be listed as follows:

1. Higher concentrations of Ag I may be used without corrosion or deposition.

2. Solution preparation is simple and direct. No KI or NaI is needed.

3. Straight IPA may be used to keep the system clean.

4. No supporting fuel is needed.

5. Higher effectiveness (nuclei per gram AgI).

Some discussion of the above points is in order. The first is an advantage only if high concentrations produce nearly equal generator performance per unit mass of carrier that low concentrations produce. Preliminary data indicates that this is not as serious a problem with IPA as with acetone systems. As to deposition, and corrosion, there are none at reasonable concentrations if copper bearing materials are not used. A complex of IPA at 30% concentration will always complex more AgI. This is not usually true of AgI-KI or NaI acetone systems since excess KI or NaI in this complex is normally undesirable. A 30% solution in acetone will not pick up AgI deposits without excess KI or NaI.

Item two yields a distinct advantage. The complex is prepared by simply adding the desired amount of AgI directly to the IPA. The complex is formed upon slight agitation.

The third item is related to the second. Should a deposit form anywhere in the fuel handling system, it is "washed away" by the straight IPA. This statement at first

appears to be contradictory to item (1). However, a deposit will form wherever a system is shut down, since the carrier will evaporate in most any system, and deposit the AgI. A purge is therefore necessary to keep the system clean. There is no deposition from precipitation as in acetone systems.

The fourth point is a real advantage in comparison to those systems which use supporting fuel. A supporting fuel complicates the logistics in a field situation. For example, the use of propane as a supporting fuel gives rise to operating problems at low ambient temperatures due to the corresponding low propane pressure. Furthermore, a supporting fuel means the addition of another operating system which may limit reliability.

The last item (5) is discussed in a separate section.

Disadvantages of IPA

There are two disadvantages to IPA as compared to acetone. These are:

1. Somewhat higher carrier cost.

2. Toxicity

Carrier costs are higher with IPA but not markedly so. IPA costs about twice as much as acetone. However, the major cost in dispersion of AgI is the AgI. Furthermore, no KI or NaI is needed nor is a supporting fuel. These factors offset the higher carrier dispersion cost. In the case of no supporting fuel, IPA dispersion would be about 12% more than acetone. When delivery costs and logistics are included the IPA system is definitely competitive.

The second disadvantage can be a problem since IPA is about as toxic as anhydrous ammonia. However, the solution can be prepared in the open air or under a standard laboratory hood with no danger if rubber gloves and goggles are used.

IPA Storage and Handling

The complex of AgI and IPA should be handled in about the same way as anhydrous ammonia except that it need not be stored under pressure. It attacks any copper bearing material readily. It does not attack carbon steel or aluminum. It softens teflon but has no effect on nylon. It deteriorates most rubbers. Steel or aluminum containers are suggested for storage of the complex. Aluminum tubing and fittings are recommended for piping. Stainless steel is best suited to valving and spray nozzles.

IPA Generator Design

The prototype IPA generator was designed with simplicity the keynote. A schematic of the unit is depicted in Figure 1. A photograph of the unit in operation at Yellowstone* in January of this year is shown in Figure 2 along with other photos. The fuel storage system consists of a tank which is fitted with a dip tube. It is filled about 7/8 full with solution. The remaining volume serves as a cushion for the pressurized gas which is connected to the tank after filling. The dip tube is connected to the nozzle with appropriate tubing, valves and fittings all of which are aluminum or stainless steel. The nozzle is a convential oil burner nozzle with stainless steel substituted for the usual brass construction. The nozzles are stock items.

The nozzle is centered in a swirl plate through which air is supplied via an 1850 rpm squirrel cage blower. An orifice and a baffle are inserted between the blower and the swirl plate to distribute the air for proper mixing of air and fuel in the combustion chamber. The combustion chamber is matched to the nozzle spray pattern so that the flame will not impinge on the chamber walls thus preventing combustion deposits and attendant problems with the ignition system.

The particular prototype was designed to burn 1/2 gal. of 3% solution per hour at a nozzle pressure of 100 psi. The solution flow can be increased to about 2 gal/hr. by changing nozzles and the orifice in the air distribution system. The dispersion rate of

*NSF Yellowstone Field Research Expedition, VI

AgI can also be increased by operating at higher solution concentrations. At 3% concentration, the dispersion rate is 42 grams/hr. At 6%--84 grams per hour. The predicted maximum capacity of this prototype is therefore 336 grams per hour. Capacities of 1000 grams per hour are feasible with simple design changes.

