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The PROJECT *Skyfire* CLOUD-SEEDING GENERATOR

by
Donald M. Fuquay And H. J. Wells



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CONTENTS

	<u>Page</u>
INTRODUCTION	1
SILVER IODIDE SMOKE GENERATORS	1
GENERATOR DEVELOPMENT	2
PROJECT SKYFIRE CLOUD-SEEDING GENERATOR	6
APPENDIX	11
Installation and operating instructions	12
Working drawings of Skyfire generator	13

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THE PROJECT SKYFIRE CLOUD-SEEDING GENERATOR

INTRODUCTION

One of the aims of Project Skyfire is to determine the possibility of preventing lightning fires or reducing their severity by cloud-seeding. Research completed to date indicates that cloud modification for purposes of lightning suppression requires the production of enormous quantities of silver iodide nuclei. These nuclei may be dispersed either from ground-based equipment or from similar equipment mounted in aircraft. In addition to being able to produce a relatively high output of silver iodide nuclei, cloud-seeding generators for experiments in lightning suppression should be economical and simple to operate; easy to transport and service in rough, mountainous country; and be safe for use in highly flammable forests. This publication presents the reasons for development of the generator, summarizes calibration procedures and results, and describes the equipment. The generator calibration and development program will be covered fully in a later report.

The Project Skyfire cloud-seeding generator is designed to produce silver iodide nuclei for experiments performed in devising techniques for lightning suppression. This generator produces freezing nuclei by volatilizing a silver iodide-acetone solution in a propane flame.

The Project Skyfire cloud-seeding generator described in this publication is the result of equipment research by the writers during the spring and summer of 1957 aimed at meeting the broad objectives described above. Although preliminary tests indicate success in meeting the general objectives, the generator must be considered as still being in a developmental stage. Final evaluation of its performance awaits full-scale field tests.

SILVER IODIDE SMOKE GENERATORS

Several different types of silver iodide smoke generators were used during exploratory field programs. During 1956 an airborne string-type generator, designed for Skyfire operations and mounted in a Cessna 180 aircraft, was operated for about 60 hours. In addition, three ground-based string-type generators were employed several times near Flagstaff, Arizona and Missoula, Montana. Late in the 1956 field season a network of 10 acetone-burning generators was used at the Montana test site.

The two general types of generators tested, string- and acetone-burning, differ mainly in the manner in which the silver iodide is injected into the flame to form a smoke of silver iodide crystals. In the acetone-burning type, silver iodide is first dissolved in a solution of acetone and sodium iodide. The resulting solution is then sprayed into a flame by propane gas pressure through an internal-mixing paint spray nozzle (fig. 1). The mixture of propane gas and acetone solution burns in a flame holder.

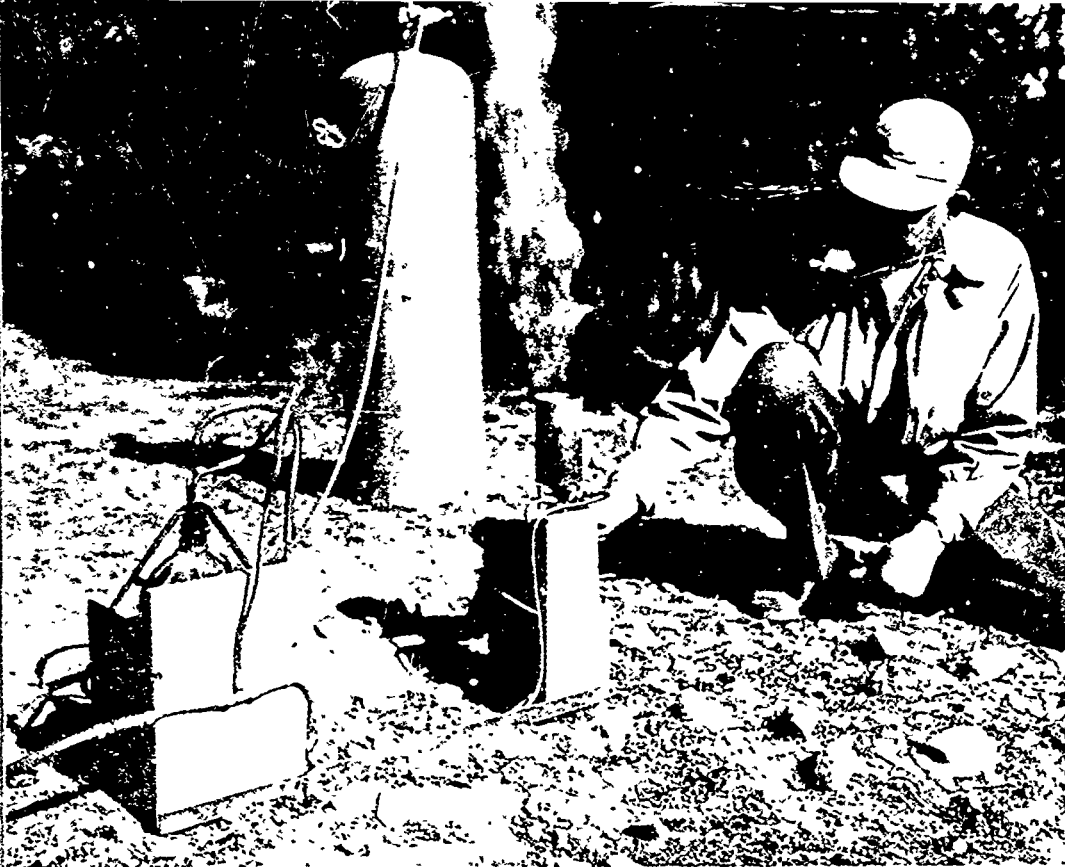


Figure 1.--Acetone-burning silver iodide generator.

