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FINAL REPORT
NOVEMBER 1962

**DEVELOPMENT OF INSULATING AQUEOUS FOAMS
FOR PROTECTION OF ICE SURFACES**

By

F. C. SHIBEL
C. S. GROVE, JR.
A. R. AIDUN

Sponsored by
POLAR DIVISION
U. S. NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA
CONTRACT NO. NBy 32210



ONONDAGA ASSOCIATES, INCORPORATED

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ONONDAGA ASSOCIATES, INCORPORATED

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ABSTRACT

This report was prepared by Onondaga Associates, Inc. under Contract Number NBy 32210 which was a continuation of the study conducted under Contract Number AF 19(604)-6635 (see Reference 1). The objective was to find a means of protecting ice runways in the Arctic regions during the summer months when melting or thawing can occur causing soft spots or "pot holes". Many insulating materials are available, but the difficulties of application and/or transportation and the resultant increased cost preclude their use. A proprietary concept utilizing aqueous foam insulation was suggested by Onondaga Associates, Inc. The use of aqueous foam has many advantages including ease of application and no need for removal. The stability, insulating and generation properties of the foam were studied in detail in both small and large scale laboratory tests. Actual Arctic field testing substantiated these findings and proved the use of aqueous foam to be both feasible and promising.

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I INTRODUCTION

Considerable effort has been devoted to the development and maintenance of both permanent and emergency airfields in the Arctic and Antarctic regions of the world. Such facilities are a vital part of the national defense system and of the scientific exploration effort. The weather and temperature conditions prevalent in these regions cause the runways to be permanently covered by ice or packed snow. During much of the year, such runways can be maintained quite satisfactorily. There is, however, a shorter season of the year when the temperature conditions (heat and radiation from the sun, etc.) reach the point where thawing can take place, causing the runways to become inoperable. It is important for these installations to be useable during the entire year to permit the transfer of personnel between installations, and to eliminate the present need of air-dropping food and supplies during the inoperable thaw-period. It is very desirable, therefore, to find a means of protecting the runways during the summer months in those areas where melting or thawing can occur. Many insulating materials are available, but the difficulties of application, the logistics and the resultant increased cost, limit or preclude their use. A proprietary concept utilizing aqueous foam insulation was suggested by Onondaga Associates, Inc. The most important single factor in utilization of this concept is the maximum usage of materials indigenous to the area (snow, ice, sea-water and air) which are used in the foam's preparation. The ingredients requiring transportation to the site amount to less than 10% of the formulation requirements. The more common insulatory materials such as saw dust, ground cork, etc. require 100% movement to the area to be protected from melting.

The initial feasibility research concerned with the development of aqueous foam for the protection of Arctic airfields, was sponsored by the Geophysics Research Directorate under Contract Number AF 19(604)-6635. The study involved both laboratory and larger scale tests carried out in the Climatic Chamber at Eglin Air Force Base, Florida. The results of these studies revealed that aqueous foams provide an excellent means of protecting ice and snow airfields from melting during the warmer months of the year.

However, the foams produced were very fragile and not capable of withstanding the freeze-thaw cycles encountered in the Arctic regions. It was concluded, therefore, that additional formulation, generation and development work was needed before any large scale field test could be planned.

During the past year continuation and expansion of this investigation have been carried out under the sponsorship of the Naval Civil Engineering Laboratory, Contract Number NBy 32210.

The laboratory phase of this study was concerned with finding a suitable stabilizer or stabilizer system for the protein base foaming agent, Mearlfoam-Type 5. This investigation revealed that a family of aqueous foams based on Carboxy Methyl Cellulose (CMC) stabilizers plus a gelling agent, produced strong and stable foams, capable of withstanding freeze-thaw cycles which might be encountered in the Arctic and Antarctic regions. With the basic formulation established, a foam-generator was designed and built for large scale laboratory testing of this family of foams.

As a result of the successful laboratory studies at Onondaga Associates, Inc., it was decided to conduct larger scale tests on the more promising formulations. This was undertaken to more accurately determine the effectiveness of these foams as ice insulators, when exposed for long periods to conditions simulating Point Barrow, Alaska. The generation phase, including solution preparation, generation rate and expansion ratio of each formulation, was also studied under these simulated Arctic conditions. These tests were carried out in the Climatic Chamber at Eglin Air Force Base, Florida, where it was possible to prepare relatively large ice ponds which could be subjected to wind, rain and snow under controlled conditions.

Based on the Climatic Chamber test results, the CMC-7 LT base foam was chosen for the Arctic Field Test because of its satisfactory performance at Eglin and also its ease of generation. The use of compressed versus atmospheric air in the generation of these foams was also studied and resulted in a substantial improvement in generation rates and expansion ratios.

The Field Test, conducted at Point Barrow, Alaska, proved conclusively that an aqueous base foam would protect ice from melting due to solar radiation. It also revealed the limitations of both the equipment and the CMC-7 LT formulation when used under Arctic conditions, and suggested means of overcoming them. These suggestions dealt with the substitution of a high molecular weight stabilizer (CMC-7 HP) for the low molecular weight Type 7 LT employed. Also, the need of a more rugged and trouble-free prime mover for the foam generator. Other suggested improvements in the generation equipment included the installation of an automatic metering device for the compressed air and foam solution and also, a technique for post-adding the gelling agent.

This report contains a description of the work to date, the results of that work, the conclusions obtained and recommendations for future proliferation of the work to actual operational conditions.

II BACKGROUND

For many years, the use of aqueous foams was generally restricted to fire fighting, shaving lathers, etc. However, in recent years, some scientists have taken a second more illuminating look at foams. They have found that the qualities which make foams so desirable for fire extinguishment, such as complete coverage of a surface, smothering qualities, ease of application and slow drainage, also make them desirable for other uses. One of these uses was conceived as an insulation of ice runways in the Arctic areas. The Air Force found that the summer thaws occurring in the Arctic areas often made their airfields inoperable. Some way had to be developed to protect these airfields from thawing. Onondaga Associates, Inc. suggested the use of aqueous foam as an insulator, and for the past two years has been conducting an intensive investigation into its development.

When this application was first considered, it was necessary to choose a foam and method of generation which had certain characteristics. The foam liquid itself had to provide effective performance at a high expansion ratio. The reasons for this were two-fold. First, it would not be feasible to require extensively large quantities of a foam liquid since this application would not be practical if the cost was prohibitive. Also, a foam was needed which would not pose great resistance to easy handling. These requirements precluded the use of plastic foams. It was decided that an aqueous foam would be most suitable since it met most of the requirements. Mearlfoam-Type 5 was the foam liquid primarily used, because it provided a high expansion foam of fairly stable properties.

There are three methods for generating foams. These methods are mechanical foaming, chemical foaming and mechanical-chemical foaming. For the purposes of this program, the most effective foaming method is mechanical foaming. This process is based on the principle of continuous injection of air, into a stream of either the foam liquid alone or a foam liquid containing a suitable foam stabilizer. It makes use of the availability of in situ materials, such as air and water.

Mechanically generated foams have several advantages over other methods:

1. A simplified generator, which is easily moved from site to site.
2. Uniformity and control of the bubble size.
3. Economy of mechanical foaming with continuous production at high capacity.
4. Control of the total expansion of the foam, i.e., ratio of the volume of foam to the volume of foam liquid.

All of the above characteristics are particularly important to the present program and planned use as insulation.

The personnel at Onondaga Associates, Inc. have long been interested in the possibilities of utilizing foams for a variety of purposes. Two papers have been written dealing with the "Thermal Conductivity of Foam" and "Novel Uses of Foams" by the staff personnel. All of the personnel have had extensive foam experience and have also been actively engaged in testing the effectiveness of certain viscosity additives as foam stabilizers. The results of the field test conducted at Point Barrow, Alaska, proved conclusively that an aqueous base foam will protect ice from melting due to solar radiation. This report describes in detail the work accomplished from November 1961, to date.

III EXPERIMENTAL APPARATUS AND PROCEDURE

A. Materials

The following list of raw materials were used during the course of this investigation.

1. Foaming Agents

- a) Mearlfoam-Type 5. This is a partially hydrolized protein base foam liquid manufactured by the Mearl Corporation, Roselle Park, New Jersey.
- b) Myverol Type 18-00. This is a distilled monoglyceride prepared from fully hydrogenated lard. It is manufactured by the Distillation Products Industries, Division of Eastman Kodak Company, Rochester, New York.

2. Stabilizing Agents

- a) Gelatin, USP - Manufactured by Knox Gelatin, Inc., Johnstown, New York.
- b) Gantrez 4621 - Polymethyl vinyl ether/maleic anhydride, manufactured by the General Aniline and Film Corporation, 435 Hudson Street, New York 14, New York.
- c) Alcogum AN-25 Salts of polymerized acrylic resin acids (25% solids), low molecular weight polyelectrolyte, manufactured by the Alco Oil and Aluminum Corporation, Philadelphia, Pennsylvania.
- d) Bone-Glue - Manufactured by the Armour Alliance Industries, 16123 Armour Street, N.E., Alliance, Ohio.
- e) Carbose - Sodium carboxymethyl cellulose, manufactured by the Wyandotte Chemical Corporation, Wyandotte, Michigan.
- f) Dow ET-460-4 - This is an ammonium salt of sulfonated polyvinyl-toluene. It is a water soluble viscosity increasing agent and is produced by the Dow Chemical Company, Midland, Michigan.

- g) CMC - Sodium carboxymethyl cellulose, manufactured by the Hercules Powder Company, Wilmington, Delaware. The types used in this investigation were as follows:

CMC - 7 HP - High molecular weight-high viscosity.

CMC - 12 HP - High molecular weight-lower viscosity than 7 HP.

CMC - 7 MP - Medium molecular weight-medium viscosity.

CMC - 7 LP - Low molecular weight-low viscosity. (Pure Grade)

CMC - 7 LT - Low molecular weight-low viscosity. (Tech. Grade)

- h) Natrosol 250 - Hydroxyethyl Cellulose, manufactured by the Hercules Powder Company, Wilmington, Delaware.

3. Gelling Agent

Aluminum Acetate - Purified basic (powder). This is one of the gelling agents recommended by Hercules for CMC stabilizers, and is produced by the Mallinckrodt Chemical Works, New York, New York.

B. Equipment and Procedure -- Laboratory Investigation

1. Stability Tests

The screening of potential stabilizers was conducted by mixing various concentrations of these materials with six percent by volume Mearlfoam-Type 5 liquid and generating the mixtures into foams. An ordinary high speed electric kitchen mixer was used to generate the foam. The expansion ratio, i.e. the volume of foam to the volume of liquid contained within the foam, was measured. Clear drinking-water glasses found in the home, were used to sample the foam. The volume of each glass was determined and etched on the bottom, to facilitate calculation of the expansion ratio. Two samples were taken from each foam formulation tested. One was evaluated after an overnight aging at room temperature, while the other was subjected to 0°F for a minimum of two hours, immediately after which

it was placed under an infra-red lamp at a temperature of 100°F for an additional two hours. This constituted a severe freeze-thaw cycle. The foam samples were rated regarding their: a) expansion ratio, b) tendency to drain, and, c) strength and bubble size. (Items b and c were rated qualitatively.)

Based on Point Barrow temperature profiles made available by NCEL, a more realistic freeze-thaw cycle than that initially used, was established as follows: Frozen samples were maintained at 25°F for a minimum of two hours and evaluated after they had been allowed to come to room temperature.

2. Melting Apparatus

The apparatus used to determine the insulation value of foam consisted of a horizontal freezer cabinet minus the lid, atop which was placed an insulated chamber pyramidal in shape with a sun lamp forming the apex, (see Figure 1). The chamber was constructed to permit the simultaneous exposure of a protected versus and unprotected ice-sample. The freezer section was maintained as close to 25°F as possible while solar heat and radiation from the sun lamp maintained the air temperature above the samples between 50 and 70°F. To minimize melting of ice prior to start of test, the foam samples were precooled to their freezing points before being applied.

The melting rate of each sample was determined by measuring the volume of the liquid drained into a graduated cylinder as a function of time. A 500 milliliter ice sample was used in each test.

C. Equipment and Procedure -- Climatic Chamber Test

1. Ice Pans and Supports

In the All-Weather Chamber, a large aluminum pan measuring 4' x 6' x 6 inches was divided into three 4' x 2' x 6 inch sections using plywood dividers. (Figure 2 shows a comparable test pan, constructed of steel rather than aluminum.) This pan was placed on a wooden platform sitting approximately three feet above the chamber floor.