Generator Effectiveness

The effectiveness of the IPA generator vs. temperature is shown in Fig. 3. For comparative purposes, the effectiveness of the CSU modified skyfire generator and the hot ammonia generator are also shown. It is seen that the effectiveness over the temperature spectrum of the IPA unit at 3% concentration is greater than that of the modified skyfire. It falls short of the hot ammonia system. However, it is believed that further improvements will yield the same results as with ammonia. Preliminary data for 6% concentration is encouraging. The effectiveness is good at -20C but falls sharply as the temperature is increased. Investigation of the higher concentrations is continuing. It appears that the reason for the drop in effectiveness is due to particle size which is related to atomization, air fuel ratio and temperature. Since the effectiveness is as high as for 3% at -20C, adjustment of the system parameters should result in the same effectiveness for 6% as for 3%.

Field Test

The field performance of the IPA generator was evaluated at Yellowstone National Park during the 6th Field Research Expedition (3). The supercooled fogs produced by Old Faithful Geyser and neighboring sources were seeded and replicas of the resulting precipitation particles were collected for analysis of the seeding operation. A continuous particle replicator developed by E. Hindman of CSU was employed. Replicas were also taken by hand using slides.

Old Faithful was seeded with the IPA generator on 24 January during the intervals 0712-0722 and 0856-0918 MST. A map showing the seeded area is included as Fig. 4. The replicator was positioned approximately 1/2 mile from Old Faithful in a position such that only effects of the AgI seeding would be observed since dry ice seeding was done on the same date from 0712-0900. This was accomplished by separating the seeding sites with respect to the prevailing fog drift. The upwind component carried the AgI toward the CO_2 seeding site and slightly away from the replicator. This had the conservative effect of reducing the maximum observable crystal concentration. A time-sequence synopsis of data and events of and during the testing is presented in graphic form in Figures 5 and 6, which show the relationship between crystal concentration and time. Note that there was a negligible effect of the CO_2 seeding during the 0856-0918 run since the former was stopped at 0900.

The ice crystal data from the replicator was used to estimate the crystal concentration in the seeded area. This can be done since the film speed, aperature, crystal count and settling velocities are functionally related to the crystal concentration. The following settling velocities were assumed to calculate crystal concentrations in the volumes sampled which are shown in Figures 5 and 6.

Crystal Type	Settling Velocity	References
Plane Dendritic	30 cm/sec	Nakaya, 1954,
Hexagonal Plates		Ludlum, 1955,
300-400 μ	30	Todd, 1964
200-300 μ	20	
100-200 μ	10	
20-100 μ	2	

The concentrations of hexagonal plates Figure 6 were calculated by subdivision of the size-velocity relation. Crystal concentrations on Figure 5 are for dendrites. More confidence can be placed in this data due to the singular settling velocities of this crystal type.

According to Mason (1953), hexagonal plates, stellar and dendritic crystals form in the -10C to -25C range. The replicas and prevailing air temperatures of the 24 January tests are in quite close accord with Mason's observations. However, some simple hexagonal plates without ribs or surface markings occurred, indicative of formation in the 0C to -5C range. It is probable that the latter formed in the warmer part of the geyser plume.

Size of stellars and dendrites ranged from 200-900μ with a very few in the 900-1300μ range. Most were under 600μ, indicating a fall path of less than 700m in most cases (Ludlam, 1955). Considering the rise of the plume of Old Faithful, such a fall path is conceivable. This reduces the possibility that some of the crystals fell from clouds above the seeding area. Hexagonal plates observed were primarily in the 70-300μ range (total range, 20-500μ). These indicate a fall path less than about 400m.

Returning again to Figures 5 and 6 it is seen that there was a distinct effect from the seeding operation. The data for Fig. 5 is more reliable than Fig. 6 for reasons cited above. Shortly after the generator was started the crystal count rose abruptly. This was also very evident as one walked from the generator site to the counting site. Further evidence of the effect is the return of the crystal count with the wind shift which is shown in Fig. 4. (Time is for the sampling site.) This tends to bar any natural effect. Observed crystal sizes also strongly suggest that these came from the seeded supercooled fog rather than from the clouds above.

A discussion of mechanical performance in the field concludes this section. The unit performed well with no operating problems. It was stored outside. Pressurization was accomplished by means of a small air compressor. The nozzle was cleaned after use. This process would not be required if an IPA purge system were incorporated in the design.