The string technique involves saturating cotton cord, such as window sash cord, in a concentrated silver iodide-sodium iodide-acetone solution. When the cord dries, it remains impregnated with silver iodide. In the various string-burning generators, the cord impregnated with silver iodide is fed into a propane or oxy-propane flame through a feed gear driven by a light battery-powered motor (fig. 2). As many as 100 operating hours can be obtained from a single spool of impregnated cord.

GENERATOR DEVELOPMENT

All previously developed generators tested during and after the 1956 season had serious disadvantages for Skyfire use. The acetone type produced a relatively high output of effective nuclei but had high consumption rates for both the silver iodide solution and propane gas; furthermore, it operated irregularly because of clogging in the spray nozzle. This type presented problems in logistics and maintenance and was a serious fire hazard. The string type was virtually trouble-free in operation, and had simple supply requirements. However, it had the serious disadvantages of relatively low cutput per unit and high initial cost. After all known facts about existing silver iodide smoke generators had been considered, it was obvious that none of these generators was entirely suitable for Skyfire operations. In addition, not enough was known about the generation of silver iodide nuclei and the general characteristics of generators to make recommendations for a generator suitable for Skyfire use.



Figure 2.--String-burning silver iodide generator.

Experience with generators used during the 1956 season indicated what features were necessary for silver iodide generators designed to operate in mountainous country and in forested areas.

First, the generator must be absolutely safe; particularly, it should create no fire hazard and present no danger to operating personnel. Second, the generator must operate reliably for extended periods (up to 8 hours) without maintenance. Third, it must produce the highest possible output of nuclei from a minimum of materials to reduce the logistics problems in mountainous terrain. Fourth, the generator must be simple to operate since any sizable operation would require several generators to be operated and maintained by relatively inexperienced personnel. The goal set for a generator was 8 hours' unattended operation each day with procurement and operating costs within a limited budget.

Accordingly, in the fall of 1956 a program for the calibration of all available silver iodide smoke generators used, or considered for use, in Project Skyfire was started. The calibration program had three objectives: (1) to determine the effective output of nuclei from smoke generators used during the 1956 operation; (2) to investigate the effects of changes in design on the output and efficiency of smoke generators; (3) to supply data necessary for planning future cloud-seeding operations. The complete calibration program will be reviewed in a later report.

The following method was used to calibrate the output of effective freezing nuclei of the generators at various activating temperatures. The smoke from a generator being calibrated was mixed with a large volume of air forced at a known rate through a vertical wind tunnel placed over the generator. A measured sample was taken from the mixed air stream, diluted by a known amount, and introduced into a cold box. Each effective silver iodide crystal present in the sample would cause an ice crystal to grow to visible size in a supercooled fog already present in the cold box. The number of crystals found within a known volume in the cold box was visually counted with the aid of a 10-power microscope as the crystals scintillated in a bright beam of light. Subsequent samples were introduced as the cold box temperature was changed from -22° to -6° C. Calibration values for various generators tested are shown in table 1. A 4-percent silver iodide-acetone solution was used in the calibration studies.^{1/}

The calibration tests, construction details, and generator designs indicated need for more information about the effects of such factors as flame temperature, quench rate, shape of flame chamber, and solution injection rate on the number of effective nuclei produced by a generator. A series of tests was performed to gather the necessary data. Since a large quantity of silver iodide solution was already available to the project, and since comparative studies of other generators showed the acetone-burning type most likely to fit our needs, study was concentrated on this type of generator.

The first problem was to develop a satisfactory nozzle for injecting the acetone solution into a flame. No internally mixing nozzle was found that was free from clogging. After several tests, a nebulizer using a propane stove orifice and a hypodermic needle was devised. This nozzle proved to be very reliable, was inexpensive to build, and easy to adjust.

A great many flame chambers of various sizes and shapes were tested. Cylindrical chambers of steel pipe, perforated tubing, and various ceramic materials were tried. A cylindrical chamber capped by a quench plate yielded the highest output. A series of ports near the bottom of the chamber regulated the amount of air drawn into this chamber. The ceramic material alundum was found to be best for the flame chamber. However, no material that was immediately available at a reasonable price withstood the periodic, nonuniform heating and cooling without cracking or crumbling. Steel tubing proved almost as effective as the ceramic material and was cheaper and more rugged.

Temperature in the flame chamber was varied by changing the amount of propane gas introduced into it. The output of nuclei increased linearly as

^{1/} Sixteen pounds of commercial grade silver iodide dissolved in a solution of 4 pounds of sodium iodide and 55 gallons of acetone. Sediment was removed by filtering through glass-wool filters.

Table 1.--Output of effective silver iodide nuclei at various
activating temperatures

Temp. of cold box (°C.)	Standard MRI ^{1/}	High output MRI ^{2/}	C ^{3/}	Skyfire ^{4/}
-8	4×10^6	1.5×10^8	3×10^8	9×10^{10}
-9	3×10^7	7×10^8	2×10^9	3×10^{11}
-10	2×10^8	3×10^9	2×10^{10}	8×10^{11}
-11	2×10^9	1.5×10^{10}	2×10^{11}	1×10^{12}
-12	1×10^{10}	7×10^{10}	6×10^{11}	3×10^{12}
-13	1×10^{11}	3×10^{11}	1×10^{12}	4×10^{12}
-14	4×10^{11}	1×10^{12}	2×10^{12}	6×10^{12}
-15	6×10^{11}	2×10^{12}	3×10^{12}	9×10^{12}
-16	9×10^{11}	3×10^{12}	4×10^{12}	1×10^{13}
-17	1×10^{12}	4×10^{12}	7×10^{12}	1.5×10^{13}
-18	----	5×10^{12}	1×10^{13}	2×10^{13}
-19	----	6×10^{12}	2×10^{13}	2.5×10^{13}
-20	2×10^{12}	8×10^{12}	2×10^{13}	3×10^{13}
-21	----	1×10^{13}	3×10^{13}	4×10^{13}

1/ A standard string-burning generator manufactured by Meteorology Research, Inc. String feed is 2.5 centimeters per minute into a propane torch burner; silver iodide consumption is 0.9 gm. per hour.