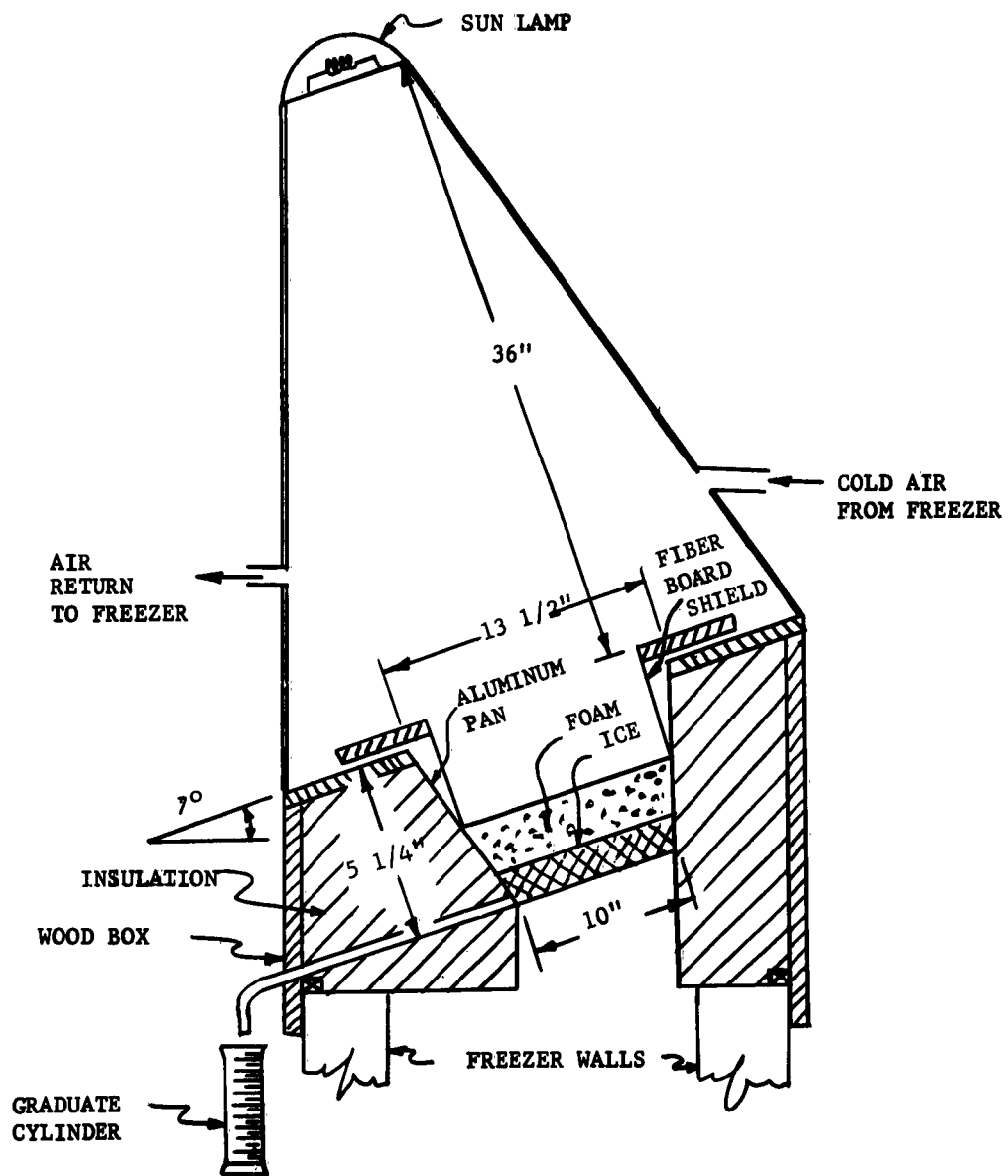


FIGURE 1 ICE MELTING APPARATUS



FIGURE 2 PHOTOGRAPH SHOWING ICE SURFACE PRIOR TO FOAM APPLICATION,
PLYWOOD SEPARATORS AND PLATFORM - ALL-WEATHER CHAMBER

The size of the door in the Strato Chamber necessitated the construction of three individual metal pans measuring 4' x 2' x 6 inches, (see Figure 3). These were of steel construction and painted black.

Tap water was frozen in these metal pans by storing in the All-Weather Chamber held at 25°F. Generation of the foam samples was also conducted in this chamber at this temperature. Foam was applied to the ice surfaces and also to the exposed metal surfaces of the pans which faced the sun lamps, and allowed to remain in the chamber over night. Following this precooling period, one set of pans was transferred to the Strato-Chamber while the other set was left in the All-Weather Chamber. Thermocouples were positioned in the ice and foam phases and connected to automatic temperature recorders so that periodic readings could be obtained. A bank of sun lamps was suspended above the pans and the turning on of these lamps signified the beginning of the exposure tests. The amount of solar radiation in gram calories/sq.cm.-min. was measured and adjusted to 0.37 in the All-Weather Chamber to match the 0.40 value reported for Point Barrow, Alaska during the thaw period. Due to the ceiling height limitation in the Strato-Chamber, the solar radiation level was 0.75 gram calories/sq.cm.-min.

2. Arrangement of Sun Lamps

Twelve sun-lamps, producing a total of 3,000 watts, were geometrically spaced on a 4 x 8 ft. plywood board to produce a uniform distribution of simulated solar radiation when suspended above the pans (see Figure 20).

3. Temperature Measuring Instrument

A Daystrom-Weston multiple station recorder Model 6702, was used to monitor temperatures in the range minus 50 to plus 100°F.

4. Solar Radiation Measuring Instrument

An Eppley Pyrheliometer, Model 2435, was used to measure the solar radiation under each bank of sun lamps.



FIGURE 3 PHOTOGRAPH SHOWING ICE SURFACE PRIOR TO FOAM APPLICATION,
INDIVIDUAL PANS AND PLATFORMS - STRATO CHAMBER

5. Foam Generator

Due primarily to the high viscosity of the foam solution being used, the conventional foam generator used in fire fighting was not adequate. A special foam generator had to be designed specifically for this stabilized foam. The apparatus used in both the Laboratory study and Climatic Chamber test is shown schematically in Figure 4 and pictorially in Figure 5. Although it was not capable of rates satisfactory for commercial application, it was adequate for the test conducted in the Climatic Chamber at Eglin Air Force Base, Florida. A description of the apparatus follows. The foam liquid was pumped by a gear pump from the feed tank to the mixing chamber packed with 1/2 inch ceramic Intalox saddles. At this point, atmospheric air was drawn in and thoroughly mixed with the foam solution. The partially foamed mass was fed into the suction side of the smaller of two Roots-Connersville blowers placed in series. The generated foam was then forced through two refining sections packed with 1/2 inch ceramic Intalox saddles to break up the large, unstable bubbles into smaller more stable ones. The blowers and the gear pump were operated from a single 22 horsepower gasoline engine. It should be noted that the impellers on both blowers were ground-down to obtain better mixing action and to reduce internal pressure build-up.

D. Equipment and Procedure -- Arctic Field Test

1. Construction of Ice Plots

Three types of ice plots measuring 100 feet in diameter each, were constructed by the Naval Civil Engineering Laboratory, (NCEL) for this field test. These consisted of: a) natural, b) free-flooded, and c) confined-flooded ice plots. Figures 6 to 9 inclusive, show in some detail: a) the position of the thermocouples in the foam, ice and water layers, b) the arrangement of the ablation stakes, and c) the technique used in diking the confined-flooded plots. For more detailed information concerning

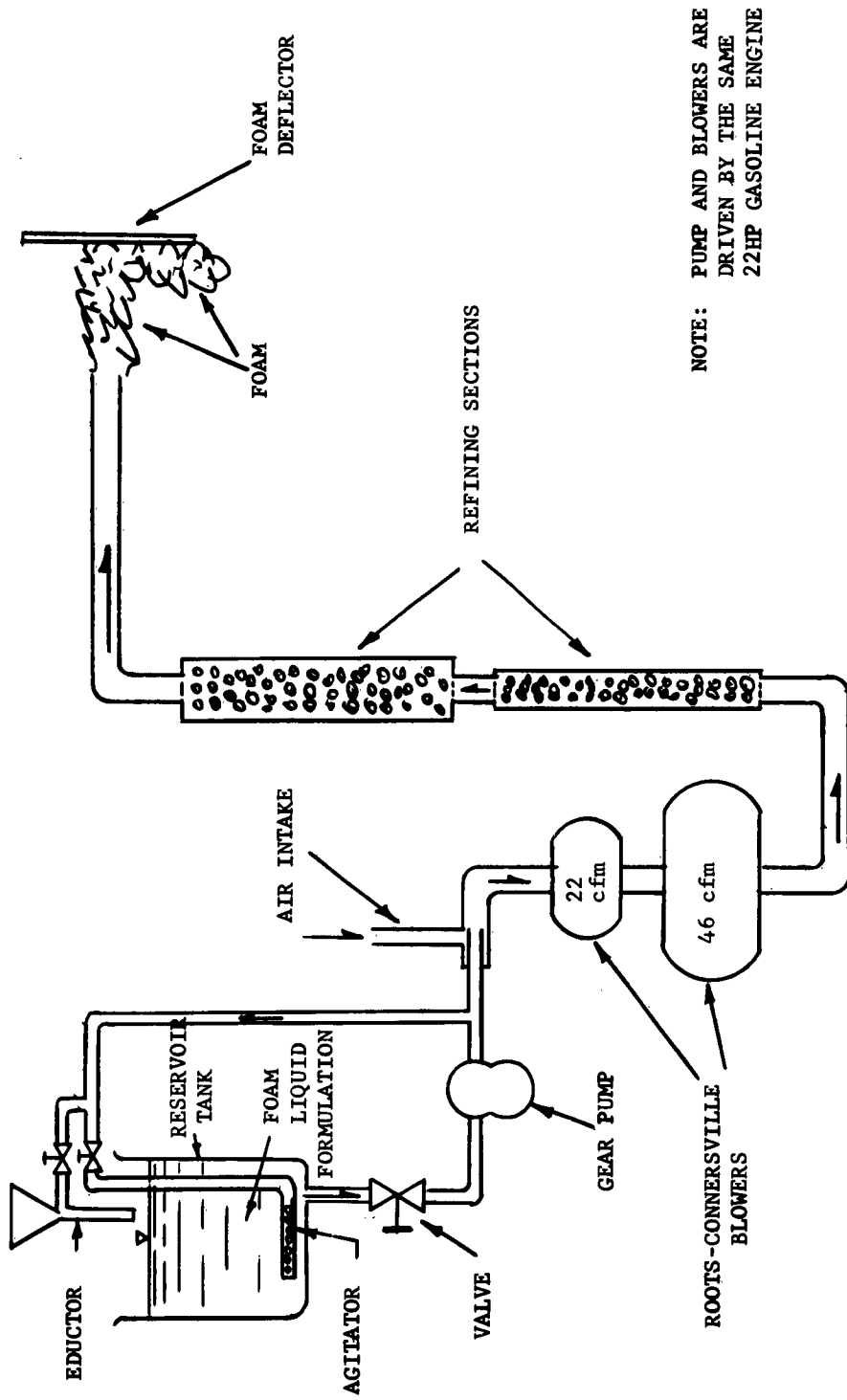


FIGURE 4 SIMPLIFIED SCHEMATIC OF FOAM GENERATOR



FIGURE 5 PHOTOGRAPH OF FOAM GENERATOR - CLIMATIC CHAMBER TEST

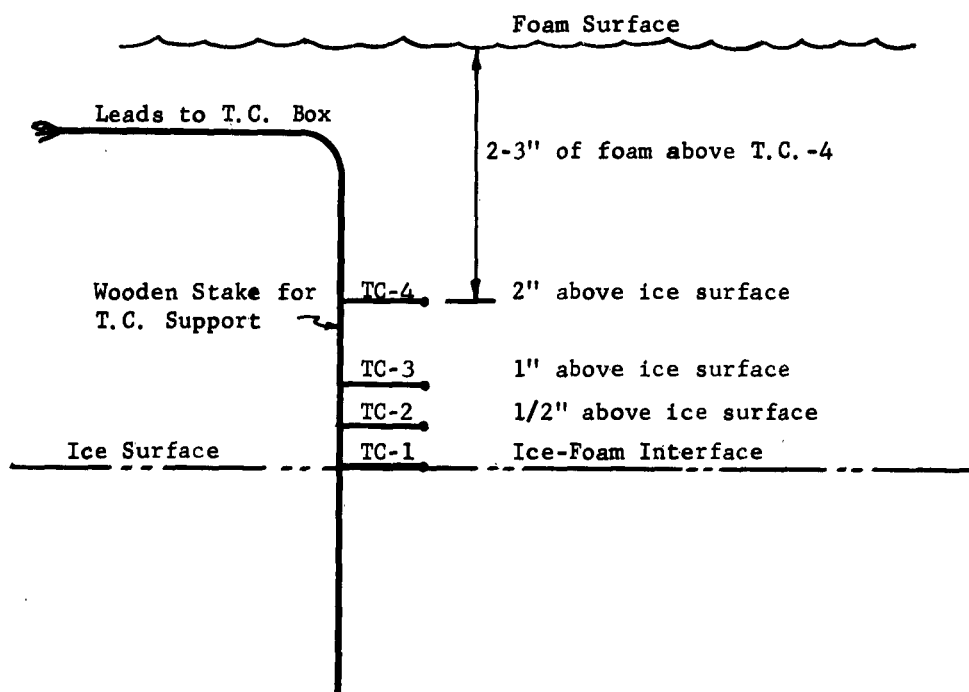


FIGURE 6 SCHEMATIC OF THERMOCOUPLE INSTALLATION IN FOAM LAYER
(Plots 5 and 6)