Conclusions

Preliminary data indicate strongly that Isopropylamine - Silver Iodide complexes can be processed thermally to produce ice Nuclei at rates and mass efficiencies competitive with existing systems. Experience using a 3% solution of AgI in IPA has been sufficient to warrant using the unit in field operations. Data for the 6% and higher concentrations is encouraging. Additional investigation should produce as high an effectiveness as with 3% solutions. Investigations of other amines should be carried out along with the effect of flow rate of solution at a given concentration.

The data from the field test is conservative. Distinct seeding effects were produced by the generator.

REFERENCES

1. Steele and Krebs: Characteristics of Silver Iodide Ice Nuclei originating from Anhydrous Ammonia-Silver Iodide complexes. Atmospheric Science - Technical Paper No. 73. Mechanical Engineering Technical Paper No. 66.1 - Colorado State University

2. Steele, R. L. and Sciacca, F. W.: Characteristics of Silver Iodide Ice Nuclei Originating from Thermally Processed Complexes of Silver Iodide and Ammonia. (Paper to be presented at 6th International Conference on Condensation Nuclei, Albany, New York, May 1966).

3. Steele, R. L. and Reinking, R. F.: Super Cooled Fog Seeding and Particle Replication. Report, Yellowstone Field Research Expedition VI, State University of New York, Albany, N. Y.
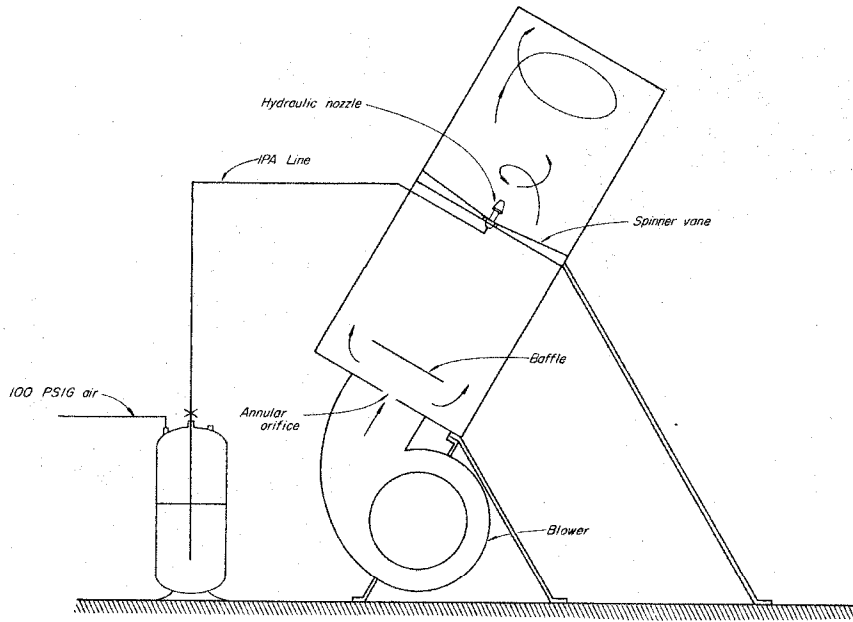
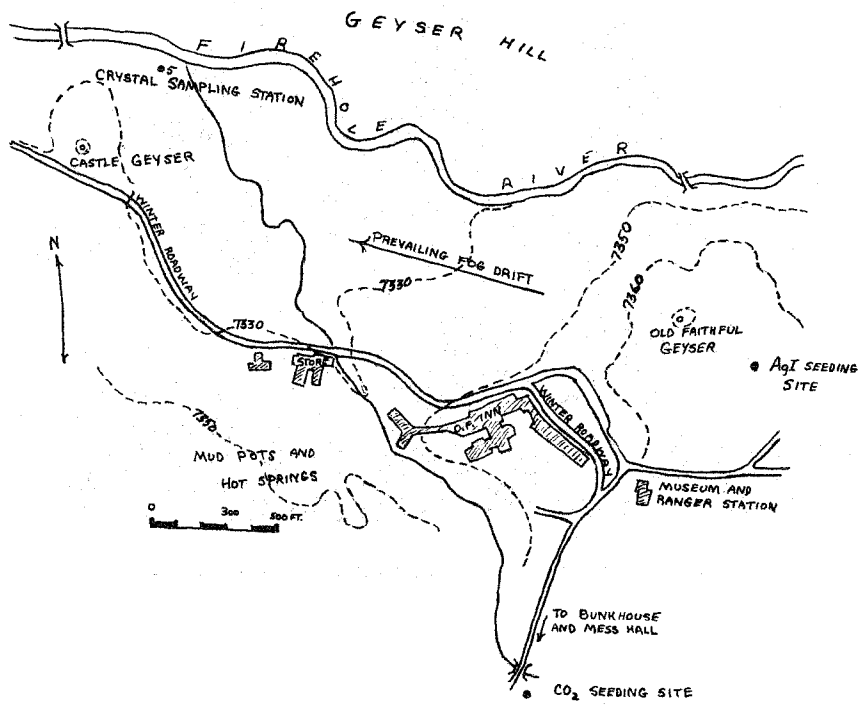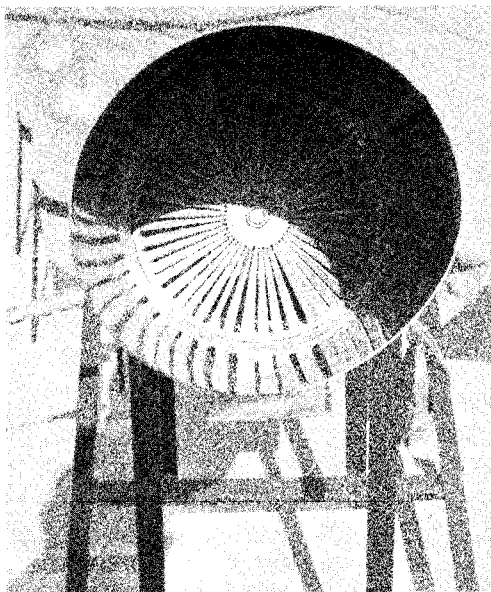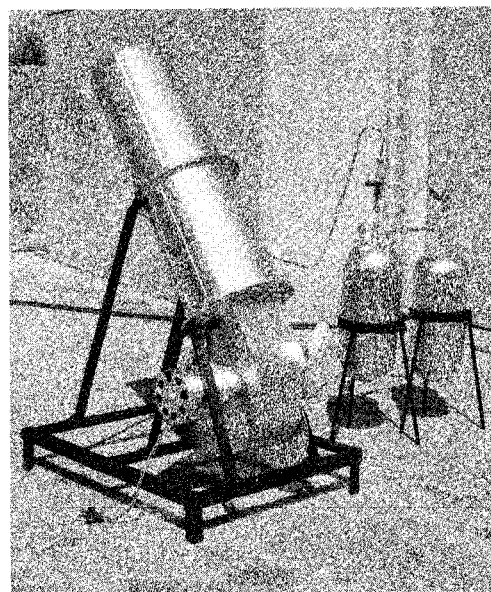Figure 1. Schematic Diagram of CSU - API Generator