2/ Similar in principle to Standard MRI except that it has an oxy-propane flame; string feed 10 cm. per minute; silver iodide consumption, 14.4 gm. per hour.

3/ An acetone-burning type used on Project Overseed, in which propane pressure forces a silver iodide-acetone solution through an internal mixing spray nozzle; silver iodide consumption, 33 gm. per hour.

4/ Silver iodide consumption about 16 gm. per hour.

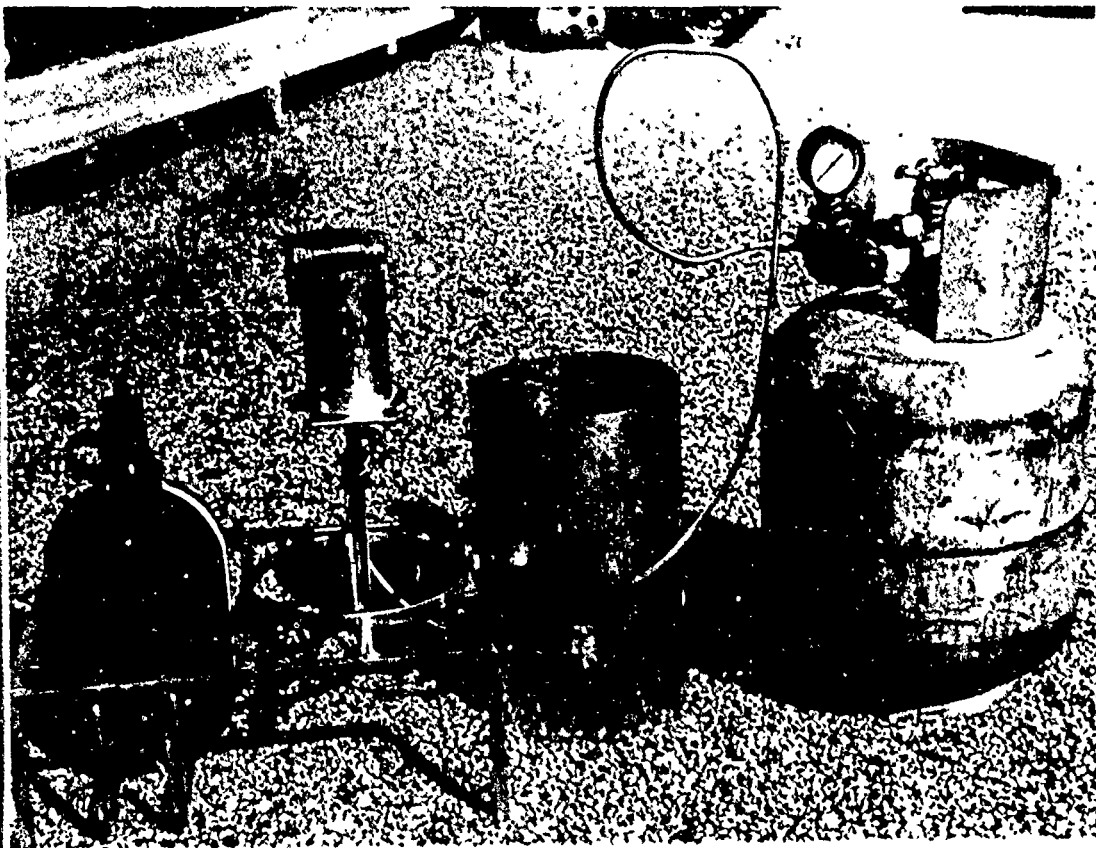
the temperature was increased from about 400° F. to about 2,000° F.; the rate of increased output decreased as temperature rose above 2,000° F. About 2,000° F. appeared to be the most efficient operating temperature for all flame chambers tested.

Attempts were made to increase the generator output by injecting chemicals into the flame. In some tests, output was increased from two- to threefold by injecting iodine vapor. However, when the problems of injection and personnel safety were considered, such injections did not appear feasible. Ammonia vapor kept the generator free of deposits in the flame chamber but did not change the generator output.

PROJECT SKYFIRE CLOUD-SEEDING GENERATOR

Since the acetone-burning type of silver iodide smoke generator had performed most satisfactorily in preliminary tests, a generator of this type was designed for Project Skyfire (fig. 3). In use, silver iodide dissolved in a solution of acetone and sodium iodide is drawn from a reservoir through a modified hypodermic needle and nebulized by a jet of propane gas. This mixture of atomized acetone solution, propane, and air is directed into a flame chamber and ignited. The volatilized silver iodide condenses into crystals as the smoke passes from the flame around a quench plate mounted

Figure 3.--Skyfire generator showing from left to right the solution reservoir, framework, flame holder, windshield, and propane supply tank.



above the flame chamber. The quench plate serves the dual function of containing the mixture in the flame chamber and also disperses the smoke immediately above the flame. This quenching action yields a larger crystal output than an open chimney. This rapid quenching also seems to give a more nearly uniform size to the nuclei produced, as indicated by the action of the nuclei in forming ice crystals.