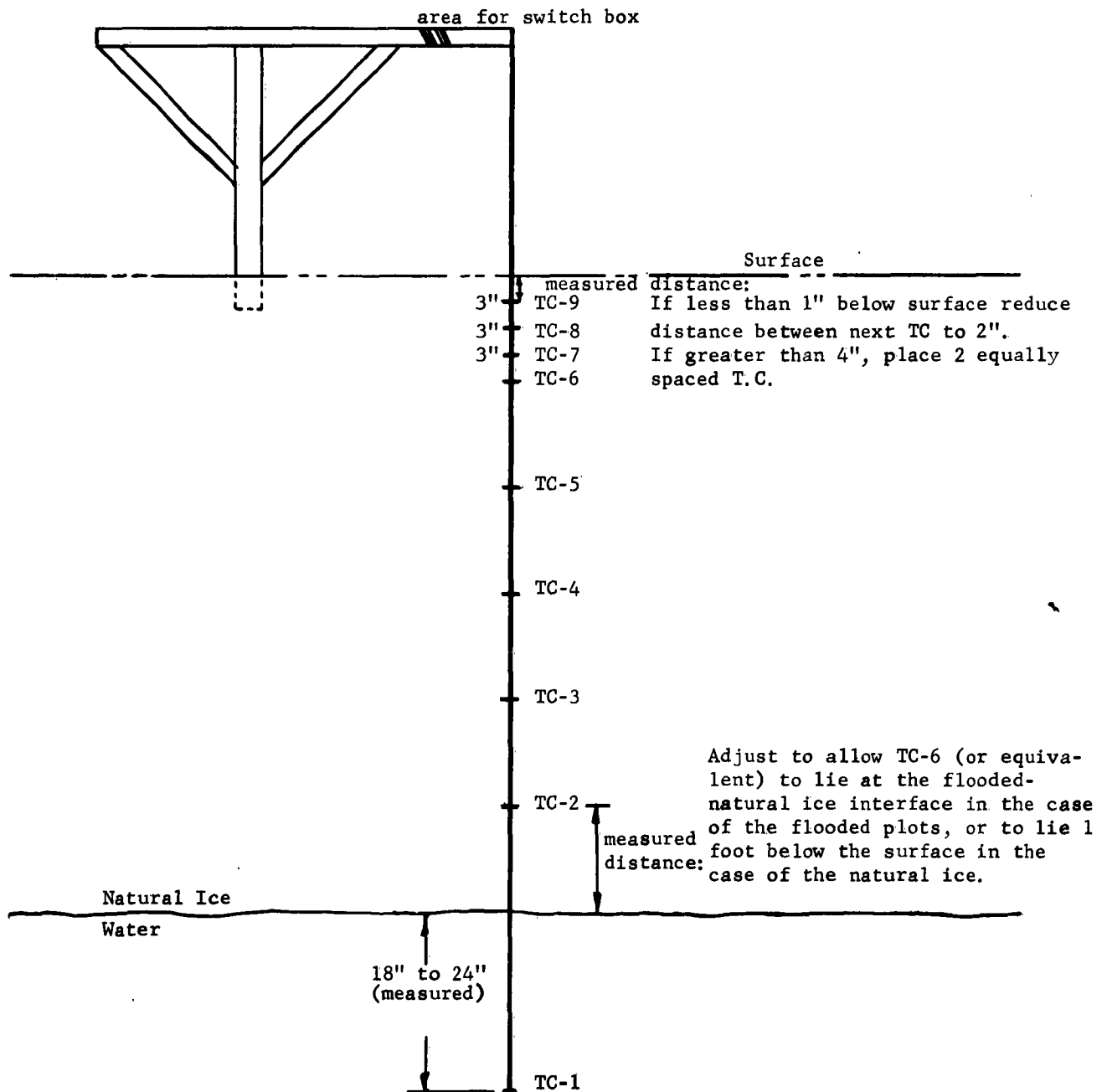


FIGURE 7 SCHEMATIC OF THERMOCOUPLE INSTALLATION IN ICE AND WATER LAYERS

FIGURE 8 Arrangement of Ablation Stakes

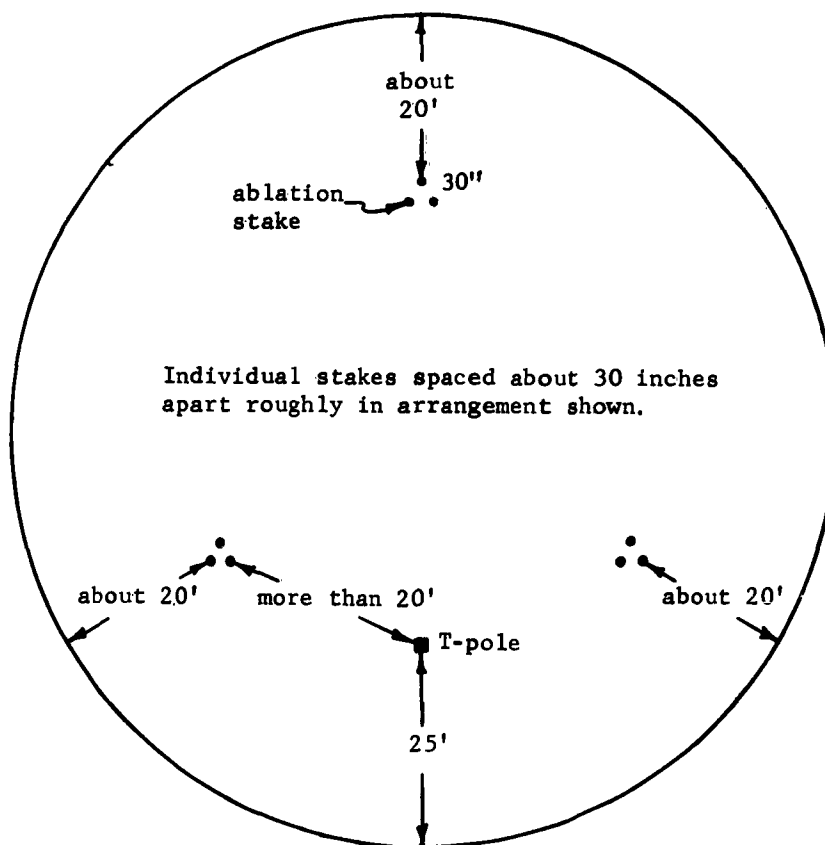
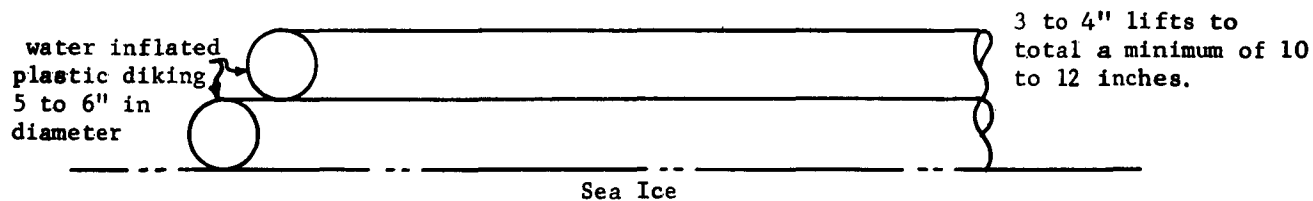


FIGURE 9 Diagram of Diking Technique



Construction diagram of diking for confined flooded plot 2.

the construction of these test sites, see NCEL "Memorandum of Procedure (Supplement)", coded L61/NLS/dy and dated 19 March 1962.

2. Preparation of Foam Solution

50 gallon foam solutions were made up in the following manner. Sea water obtained at the site was charged to a precalibrated 55 gallon feed tank. The preweighed stabilizer and gelling agents were dissolved utilizing the eductor device. These materials had been weighed, mixed together and stored in plastic bags. Following the dissolution of these powders, the Mearlfoam-Type 5 foam liquid, measured out volumetrically in a precalibrated 5 gallon can, was added as the final material. The resulting solution was recycled until thoroughly mixed, after which time foaming was initiated.

3. Application of Foam on Test Plots

With the initial generator the foam was discharged through a short flexible hose onto the ice surface to be protected. Spreading of the foam was accomplished by hand, using a squeegee.

The modified foam generator apparatus was purposely located some distance away from the area to be protected due to melting caused by the equipment. The foam was discharged through a spreader device onto a large section of canvas, transported to the site and put in place with a squeegee.

4. Weather Data

Maxima-minima air temperatures measured in the shade were taken daily. Air temperature along with wind speed and direction, and sky cover were reported twice daily. The daily average, of the total hourly solar incident radiation measured and reported by the U. S. Weather Bureau at Point Barrow, Alaska, was also obtained.

5. Ice and Foam Temperature Profiles of Test Plots

The sea-water temperature below each ice plot, as well as the temperature gradient of the ice plot itself, were determined twice daily. The temperature profile of the foam layer on each protected plot was recorded simultaneously.

6. Ablation Data of Test Plots

The amount of ice ablated from each unprotected plot was measured periodically, while ablation readings of the protected plots were taken just prior to the application of foam and at the conclusion of the exposure period.

7. Foam Generators

a. Initial Foam Generator

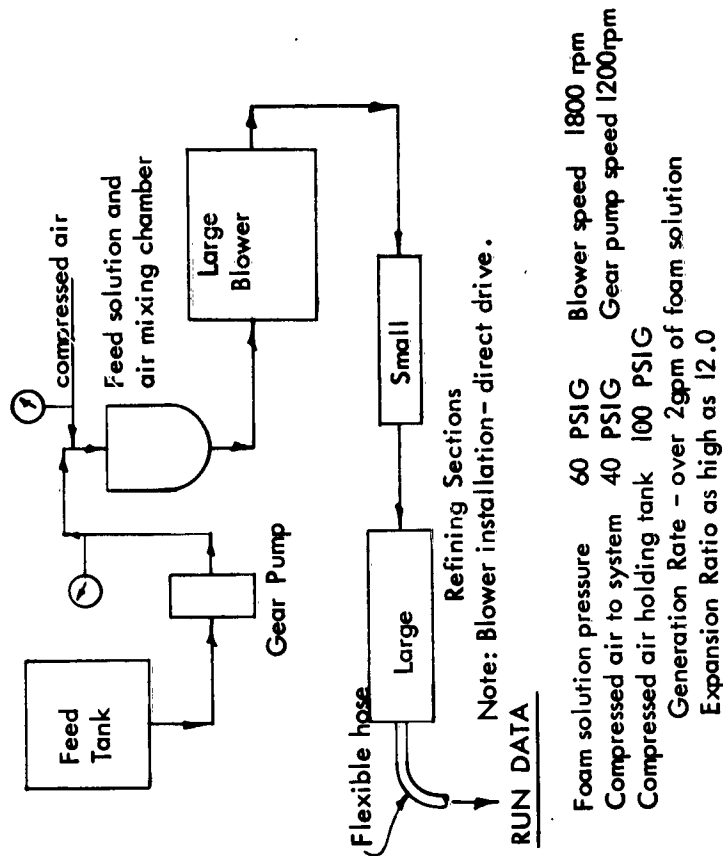
The initial foam-generator employed the following features: 1) a closed feed system, 2) compressed air, 3) a Roots-Connersville blower installed for direct drive, and 4) a flexible hose through which the foam was discharged. A schematic diagram and a photograph of the apparatus are shown in Figure 10. Mechanical difficulties were encountered with this apparatus when run at top speeds for extended periods of time.

b. Modified Foam Generator

In view of the difficulties encountered with the closed-feed and direct-drive system, the equipment was modified to eliminate these features. In this modified version (see Figures 11 and 12) the blower was belt driven to eliminate shaft strain during transportation, and the speed reduced as a further precaution against damage. This reduction in rate of blower rotation negated the advantage of compressed air, since the same rate and foam expansion was achievable by introducing air at atmospheric pressure. This reduction in blower speed reduced the foam generation rate to slightly less than 1 gpm. Also incorporated in this modified set-up was a spreader device

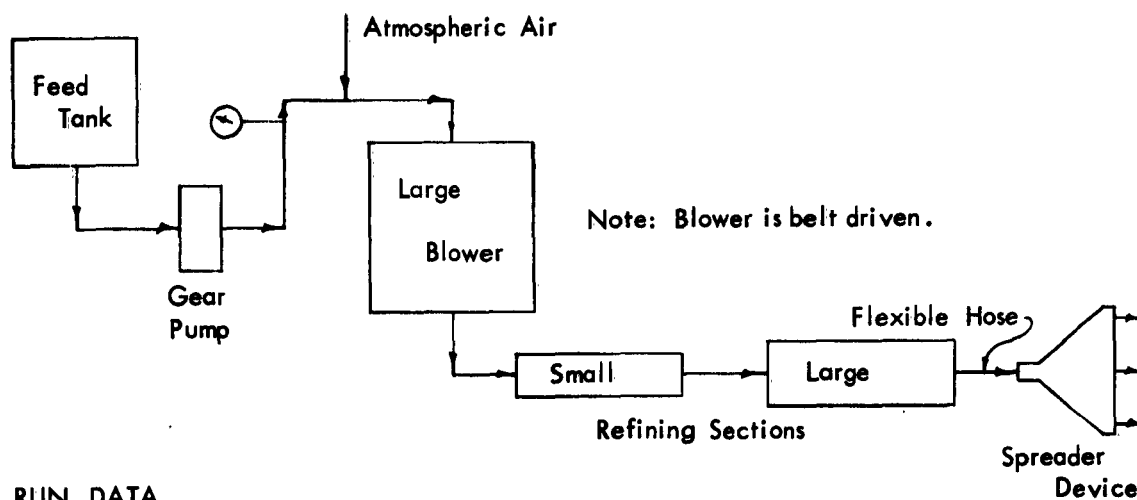
FIGURE 10

Schematic and Photograph of Initial Foam Generator Apparatus



View of Initial Foam Generator in Action

FIGURE 11 SCHEMATIC AND PHOTOGRAPH OF MODIFIED FOAM GENERATOR APPARATUS



RUN DATA

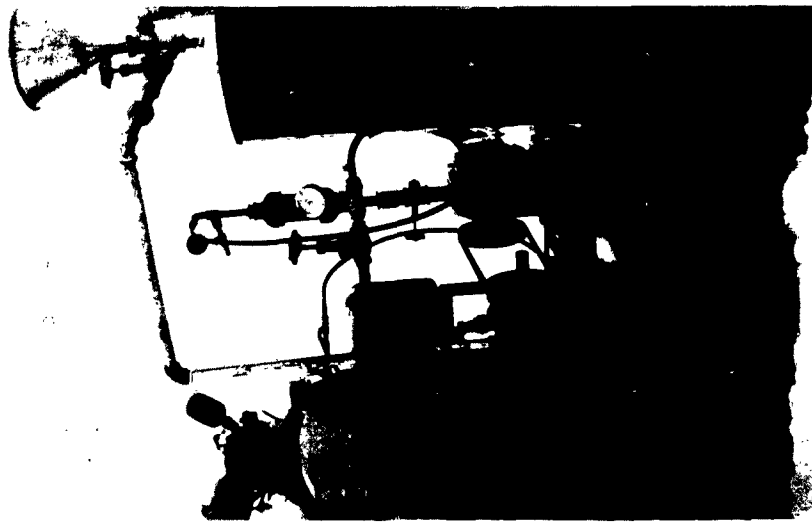
Foam solution pressure 40 PSIG
 Blower speed 1000 rpm
 Gear Pump 1200 rpm