Figure 4

View Forward Nozzle

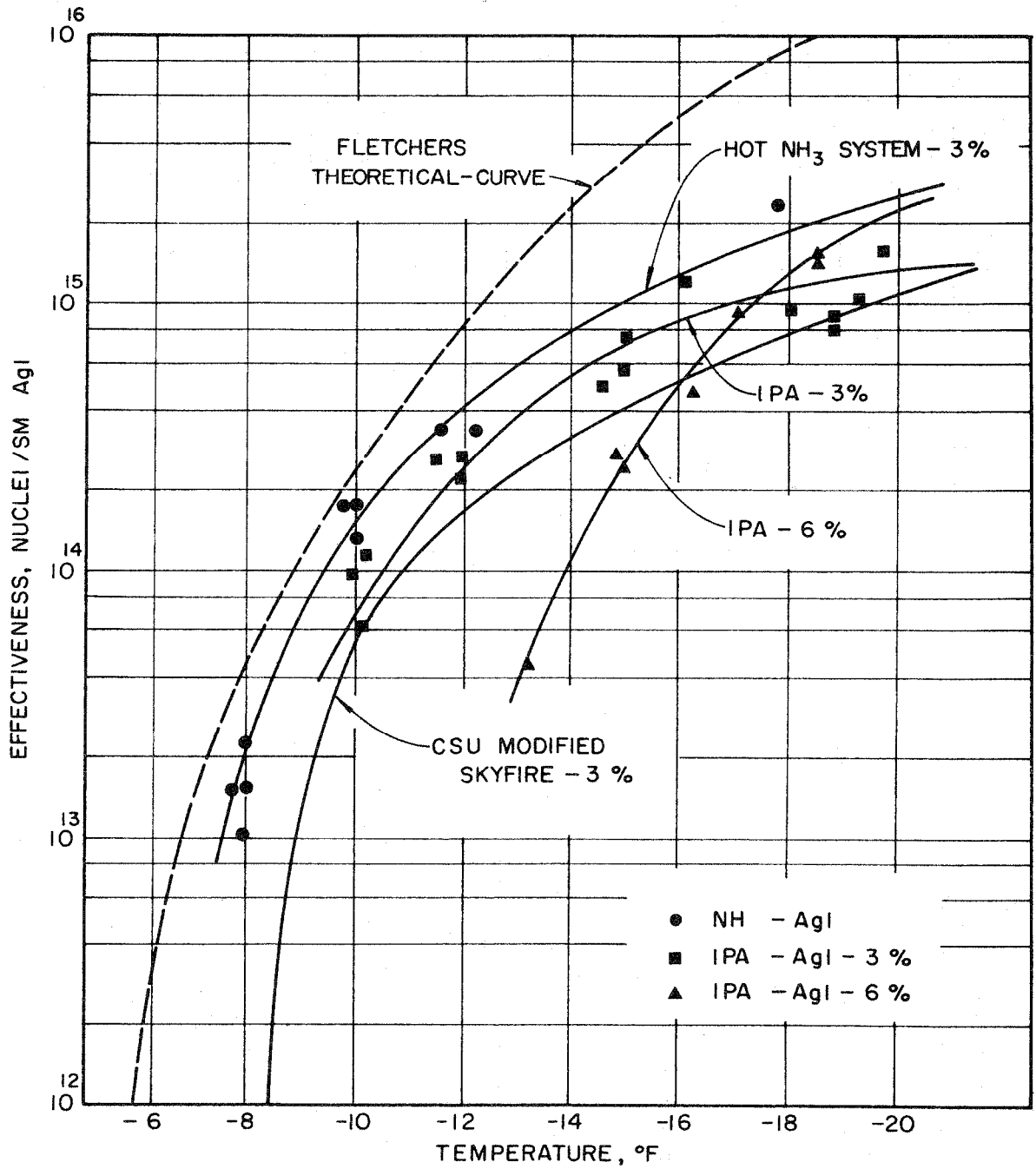Overall View

Unit in operation at Yellowstone National Park

Figure 2

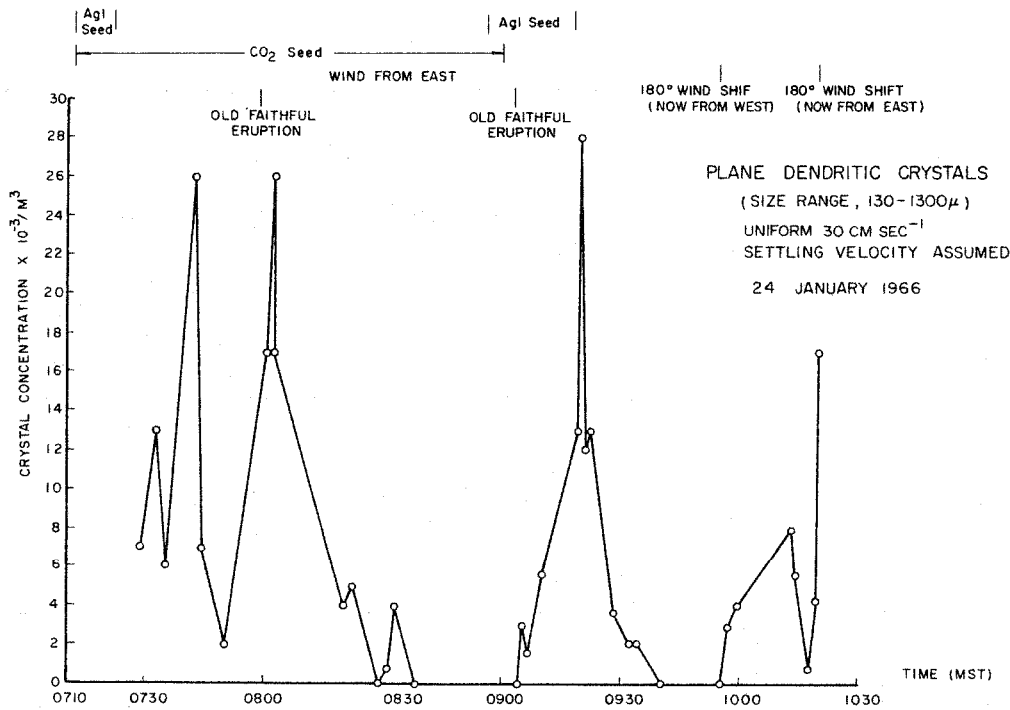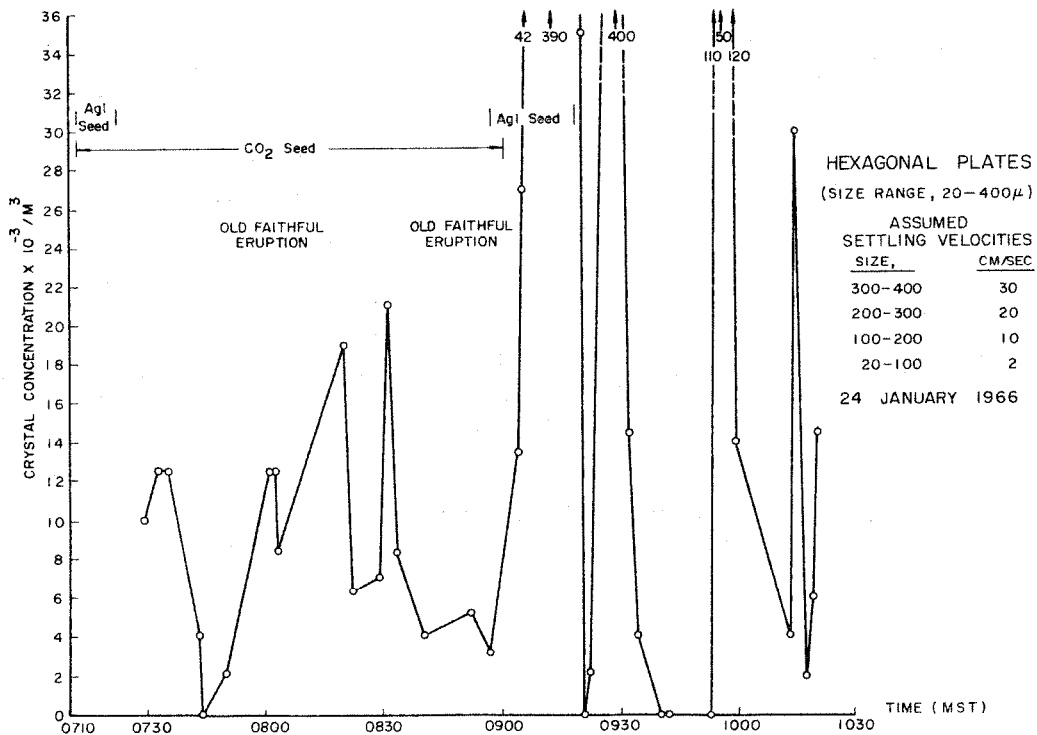Figure 3. Comparison of IPA Generator Effectiveness

Figure 5

CRYSTAL CONCENTRATION X 10^{-3}/M^3

| Agi | Seed |

| CO$_2$ Seed |

WIND FROM EAST

| Agi Seed |

180° WIND SHIFT (NOW FROM WEST)   180° WIND SHIFT (NOW FROM EAST)

OLD FAITHFUL ERUPTION

OLD FAITHFUL ERUPTION

PLANE DENDRITIC CRYSTALS

(SIZE RANGE, 130-1300μ)

UNIFORM 30 CM SEC^{-1} SETTLING VELOCITY ASSUMED

24 JANUARY 1966

TIME (MST)

Figure 5

Figure 6

CRYSTAL CONCENTRATION X 10^{-3}/M^3

| Agi Seed |

| CO$_2$ Seed |

| Agi Seed |

42 390   400   50   110 120

OLD FAITHFUL ERUPTION

OLD FAITHFUL ERUPTION

HEXAGONAL PLATES

(SIZE RANGE, 20-400μ)

ASSUMED SETTLING VELOCITIES

SIZE,	CM/SEC
300-400	30
200-300	20
100-200	10
20-100	2

24 JANUARY 1966

TIME (MST)

Figure 6