The Skyfire generator is constructed in four parts: a support frame, an externally mixing spray nozzle, a flame chamber, and a windshield. The support frame serves as a mount for the flame chamber, windshield, and reservoir for the silver iodide solution. All the major components can be removed easily as separate units for servicing or for replacing defective parts.

At sea level the generator consumes about 600 milliliters per hour of 4-percent silver iodide-acetone solution when 6 p.s.i. propane gas pressure is applied to the mixing nozzle. Propane gas consumption at this gas

Table 2.--Approximate consumption rate of silver iodide-acetone solution by the Skyfire generator (milliliters per hour)

Elevation (MSL)	Propane gas pressure at orifice (p.s.i.)		
	5	10	15
Sea level	600	750	900
3,000 feet	500	600	700
6,000 feet	400	500	600

pressure with a 0.029-inch orifice, is about 1 pound per hour. The output of nuclei under these conditions was 3×10^{13} nuclei per second effective at -20° C. (fig. 4).

Since the rate of flow of the acetone solution depends upon the difference between the nozzle gas pressure and the ambient air pressure, the gas pressure must be increased in order to maintain a constant flow of 600 milliliters per hour at higher elevations. At 3,200 feet MSL the solution flow at 6 pounds gas pressure was about 500 milliliters per hour. At 6,500 feet MSL, 12 pounds of propane pressure was necessary to yield the calibrated output. The average propane consumption was about 2 pounds per hour at 6,500 feet elevation.

Soon after the Skyfire generators were installed in the field, it was found that high ambient temperature, or operation at higher elevations (5,000-7,000 feet MSL) at even moderate temperatures, would develop vapor lock in the vacuum line that fed the silver iodide solution to the nozzle. The vapor lock occurred at the highest point where the solution line left

the reservoir and passed down under the windshield to the nozzle. The vapor lock developed because under these operating conditions the entire unit was near the boiling point of the acetone solution. Further reduction in pressure, coupled with radiational heating from the flame chamber, caused a bubble to form in the line; this bubble blocked the flow of silver iodide solution.