Generation Rate - 0.9 gpm of foam solution
 Expansion Ratio as high as 10.0

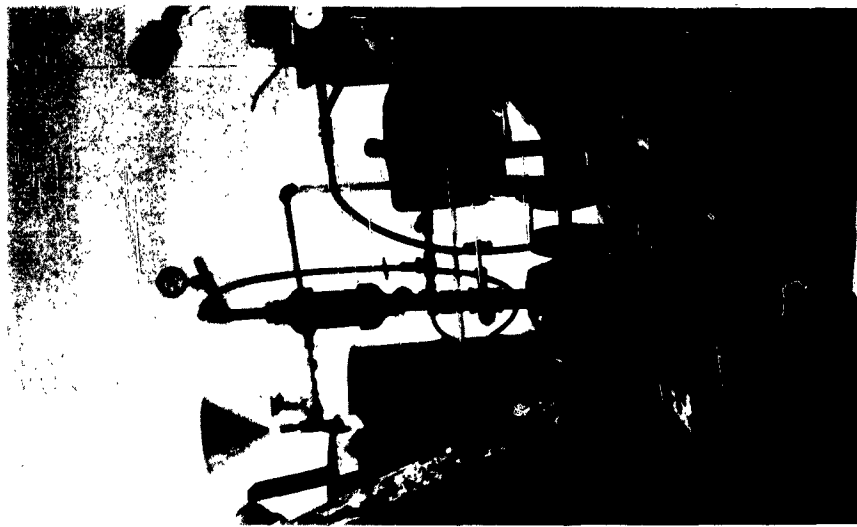


VIEW OF MODIFIED FOAM GENERATOR SHOWING SPREADER DEVICE IN PLACE

FIGURE 12 ADDITIONAL PHOTOGRAPHS OF MODIFIED FOAM GENERATOR APPARATUS



VIEW FROM GEAR PUMP SIDE



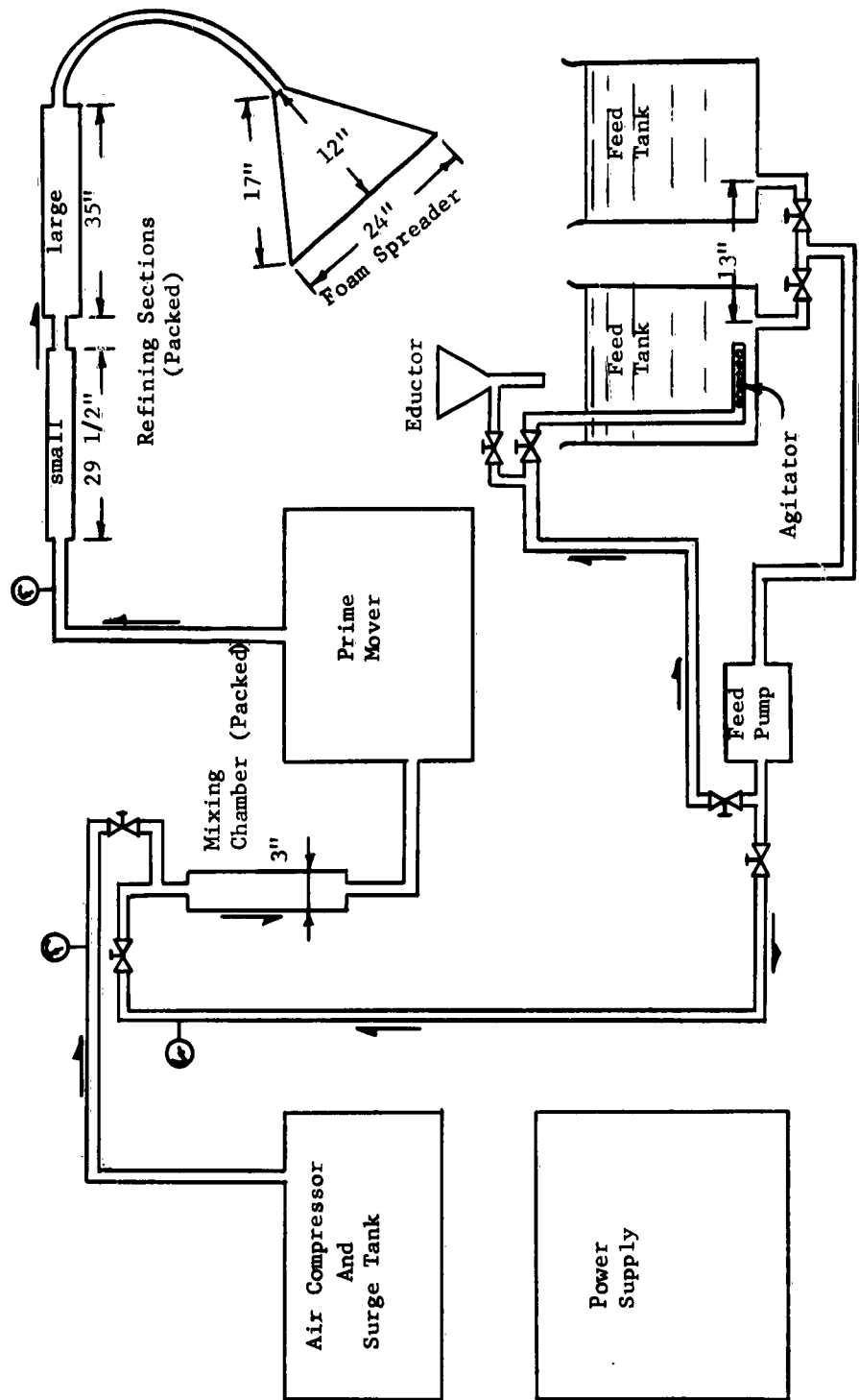
VIEW FROM BLOWER SIDE

(see Figure 11) designed to knead the foam and produce a more homogeneous and continuous mass.

E. Equipment and Procedure -- "Post" Arctic Field Test

1. Foam Generator

The present apparatus (see Figure 13) resembles closely the initial foam-generator used in the Arctic Field Test with two exceptions. First, a more rugged and trouble-free Blackmer Sliding Vane Pump has been substituted for the Roots-Connersville blower and secondly, the spreader device has been incorporated in this design. A detailed schematic drawing showing provisions for two feed tanks, as employed in the Field Test, can also be seen in Figure 13. In this two tank feed system the eductor-agitator section was designed for use in either tank. This was accomplished simply by providing unions and sections of pipe sufficient in length to position the eductor-agitator section in either tank. The power supply suggested for this generator is 50 horsepower and a separately driven air compressor capable of producing 3-4 cfm of air at 40 PSIG is recommended.



Assembly Details:

Power Supply Recommended - 50HP.

Air Compressor Capacity - 3-4cfm at 40PSIG.

Compressed Air Surge Tank - 50 Gallon Capacity.

Prime Mover - Blackmer sliding vane pump.

Feed Pump - Oberdorfer Bronze Rotary Gear Pump Gear size No. 7,

inlet and outlet pipe size - 2 inch.

Feed Tanks - 55-Gallon Steel drums.

Foam Spreader - Fabricated from Galvanized Steel.

Refining Sections - Packed iron pipe,
2 and 3 inches in
diameter.

Mixing Chamber - Packed 3-inch section
of iron pipe.

Packing Material - 1/2-inch ceramic
Intalox saddles.

Eductor - 3/4-inch discharge.

Figure 13 DETAILS OF PRESENT FOAM GENERATOR ASSEMBLY

IV RESULTS AND DISCUSSIONS

A. Background

A previous investigation conducted by Onondaga Associates, Inc., concerned with the development of aqueous foam insulation for the protection of Arctic airfields, revealed the following:

- a) Protein base foam, e.g. Mearlfoam-Type 5, was more stable for a longer period of time than foam generated from synthetic detergents.
- b) The stability of protein base foam was considerably improved by the addition of stabilizing agents, such as Dow ET-460-4.
- c) Although these foams afforded excellent insulation properties they were prone to rapid decay when subjected to a severe freeze-thaw cycle of 0 to 100°F.

The current investigation was designed to find a suitable stabilizer or stabilizer system for Mearlfoam-Type 5, that would permit the resultant foam structure to withstand the severe freeze-thaw cycle mentioned above and be acceptable for its intended use in the Arctic and Antarctic regions.

B. Laboratory Investigation

1. Stabilizer Study

The screening of potential stabilizers was conducted by mixing various concentrations of these materials with six percent by volume Mearlfoam-Type 5 solution and generating the mixtures into foams. The stabilizer types tested were: a) CMC, b) Gelatin, c) Gantrez 4621, d) Alcogum AN-25, e) Bone-Glue, and f) Carbose. (See Table I for formulation details and results.) None of these stabilizers produced a foam capable of withstanding even one cycle of the severe freeze-thaw cycle described in detail in Table I. However, of those tested CMC 7 HP stood up best. Even though the foam based on this stabilizer was weak and shrunk badly, it did indicate that this family of stabilizers merited additional study.

2. Effect of Gelling Agent

Further investigation of these CMC stabilizers revealed that the gelling rate of these cellulose gum solutions could be controlled by the addition of the polyvalent cations from compounds, such as aluminum acetate. By utilizing this gelling technique foams with excellent strength properties and freeze-thaw resistance were obtained. The frozen and non-frozen foam samples did not drain even at concentrations as low as 1.0% CMC 7 HP (see Runs 13 to 16, Table I). Non-frozen samples between 1.5 and 2.0% CMC 7 HP showed good bubble strength although a concentration between 2.0 and 2.5% was required to pass the severe freeze-thaw cycle. At these higher concentrations very viscous solutions in the order of 20,000 cps. resulted, which presented generation problems. In the laboratory mixer the expansion ratio was reduced from 11 to 7 by increasing the CMC 7 HP concentration from 1.0 to 2.0%.

For comparison a 4% Dow ET-460-4 stabilized foam (Run 17) was evaluated along with those based on CMC. The non-frozen sample exhibited some drainage after two hours while the frozen sample collapsed on thawing.

3. "Myverol" -- Foaming Agent

Initial tests with this foaming agent showed that it:

- a) required much less material concentration than the protein base foam; b) was better from a logistic standpoint since it was available as a dry powder; and, c) being white in color, was a more efficient heat reflector than Mearlfoam. Based on these advantages, additional work was undertaken with this material. The results are reported in Table I, as Runs 18, 19 and 20. It can be seen from this series of runs that the aluminum acetate gelling agent adversely affected the foaming property of the Myverol solution. Therefore, for this foaming agent to be useful another gelling agent or technique must be found to produce a permanent foam structure comparable to

Mearlfoam base foam. Another disadvantage of this foaming agent is its slow rate of dehydration, caused by the formation of a thin skin over the foam surface, acting as a vapor-barrier. Also, being a hydrogenated lard material it is inherently very slippery when moist and could present a problem for aircraft landing on its foam. Because of the disadvantages listed above, no further work was undertaken with this material.

4. Revised Freeze-Thaw Conditions

During the course of this investigation it was learned from NCEL that Arctic temperature conditions would not be as severe as those used in the early laboratory freeze-thaw test. Based on Point Barrow temperature profiles for the test period in question, a more realistic freeze-thaw cycle was established as follows. Frozen samples were maintained at 25°F for a minimum of 2 hours and evaluated after being allowed to come to room temperature.

5. Formulation Refinement

With the more realistic freeze-thaw specification, an investigation was undertaken to determine the lowest concentration of each ingredient that could be tolerated. Besides being desirable from a logistic and technical standpoint, it was also beneficial from a generation standpoint (see Table II). Varying the concentration of CMC 7 HP from 1.25 to 1.75% reduced the expansion ratio from 14.5 to 11.5 and showed that below 1.5% CMC 7 HP a weak foam was produced which shrunk noticeably when subjected to the revised freeze-thaw test. In general, it was observed that foam strength increased as the concentration of CMC 7 HP increased. Varying the concentration of aluminum acetate from 10 to 50% based on the weight of the stabilizer, showed that about 25% was required for best all around properties.

A series of three runs were made using Mearlfoam-Type 5 at concentrations of 3, 6 and 7.5%. Reducing the Mearlfoam-Type 5 concentration from 6 to 3% reduced the expansion ratio from 10 to 5 and resulted in generally inferior foam properties. Foams produced from 6 to 7.5% Mearlfoam-Type 5 were comparable in all respects.

Based on the results of Table II and previous studies, it was felt that a foam meeting the requirements of freeze-thaw, strength and stability, could be generated based on 6% Mearlfoam-Type 5, 2.0% CMC 7 HP and 25% Aluminum Acetate (based on CMC weight).

6. Melting Runs

To ascertain the insulating value of foam based on sea water, Mearlfoam-Type 5, CMC 7 HP and Aluminum Acetate, melting runs were conducted in the laboratory. The melting rate of ice both with and without foam protection was measured. Tap water was used in preparing the ice samples while sea water prepared in the laboratory, (see Table III for composition) was used in the foam formulation. The foam thicknesses investigated were 1-1/4 and 2 inches, with expansion ratios in the neighborhood of 8.0. The foams were precooled at 32°F before start of test. The melting apparatus, Figure 1, was designed to simulate conditions at Point Barrow, Alaska, i.e. maintain ice temperature at 25°F while solar heat and radiation from a sun lamp maintained an air temperature between 50 and 70°F.