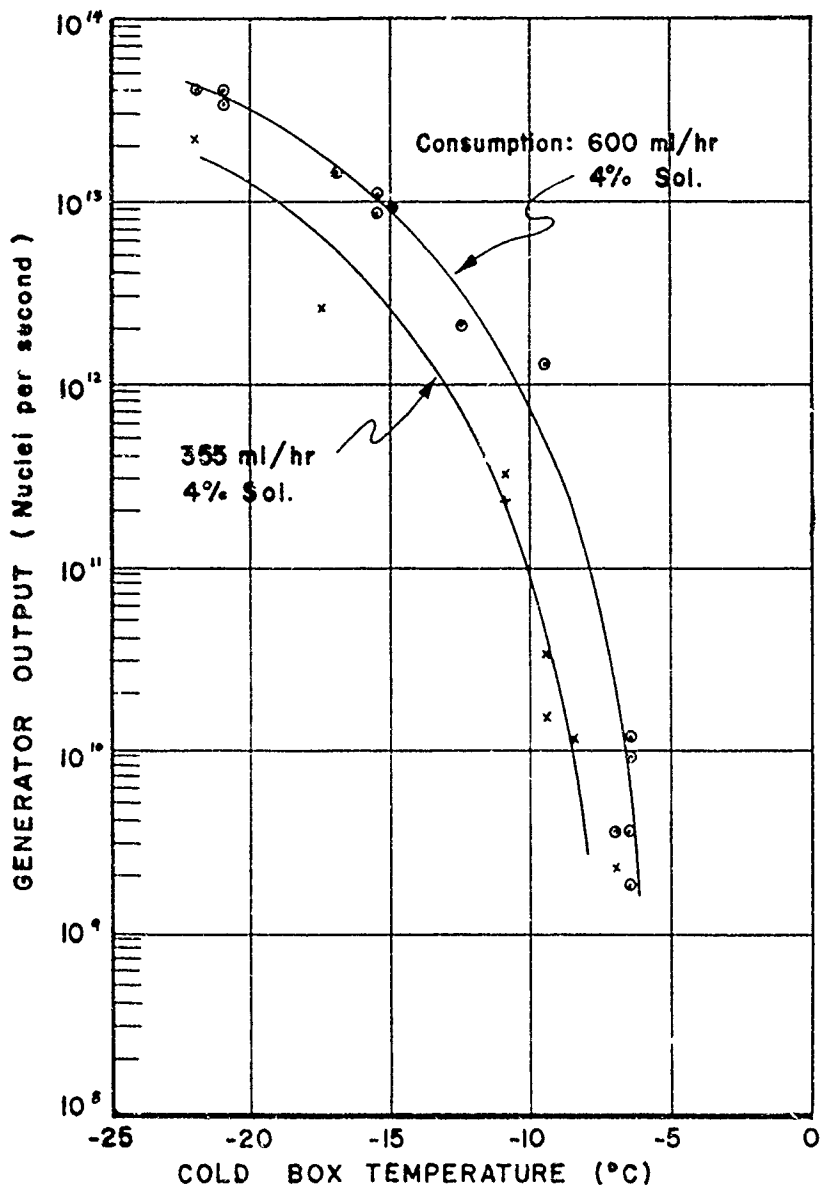
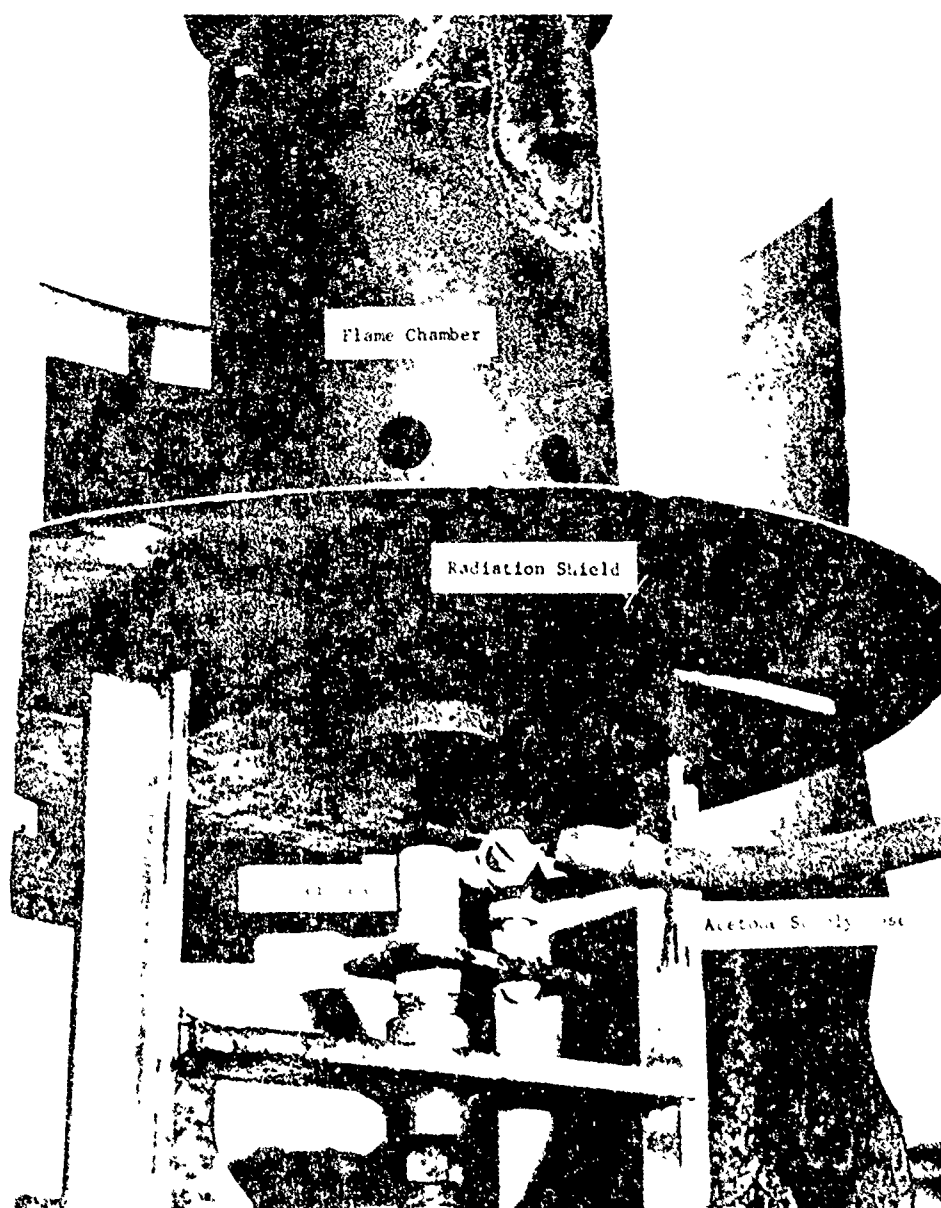


Figure 4.--Calibration diagram for Skyfire generator showing effective silver iodide crystal output at various temperatures.

The vapor-lock problem was eliminated by two slight modifications in design of the generator. The loop in the solution line was eliminated by running the line directly from the top of the solution reservoir to the nozzle through a hole in the windshield. Thus, if bubbles formed in the line, they would be drawn up the line and expelled through the nozzle.

It was still possible on hot days for radiation from the flame chamber to heat the hypodermic needle to the point where a vapor lock could occur at the base of the needle. To eliminate this, a circular aluminum shield was added below the flame chamber (fig. 5). Annular rings of asbestos fiberboard placed under the flame chamber further isolated the nozzle from the hot chamber.

Figure 5.--Modifications of Skyfire generator to prevent vapor lock.



Thirty Skyfire generators were operated in various combinations for a total of 2,560 hours during the 1957 Skyfire season. These generators were operated at elevations from 5,000 feet to 6,500 feet MSL. Average consumption for the season was 380 milliliters per hour of 4-percent silver iodide-acetone solution and about 2 pounds per hour of propane. Virtually no operating time was lost because of equipment failure after the minor modifications were made. In general, this generator met all the requirements specified for such equipment to be used in remote and forested areas.

Steel tubing was used in the flame chamber and steel plate in the quench plates in the 30 test generators as an economy measure. As expected, the usable life of these steel components was about 200 hours of operation. Stainless steel is recommended for all components subject to high temperatures, such as the flame chamber and quench plate, in any generator designed to operate longer than one season.

APPENDIX

Installation and Operating Instructions for the Skyfire Generator

The generator should be mounted on level ground in an area approximately 10 feet in diameter clear of all overhanging branches and brush. All surface litter and flammable material should be removed down to mineral soil.

After the generator is assembled, connect the gas line from the propane tank to the spray nozzle. Check the alignment of the hypodermic needle. The tip of the needle should be centered over the gas orifice and about three-sixteenths of an inch above the top of the gas nozzle. After the needle has been properly adjusted, it should not need to be adjusted for subsequent operations.