The melting and temperature profile data for these runs are presented in Tables IV and V while the melting data for these two tables are plotted in Figures 14 and 15 respectively. It can be seen that a 1-1/4 inch layer of foam retards the melting rate of ice from 56 to 24 ml/hr. while a 2 inch layer retards it from 120 to 6 ml/hr. illustrating the substantial reduction in melting rate realized by a 3/4 inch increase in foam thickness. The melting rate is determined from the slope of the straight line portion of the melting versus time curve. A previous study had

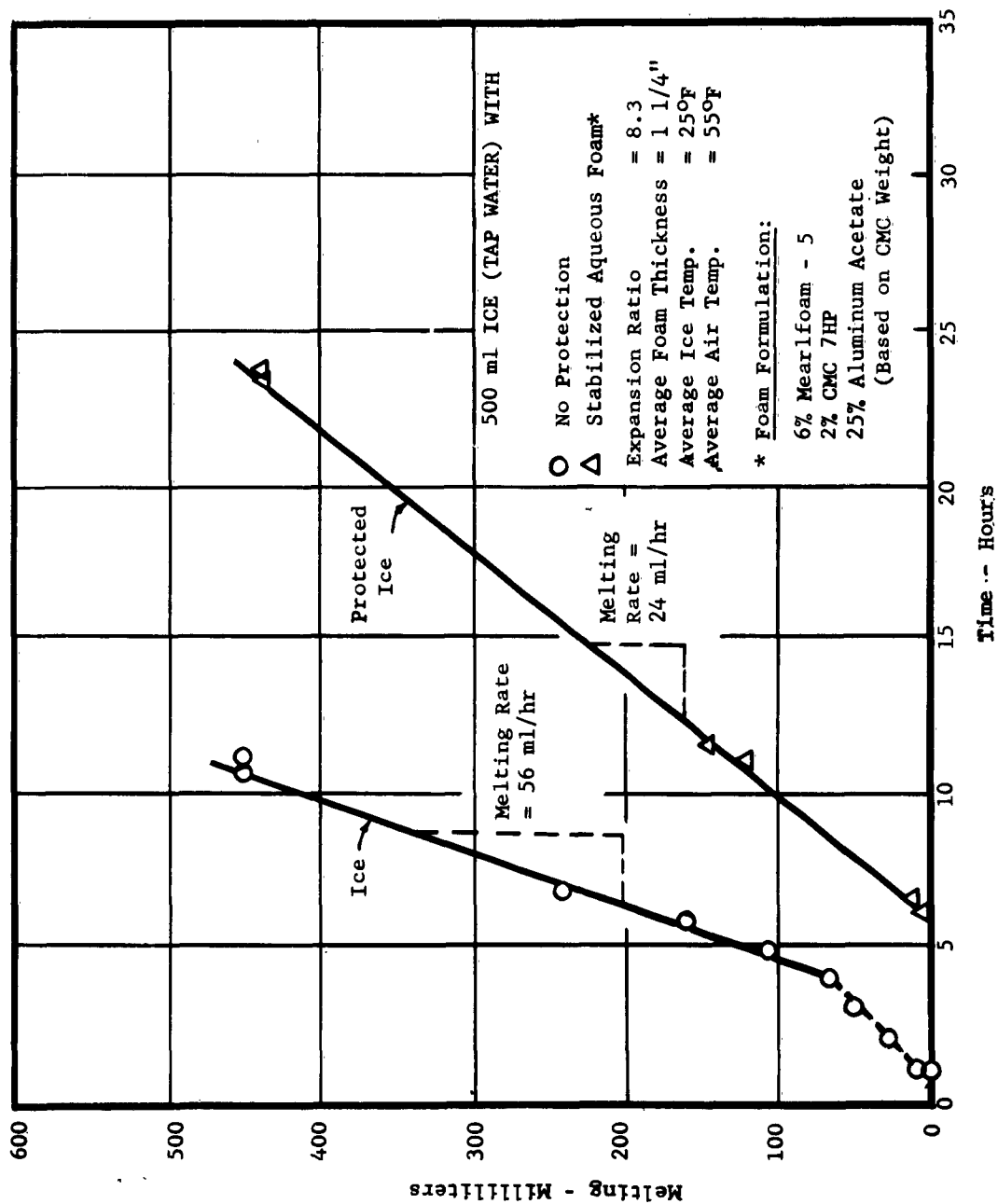


FIGURE 14 MELTING OF PROTECTED AND UNPROTECTED ICE SAMPLES VERSUS TIME

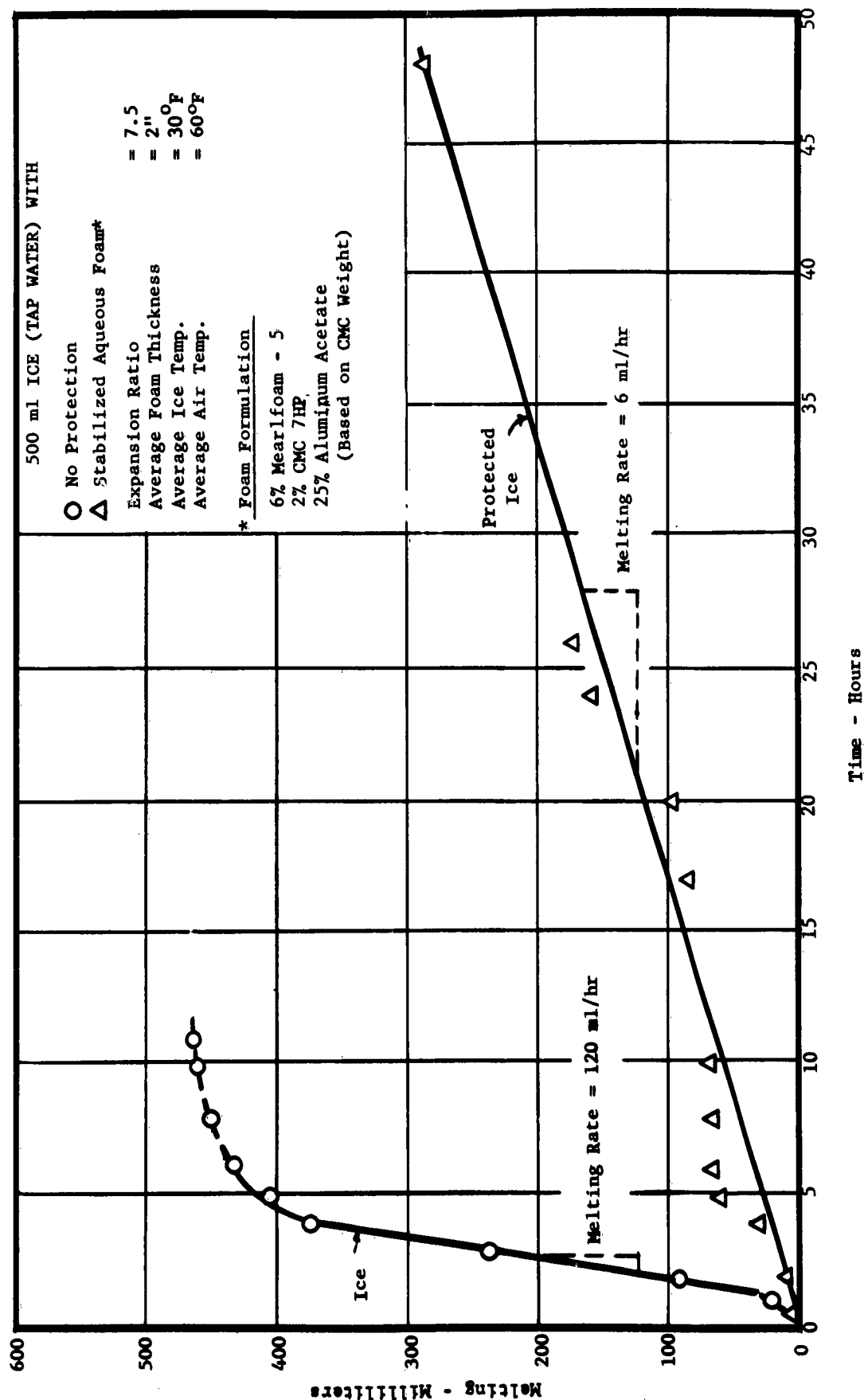


FIGURE 15 MELTING OF PROTECTED AND UNPROTECTED ICE SAMPLES VERSUS TIME

also shown this decided improvement in insulation value of aqueous foams, due to small increase in foam thickness. It had also been established that the optimum foam thickness for these materials is approximately 2 inches. The condition of the 2 inch foam layer after 48 hours continuous exposure during the present investigation, was excellent. The ice surface beneath the foam was rough, corresponding to the cell structure of the foam at the ice-foam interface. This mechanical bonding between the ice and foam resulted in good adhesion between the two surfaces.

Most of the melting in the protected sample occurred in the vicinity of the drain hole. Since the drain line was heated to prevent refreezing of the melted ice, it appeared that heat conduction to the pan was responsible for a portion of this melt. The scattering of the points in Figures 14 and 15 are directly attributable to the periodic addition of dry ice to the freezer, coupled with the turning on and off of an incandescent lamp placed inside the freezer, as a means of temperature control. This was necessary since the freezer capacity was not sufficient to maintain the desired cabinet and freezer temperature simultaneously.

7. Study of Other CMC Stabilizers

Although foams stabilized with CMC 7 HP possessed all the qualities sought, they did present a generation problem. This was due primarily to the very viscous nature of these solutions. In an effort to improve the formulation in this respect, other lower viscosity CMC types were investigated. Table VI shows the advantage gained in both solution viscosity and consequently in expansion ratio. The Brookfield viscosity of a 2% CMC 7 HP base foam solution was 20,500 centipoises while an equivalent concentration of CMC 7 LP resulted in a viscosity of only 66 centipoises. The expansion ratio, being somewhat dependent on

solution viscosity, was increased from 7 to 17 as the viscosity was decreased. The foam solution viscosities of both CMC 12 HP and CMC 7 MP were 720 centipoises and each resulted in an expansion ratio of approximately 11.

The evaluation of the frozen and non-frozen foam samples generated from the above solutions (see Table VI), indicated that this family of stabilizers was capable of producing foams with a wide range of physical properties and generation possibilities.

8. Summary of Laboratory Investigation

The preliminary investigation, conducted in the laboratory, proved that strong and stable aqueous foams could be produced from a mixture based on Mearlfoam-Type 5, CMC and Aluminum Acetate. Furthermore, these foams are capable of withstanding freeze-thaw cycles which are encountered in the Arctic and Antarctic regions. Their excellent insulatory properties were also substantiated by this investigation.

C. Climatic Chamber Test -- Eglin Air Force Base, Florida

1. Formulation and Generation

The three types of CMC stabilizers chosen for further testing at Eglin consisted of a high viscosity - high molecular weight type (7 HP), a medium viscosity - high molecular weight type (12 HP), and a low viscosity - low molecular weight type (7 LP). A foam based on stabilizer ET-460-4 was also included in this study as a control, since its performance under similar conditions was known from past experience. Table VII reports the complete formulation details, and verifies the laboratory findings that ease of generation and higher expansion ratios are obtained with lower viscosity solutions. The analysis of the salt water utilized in the formulation is given in Table VIII.

2. Initial Evaluation of Foam Samples

Samples of foam generated in the All-Weather Chamber for exposure tests were subjected to an initial freeze-thaw cycle covering the range 25°F to room temperature. Qualitative observations of these frozen and non-frozen samples are listed in Table IX and a photograph following the 24-hour conditioning period, is included as Figure 16.

The results of this initial evaluation verified laboratory findings concerning foams based on high versus low molecular weight CMC stabilizers. These were as follows:

- a) Cell expansion less affected when exposed to a freeze-thaw cycle.
- b) Result in stronger foam structures.
- c) Show no tendency to drain.

3. Effect of Solar Radiation on Foam Shrinkage and Unprotected Ice Samples

The average two-inch layer of foam applied over the ice samples in both chambers showed practically no change in thickness and remained unchanged after two days exposure to solar radiation (see Figure 17). However, after one day exposure, boundary shrinkage of the ET-460-4 stabilized foam caused it to pull away from the plywood separator, exposing the ice layer below. This sample also showed some signs of drainage.

The unprotected ice sample in the Strato-Chamber was almost completely melted by the second day, while its counterpart in the All-Weather Chamber was only approximately 30 percent liquid. The differences in the melting rates of these two ice samples are directly attributable to the differences in the solar radiation level in these two chambers. Due to the much lower ceiling in the Strato-Chamber the height to which the sun lamps could be suspended was limited. The solar radiation over the unprotected pan in this chamber was double that in the All-Weather Chamber, being on the average 0.75 versus 0.37 gm. calories/sq.cm.-min. (see Tables X

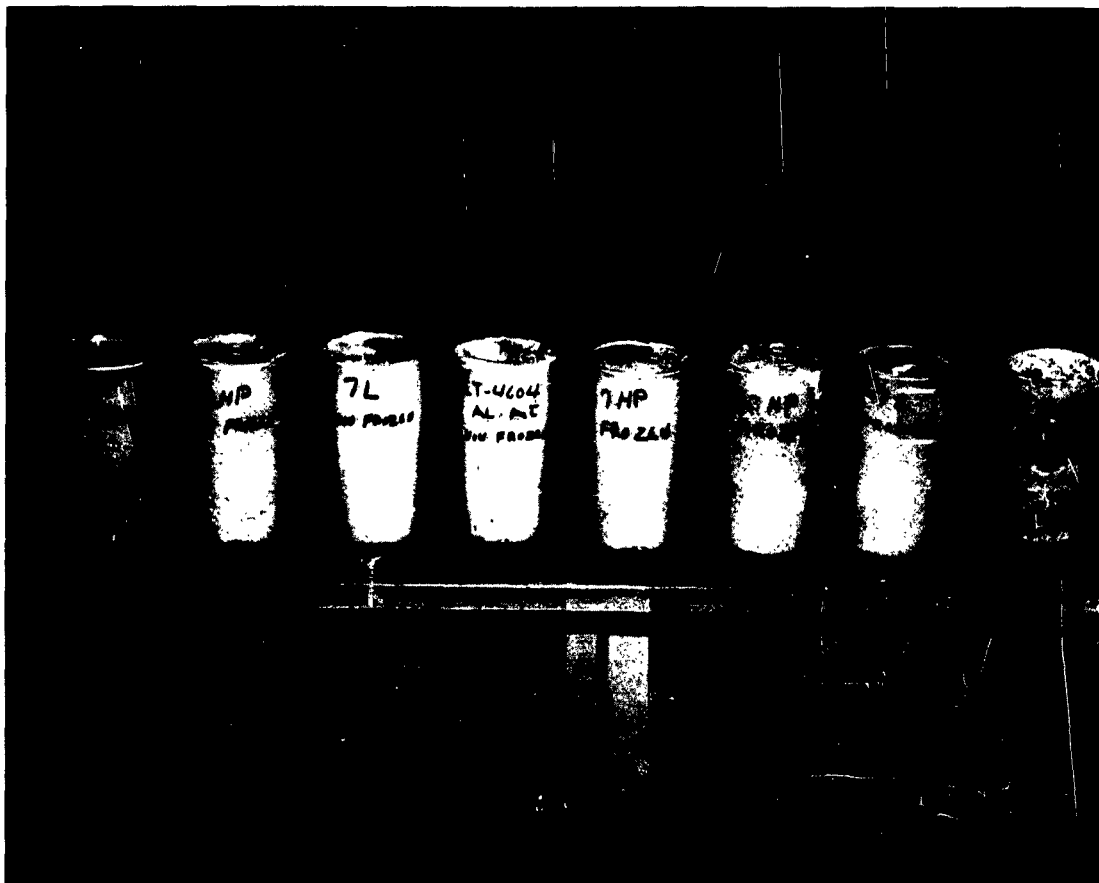


FIGURE 16 FOAM SAMPLES - CLIMATIC CHAMBER TEST

DATE & TIME MEASURED

3-16-62 (2 PM)

3-17-62 (10 AM)

3-18-62 (12 NOON)

3-16-62

3-17-62

3-18-62

3-16-62

3-17-62

3-18-62

PAN

1 1/2	2
1 3/4	2
1 1/2	1 3/4
Foam thickness measurements (in)	
2	
2	
2	
1 5/16	1
1 1/2	1 3/4
1 3/4	2

7HP

STRATO-CHAMBER

PAN

2	1 3/4
all water	4
Water depth measurements (in)	
2 3/4	
5	
Ice practically all melted 3-18-62	
2	2
4 1/2	3 1/2

Unprotected Ice

PAN

2 1/2	2 1/2
2 3/4	2 1/2
2 1/2	2 3/4
Foam thickness measurements (in)	
2 1/4	
2 1/2	
2 3/4	
1 3/4	1 3/4
2	1 3/4
2	1 3/4

12HP

ALL-WEATHER CHAMBER

PAN

2 1/2	2 1/4
2 1/2	2 1/4
2 1/4	2
Foam thickness measurements (in)	
2 1/4	
2 1/2	
2 1/4	
2 1/4	2 1/4
2 1/2	2 1/4
2 1/4	2

ET 460-4

PAN

1 1/4	1
1 3/4	2
Water depth measurements (in)	
1 1/2	
2 1/4	
1/2	1/2
1 1/4	1 1/4

Unprotected Ice

PAN

2 1/2	2 1/4
2 1/2	2 1/4
2 1/2	2 1/4
Foam thickness measurements (in)	
2 1/2	
2 1/2	
2 3/4	
2	2 1/4
2 1/2	2 1/2
2 1/4	2 1/2

7LP

Remarks: Measurements taken approx. 6" from sides & ends at each corner & one in the middle of pans.

FIGURE 17 EFFECT OF SOLAR RADIATION ON FOAM SHRINKAGE & UNPROTECTED ICE SAMPLES

and XI). The latter figure is comparable to the 0.4 value reported for Point Barrow, Alaska.

4. Effect of Solar Radiation on Ice Surfaces Both Protected and Unprotected

After six days of continuous exposure to an average of 0.75 gm. calories/sq.cm.-min. of solar radiation in the Strato-Chamber, 8 percent of the ice protected with CMC 7 HP base foam had melted. With the CMC 12 HP base foam, 6 percent had melted. The unprotected ice, as mentioned earlier, was completely melted after only two days exposure. Figure 18 is a schematic representation of the amount of ice melted as a result of the above exposure and Table X shows the measurements and calculations based on this figure. The chamber temperature was maintained at 25°F while the air temperature (measured in the "sun") directly over the foam surface was on an average 62°F (see Table XII).

After six days of continuous exposure to an average of 0.37 gm. calories/sq.cm.-min. of solar radiation in the All-Weather Chamber, 2.5 percent of the ice protected with CMC 7 LP base foam had melted. With the ET-460-4 base foam, 7 percent had melted. The unprotected ice was about two-thirds melted in this same time period (see Figure 19 and Table XI). The chamber temperature was maintained at 25°F while the air temperature (measured in the "sun") directly over the foam surface was on the average 45°F (see Table XIII). These temperature and radiation conditions are close to those reported for Point Barrow during the months of May and June.

Following the exposure test, the removal of foam from the ice samples in the Strato-Chamber, revealed the remaining ice to be floating. Two possible mechanisms which can account for this phenomena are: (a) The reflection of the simulated sun rays from the chamber walls onto the black-iron sides and bottom of the

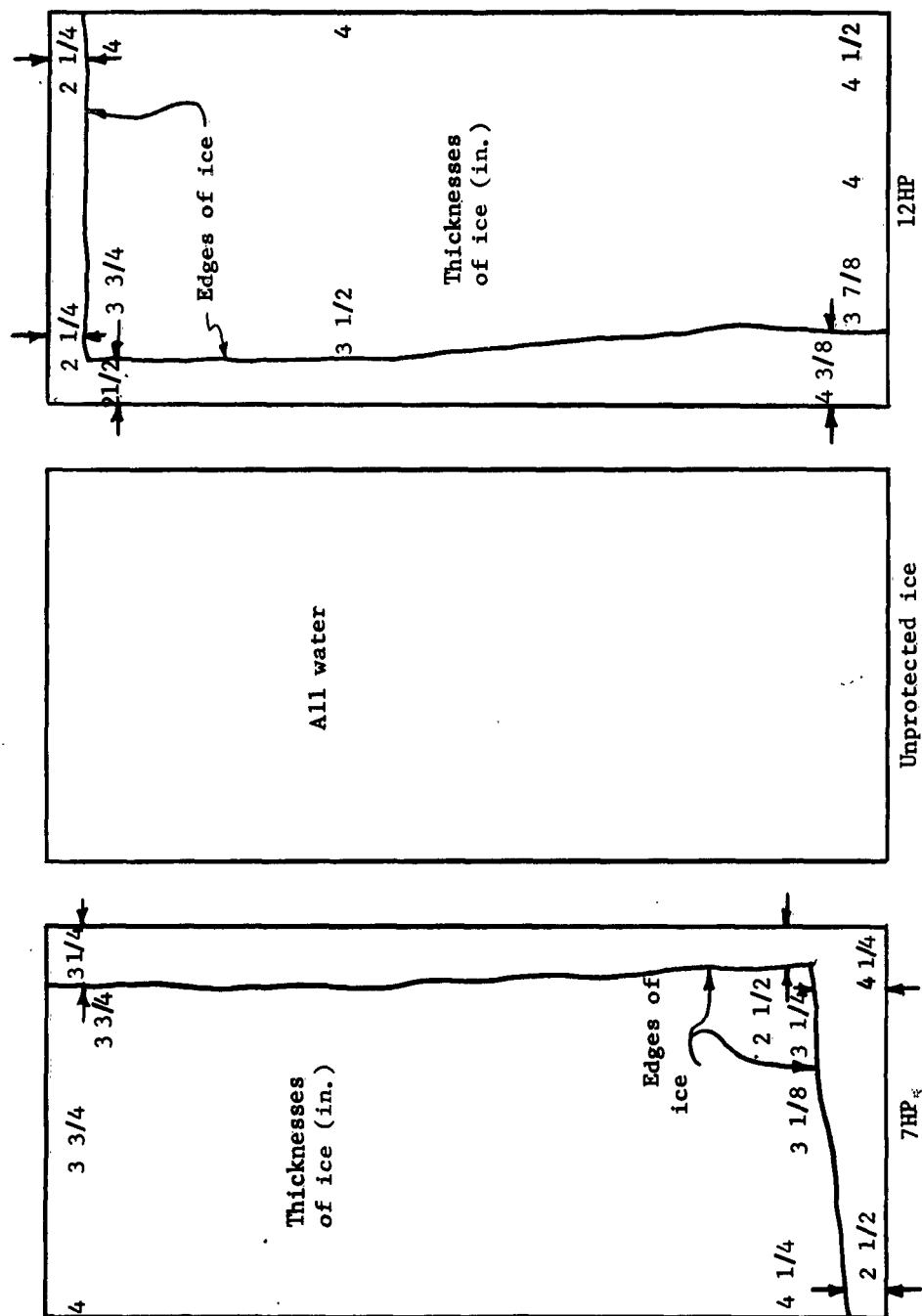
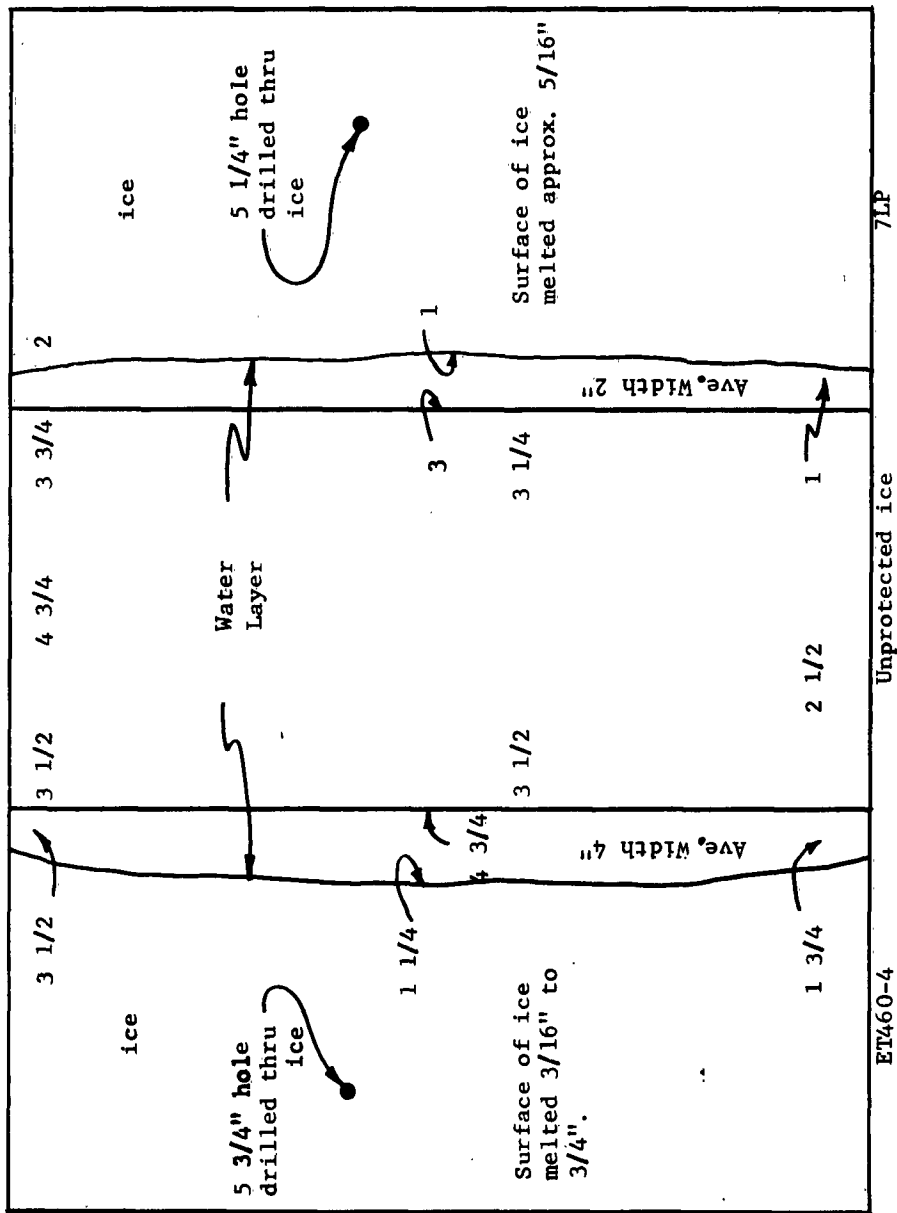


Figure 18 AMOUNT OF ICE MELTED AFTER EXPOSURE TESTS IN STRATO CHAMBER



Remarks: Measurements in All-Weather Chamber pans are: depth of water above ice surfaces - inches.