The steps listed below should be followed in lighting the generator:

1. Insert the latex tubing fastened to the hypodermic needle into the reservoir of solution.
2. Open the large valve on top of the propane tank at least 6 turns.
3. Adjust the control on the gas pressure reducer to the desired gas pressure (table 2). A light mist of atomized solution should emerge from the top of the burner.
4. Carefully insert a lighted match into the top of the flame chamber.
5. With the generator operating, visually check all parts for leaks of gas or solution.

The following steps should be taken in shutting off the generator:

1. Remove the tubing from the solution reservoir and wait until all solution has been purged from the line. This is very important. If any solution is allowed to remain in the tubing after the generator is shut off, clogging of the needle is likely to result.
2. After step 1 is completed, close the main valve on the propane tank.

The generator requires virtually no maintenance. After every third or fourth operation, remove the flame chamber and cap and clean both with a wire brush. At times a small deposit may form on top of the hypodermic needle. This can be removed by gently brushing the needle tip with the finger or a small stick. Take care not to alter the position of the needle.

WORKING DRAWINGS OF SKYFIRE GENERATOR

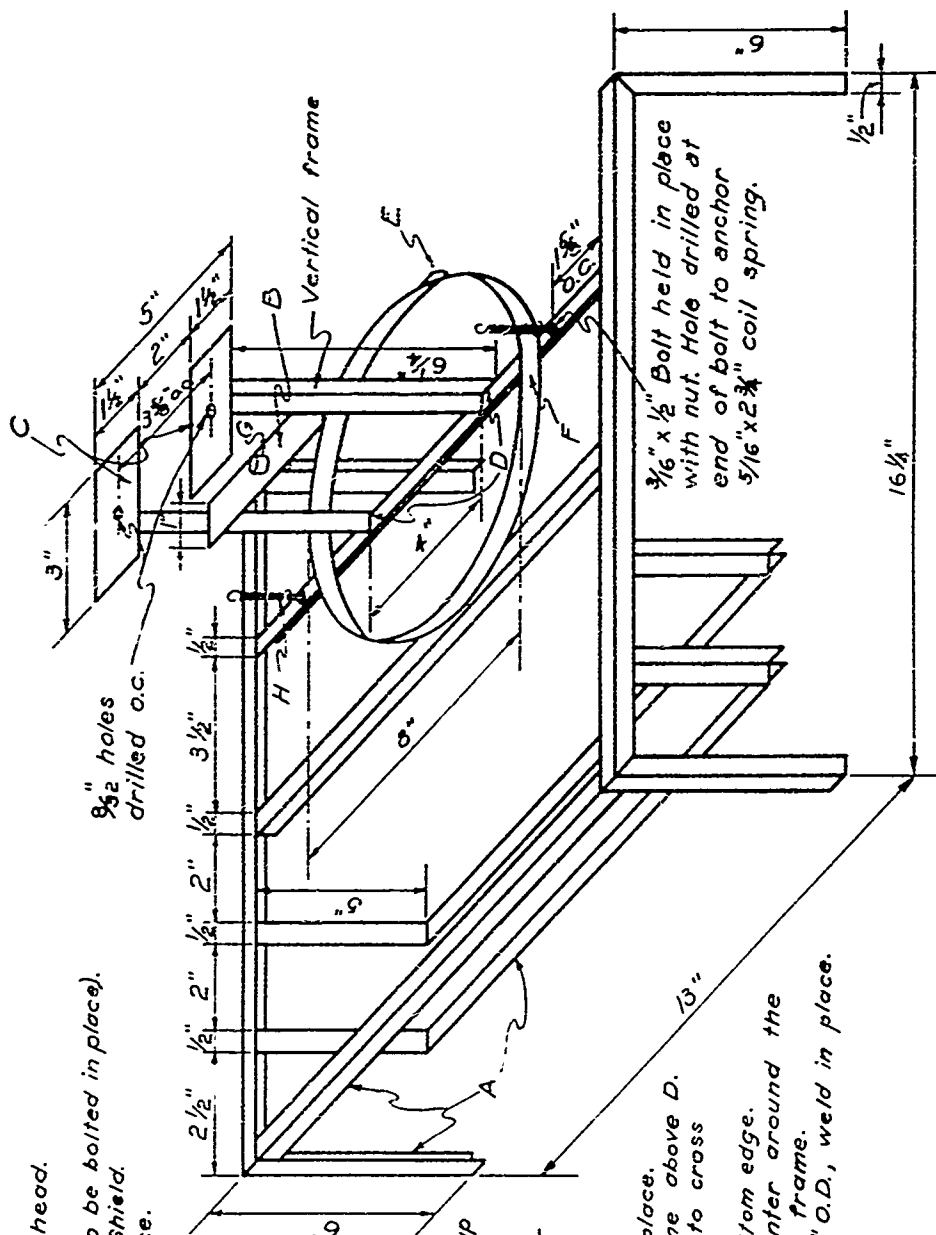
- A. Frame.
 B. Cross member to hold nozzle head.
 C. Base for flame holder.
 D. Base of vertical frame, (legs to be bolted in place).
 E. Lip to support base of Wind Shield.
 F. Ring to hold Wind Shield in place.
 G. Standard pipe union mount for nozzle head.
 H. Spring anchored to bolt, to hold wind shield in place.