Figure 19 AMOUNT OF ICE MELTED AFTER EXPOSURE TESTS IN ALL-WEATHER CHAMBER

ice pans, causing melting in these areas; and, (b) the excessive simulated solar radiation in this chamber causing some melting of the ice surface, which in turn drained down the sides of the pans causing the ice to float.

Removal of foam from ice samples in the All-Weather Chamber, revealed that in both these samples only the ice adjacent to the plywood separators had melted. The surface of the ice had no "pot" holes and was uniformly melted. This indicated that the melting of the unprotected ice sample located in the center section of the pan was allowing water to come in contact with these ice samples. In the case of the ET-460-4 stabilized sample the melting of ice in this region was increased by the boundary shrinkage of the foam itself, causing the ice underneath the foam to be exposed to the sun lamps. Since the pan in this chamber was constructed of aluminum and its edges painted white, the effect due to reflected "sun light" from the sun lamps was negligible.

The two series of figures, numbers 3, 20, 21 and 2, 22, 23 show the Strato and All-Weather Chamber ice samples, respectively. These figures show the ice samples: a) before application of foam, b) with foam-in-place, and c) immediately following the termination of the exposure test. To avoid confusion it is again pointed out that Figure 2 does not show the actual ice surface protected but instead is a photograph of a comparable ice surface. The toughness of the foam surfaces after the six day exposure period, were the same as those observed in the initial short-term exposure tests. The CMC 7 HP base foam was the toughest while ET-460-4 base foam, as expected, the weakest and most fragile. The surface of the ice samples protected with foam was uniformly pitted, indicating good mechanical bonding between the two surfaces.

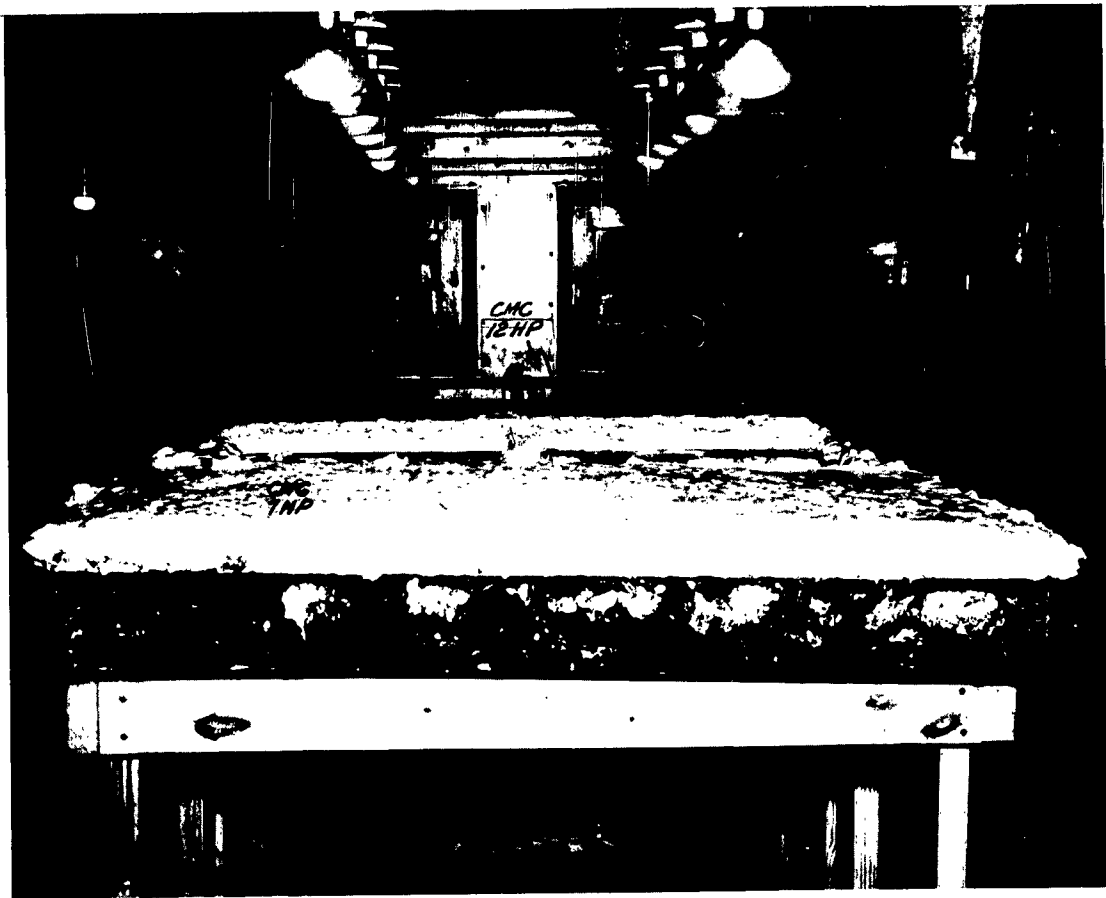


FIGURE 20 PHOTOGRAPH OF CMC 7HP AND 12HP BASE FOAMS IN PLACE
STRATO CHAMBER

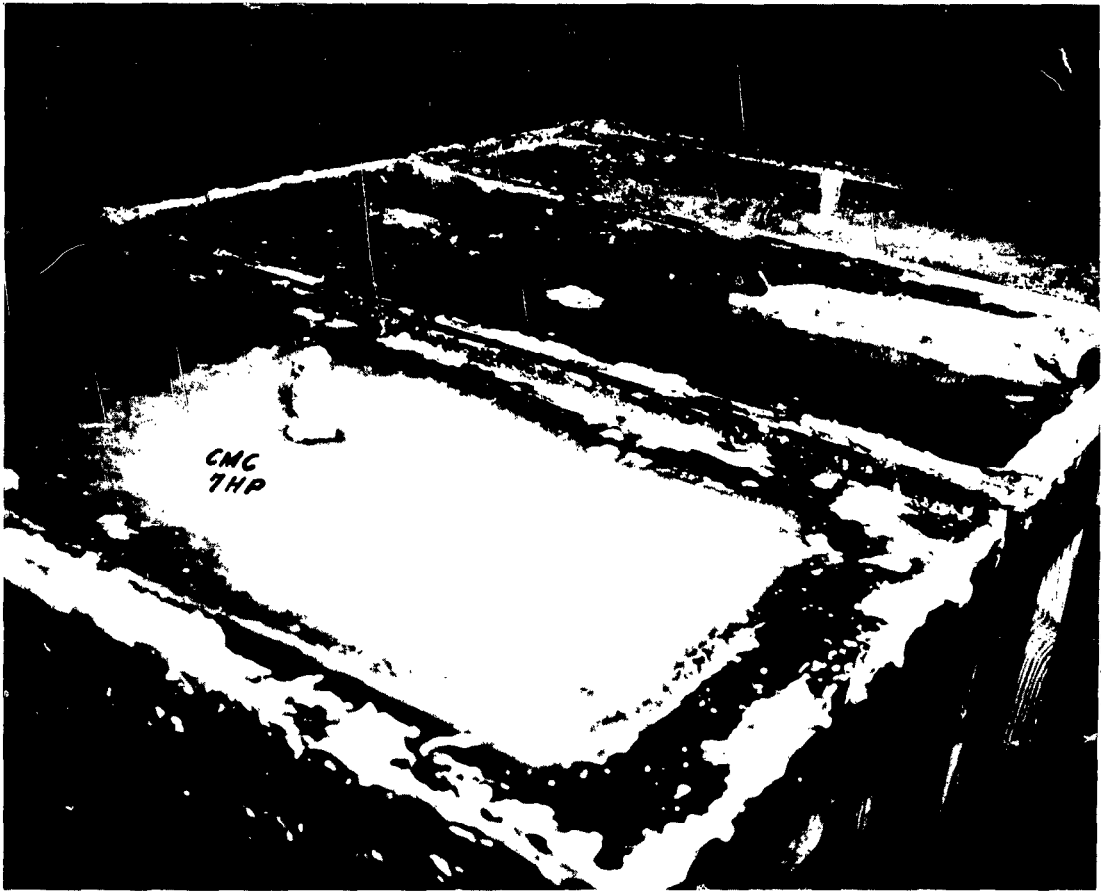


FIGURE 21 PHOTOGRAPH SHOWING ICE SURFACE AFTER REMOVAL OF CMC 7HP
AND 12HP BASE FOAMS AT END OF TEST - STRATO CHAMBER

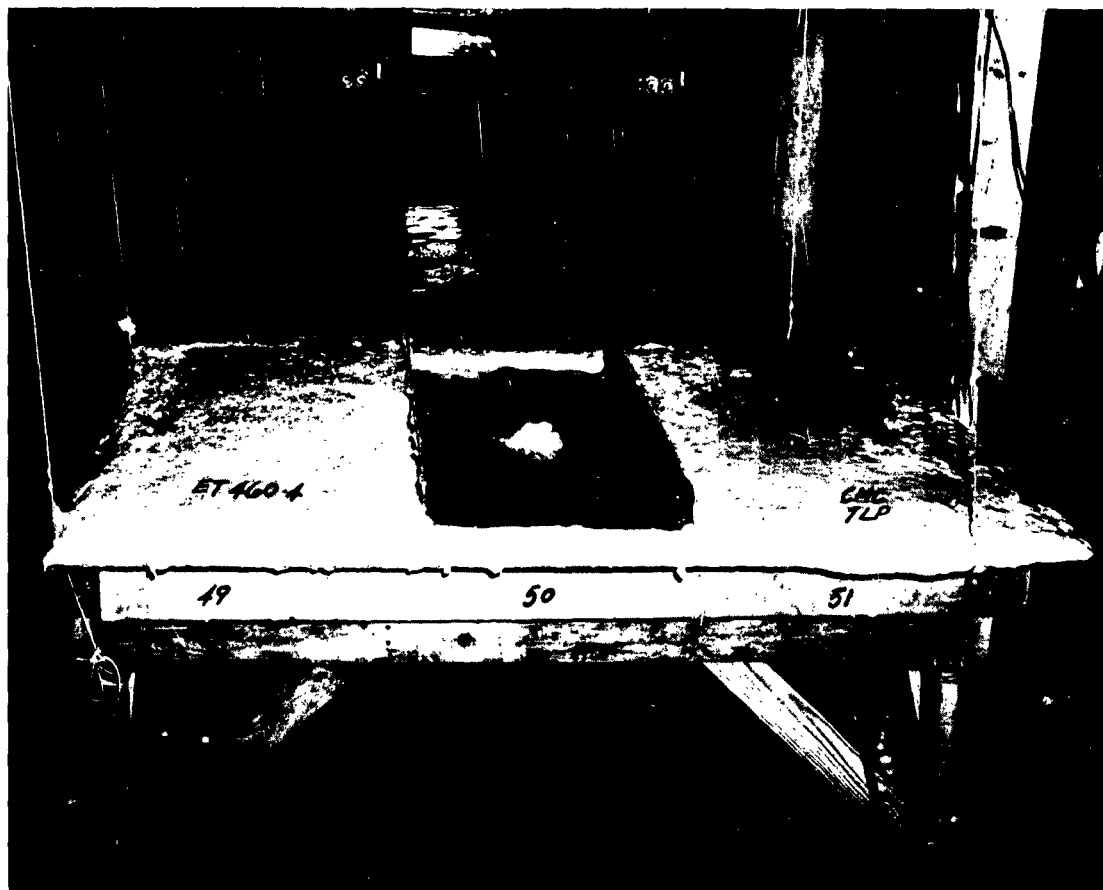


FIGURE 22 PHOTOGRAPH OF CMC 7LP AND ET-460-4 BASE FOAMS IN PLACE
ALL-WEATHER CHAMBER

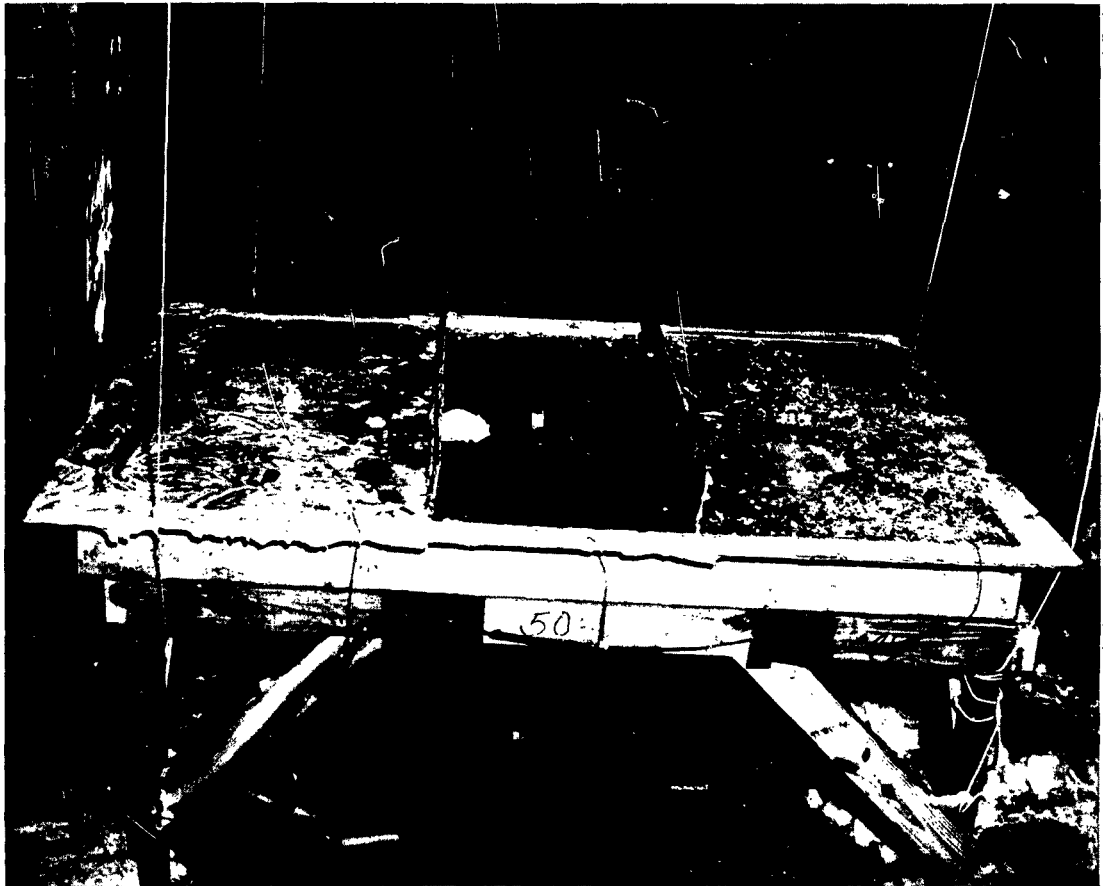


FIGURE 23 PHOTOGRAPH SHOWING ICE SURFACE AFTER REMOVAL OF CMC 7LP
AND ET-460-4 BASE FOAMS AT END OF TEST
ALL-WEATHER CHAMBER

Radiation measurements and temperature profiles obtained in the Strato and All-Weather Chambers are given in Tables XII and XIII, respectively. From these data it can be seen that the temperatures approached a state of equilibrium and leveled off soon after the exposure tests began. Due to the higher level of radiation in the Strato-Chamber the corresponding air and foam temperatures were higher than those in the All-Weather Chamber. The maintaining of ice-air temperature differentials of approximately 35°F and 20°F in the Strato- and All-Weather Chambers, respectively, without serious melting of the protected ice samples, attests to the excellent insulating qualities of these aqueous foams.