MATERIAL

- A. $\frac{1}{2}$ " angle iron $\frac{1}{8}$ " thick.
 B. $1\frac{1}{2}$ " x 4" strap iron $\frac{3}{16}$ " thick.
 C. $1\frac{1}{2}$ " x 3" strap iron $\frac{1}{8}$ " thick.
 D. $\frac{1}{16}$ " bolt & nut to hold legs to frame.
 E. $\frac{1}{2}$ " x $2\frac{1}{2}$ " strap iron thick.
 F. 8" diam. ring made from $\frac{1}{2}$ " strap iron $\frac{1}{8}$ " thick.
 G. $\frac{1}{2}$ " O.D. standard pipe union.
 H. 2 - $\frac{3}{16}$ " x $\frac{1}{2}$ " bolts with nuts & 2 - $\frac{5}{16}$ " x $2\frac{3}{4}$ " coil springs.

CONSTRUCTION

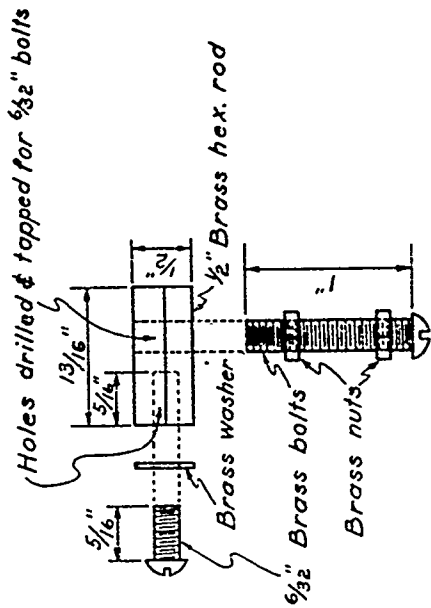
- A. All weld except at points D.
 B. Drill $\frac{1}{2}$ " O.D. at center, weld in place.
 C. Weld to legs of vertical frame above D.
 D. Bolt legs of vertical frame to cross member of frame A.
 E. Weld lip to ring at outside bottom edge.
 F. Weld ring so that it will center around the base of the of the vertical frame.
 G. Insert standard pipe union $\frac{1}{2}$ " O.D., weld in place.



Scale: 3" = 1'-0"

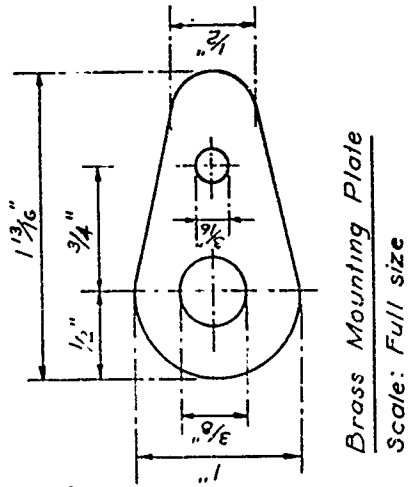
Frame of Ag I Smoke Generator

G.M.T. 57

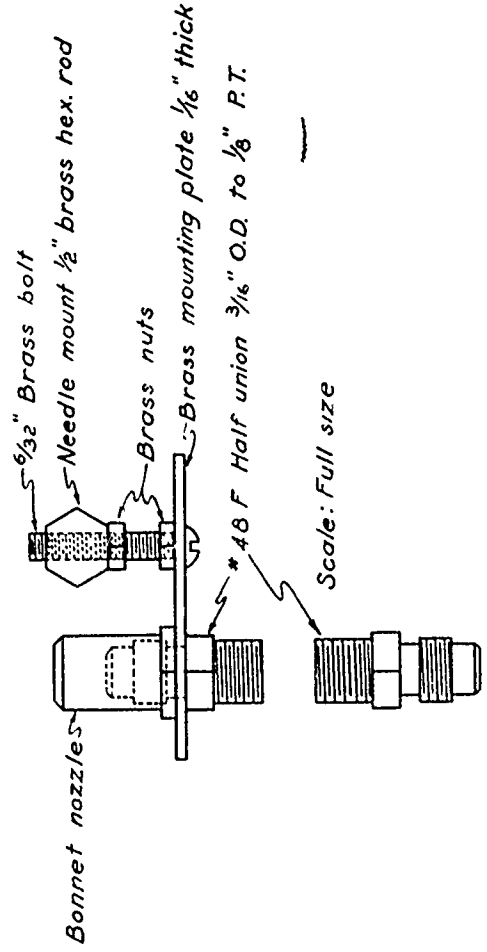


Needle Mount Details
Scale: Full size

NOTE:
Seal all threaded joints with
Harbinsons insoluble sealant or
equivalent.

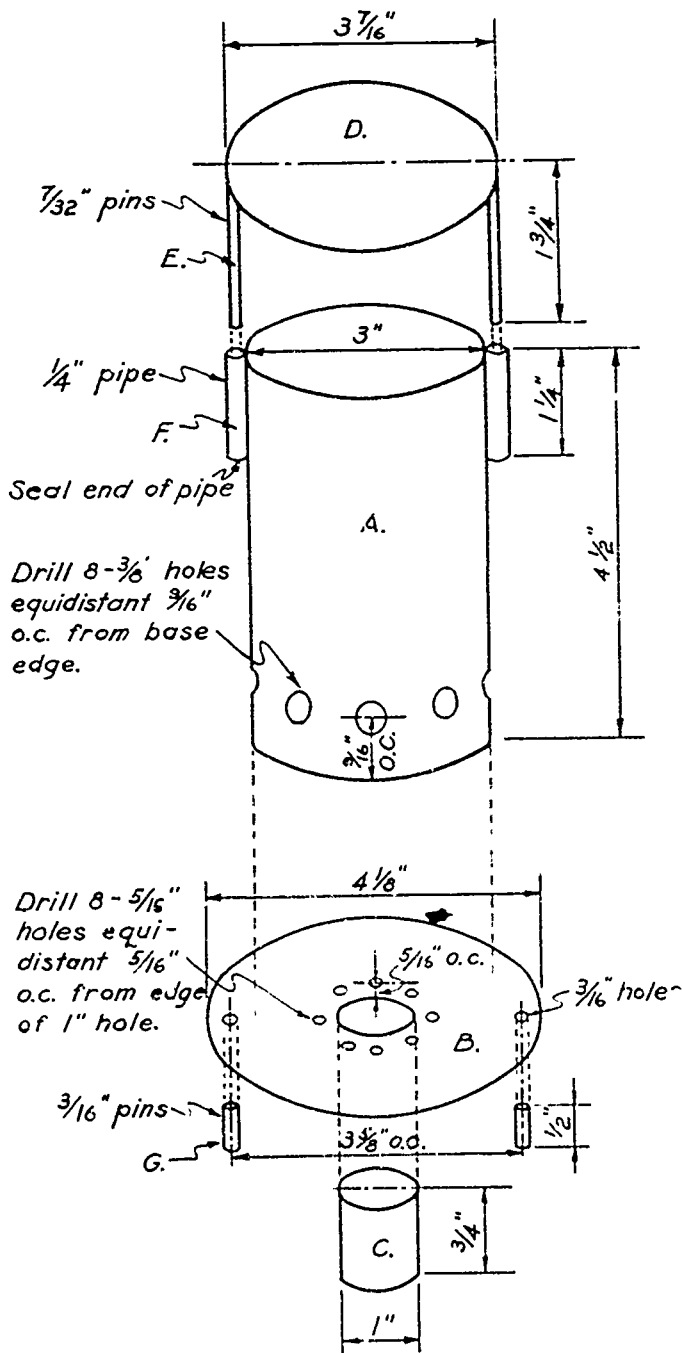


Burner Head Mounted



Burner Head Details

Burner Head Assembly



Scale: 6" = 1'-0"

MATERIAL

- A. 4 1/2" x 3" x 1/16" steel tube.
- B. 4 1/8" x 1/16" steel plate.
1" hole cut out of center.
- C. 1" x 3/4" x 1/16" steel tube.
- D. 3 7/16" x 1/16" steel plate.
- E. 2-1 3/4" x 7/32 steel pins.
- F. 2-1/4" x 1/4" steel pipe.
- G. 2-3/16" x 1/2" steel pins.

CONSTRUCTION

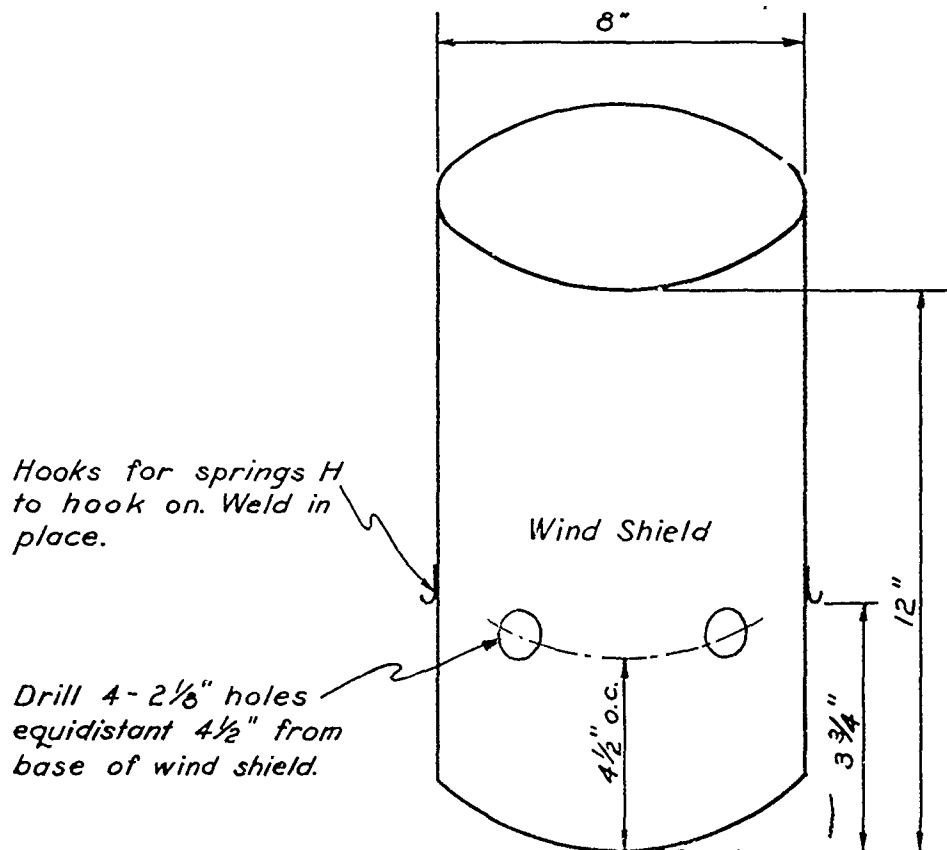
Drill 8-3/8" holes 3/8" from base edge of A. Cut base plate B, cut 1" diameter from center and drill 8-5/16" holes 5/16" o.c. from edge of 1" hole. Cut D and weld pins E and pin holders F in place. Weld pins G in holes of plate B.

ASSEMBLY

Insert C in center hole of B and weld. Place A on B with center over center of C and weld (spot 4 places). Place pins E into pin holders F.

Flame Holder

G.H.T 57



Scale: 3" = 1'-0"

MATERIAL

2 Steel hooks, weld in place.

Wind shield to be made of 16 gauge galv. steel.

Wind Shield

G.H.T. 57