5. Effect of Wind, Rain and Snow on Foam Samples

Ice samples protected with foams based on CMC 7 LP and 12 HP, after 24 hour aging at 25°F, were subjected to wind, rain and snow. Due to the fragile nature of ET-460-4 base foam and the difficulty encountered in generating foam based on CMC 7 HP they were not considered for these exposure tests. Therefore, only CMC 7 LP and CMC 12 HP base foams were evaluated.

Figure 24 shows the condition of the foam samples following their exposure to wind, rain and snow as listed below. Foam sample based on CMC 12 HP is in the right foreground while that based on CMC 7 LP can be seen in the left foreground.

WIND AND RAIN EXPOSURE SCHEDULE
(ALL-WEATHER CHAMBER)

<u>Schedule</u>	<u>Length of Exposure to</u>	
	<u>Wind</u> (min)	<u>Rain</u> (min)
1. Maximum wind velocity (35 mph)	60	----
2. Freezing rain at 25°F (no wind)	----	15
3. Raised Chamber temperature to 40°F and allowed a heavy drizzle to fall.	----	35
4. Followed by maximum wind.	20	----
5. Maximum wind velocity, after sitting overnight at 40°F.	80 160 min.	---- 50 min.



FIGURE 24 PHOTOGRAPH SHOWING CONDITION OF CMC 7LP AND 12HP BASE FOAMS
FOLLOWING WIND, RAIN AND SNOW EXPOSURE SCHEDULE

The foams not only displayed good adhesion to the ice surfaces but also good cohesive qualities. The wind caused some erosion of the foams at the exposed edge. The CMC 12 HP base foam was more affected by the wind than the CMC 7 LP. The drizzle caused the foam to soften; however, it held together even when followed by 35 mph winds. The foam regained its original integrity once the rain water evaporated. There was no serious deterioration of either foam as a result of the above exposure schedule.

Approximately 1-1/2 inches of snow were placed on CMC 7 LP and CMC 12 HP base foams (on a section not previously subjected to wind or rain), and the temperature of the chamber was maintained at 40°F. The melting effect of the snow, following an overnight exposure to the above temperature, had the same effect on the foam as the heavy drizzle mentioned earlier.

In all of the above exposures to wind, rain and snow the foams still afforded protection for the ice surfaces below.

6. Summary of Climatic Chamber Test

These more extensive tests revealed that the CMC 7 LP base foam, although rather fragile, displayed excellent insulatory properties while also permitting a relatively high generation rate.

The effect of solar radiation on foam shrinkage on all formulations evaluated was negligible. Also no serious foam deterioration resulted even to the most fragile of the CMC types, when subjected to a severe schedule of wind, rain and snow exposure.

D. Arctic Field Test -- Point Barrow, Alaska

1. Formulation

The CMC 7LT-base foam formulation (see Table XIV) was chosen mainly for its low solution viscosity, high generation rate, and its satisfactory performance in the Climatic Chamber test. Realizing the limitations of the laboratory-size foam-generator, and the larger areas to be protected, the formulation choice was limited to this one, in spite of the relatively less permanent foams produced from it.

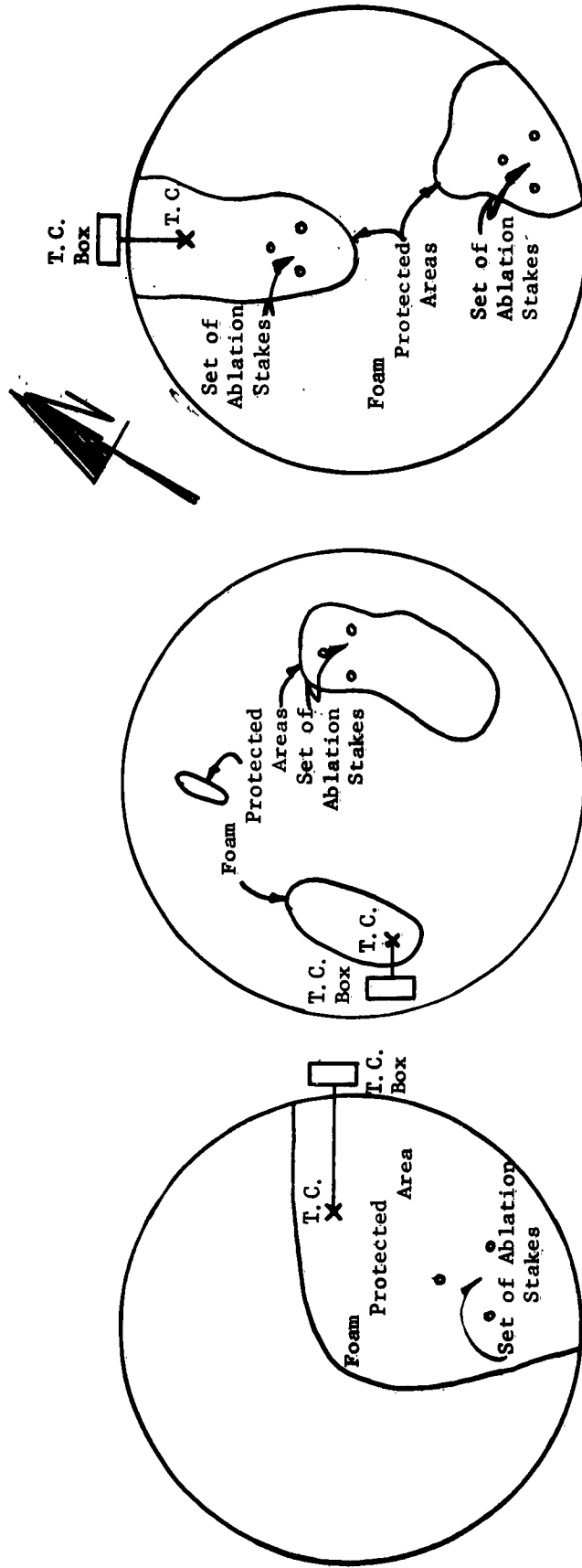
2. Generation

a) Initial foam generator

Mechanical difficulties were encountered with this apparatus when run at top speed for extended periods of time. Two Roots-Connersville blowers were rendered useless by attempting to maintain the minimum generation rate of 2 gpm. (For short periods of time, rates of 2-3 gpm of foam solution were realized.) This rate was necessary to reduce the residence time of the equipment on the plots, thereby preventing serious premature melting of the ice surface and also, to permit coverage of these larger areas in a reasonable length of time. Even though the blower impellers had been ground down to reduce internal pressure build-up, these blowers could not withstand back pressures of over 10 PSIG for long durations. Of course, the twisting and flexing of the equipment on the sled during transportation, added to the strain especially on the blower shafts.

Before this generator was modified, due to the failure of both blowers, approximately 2,400 sq. ft. of foam, three inches thick, was applied to the natural sea-ice plot (see Figure 25).

FIGURE 25 Types of Ice Plots and Areas Protected With Foam



Plot No.	Type	Thickness	Diameter
6	natural ice	3 inches	100 feet
5	free flooded	4-5 inches	100 feet
2	confined flooded	4-5 inches	100 feet

Shore Line

b) Modified foam generator

In view of the difficulties encountered with the closed-feed and direct-drive system, the equipment was modified to eliminate these features. In the modified version the blower was belt driven to eliminate shaft strain during transportation, and its speed reduced as a further precaution against damage. This reduction in blower rate negated the advantage of compressed air, since the same rate and foam expansion could be achieved by inducing air at atmospheric pressure. However, this reduction in blower speed reduced the foam-generation rate to slightly less than 1 gpm. As a consequence, time permitted covering only some of the critical areas of Plots 5 and 2, e.g. the thermocouple and ablation areas (see Figure 25). Approximately 900 sq. ft. of foam, five inches thick, was applied with this apparatus. Table XV lists the details of a controlled test-run, designed to measure rate and coverage.

Also incorporated in this apparatus was a spreader device (see Figure 11), designed to "knead" the foam and produce a more homogeneous and continuous mass.

3. Environmental Data

Attempts to correlate the weather, radiation and ice temperature data to the foam temperature profiles were of no avail. Trends could not be developed that were meaningful and worthwhile. Reasons for this can be attributed to: a) foam shrinkage and "checking", especially in the vicinity of the thermocouples, resulting in erratic and discontinuous readings; b) the various water currents encountered under these ice plots, causing reversals in ice temperatures; and, c) the ever changing Arctic weather conditions necessitating continuous measurements rather than the once and twice daily readings taken. Automatic continuous recorders should definitely be used for obtaining these data in any future field tests.

Although very little reduction of the environmental data was possible, they are tabulated and presented as additional and interesting Arctic information in Tables XVI, XVII and XVIII. The only exception to this, was the ice temperature-profile data. Rather than present the entire data collected, only the portion of the ice temperature-profile data of Plot 2 (Table XVIII) was included, since it was taken inconjunction with the foam temperature-profile data used in determining the foam's thermal conductivity.

4. Exposure Test Results

a) Insulating Efficiency of Foam

A layer of CMC 7 LT base foam, 2 to 3 inches thick, was found to be more than 90% efficient in protecting sea ice from solar radiation. This is based on ablation measurements taken over a two week period of Plots 5 and 2 versus the Control Plot 3. (See Table XIX for ablation measurements and Table XX for calculations.) The reliability of the ablation measurements are confirmed by the almost duplicate results obtained from two "confined-flooded" plots. 18-7/8 inches of ice was ablated from an unprotected ablation area of Plot 2 while 19 inches was recorded for the corresponding Control Plot 3.

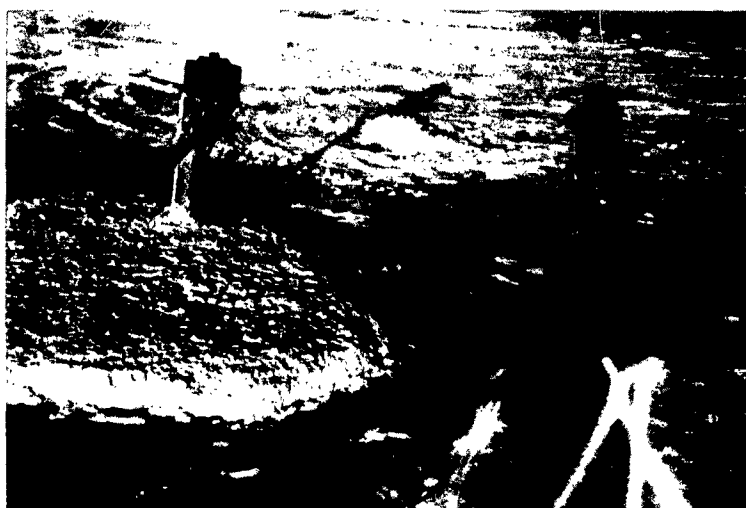
b) Photographs of Foam and Ice Plots

Figure 26 is a collection of photographs taken of the "free-flooded" Plot 5, showing: 1) the slushy condition of the ice surface prior to application of foam, 2) the foam in place above the thermocouple area, and 3) the amount of protection afforded the ice after an exposure of one week. Figure 27 demonstrates quite vividly the excellent protection afforded both the thermocouple and ablation areas of Plot 5 after two weeks exposure. Figure 28 shows the following: Top photograph -- a set of ablation stakes designated as (1), thermocouples used to measure the heat transfer through the foam in Plot 2, designated as (2), and the slushy ice

FIGURE 26 PHOTOGRAPHS OF THERMOCOUPLE AREA, FREE-FLOODED PLOT-5



JUST PRIOR TO
FOAM APPLICATION



JUST AFTER
FOAM APPLICATION



AFTER APPROXIMATELY
ONE WEEK EXPOSURE

FIGURE 27 PHOTOGRAPHS OF ABLATION AND THERMOCOUPLE AREA, FREE-FLOODED PLOT-5

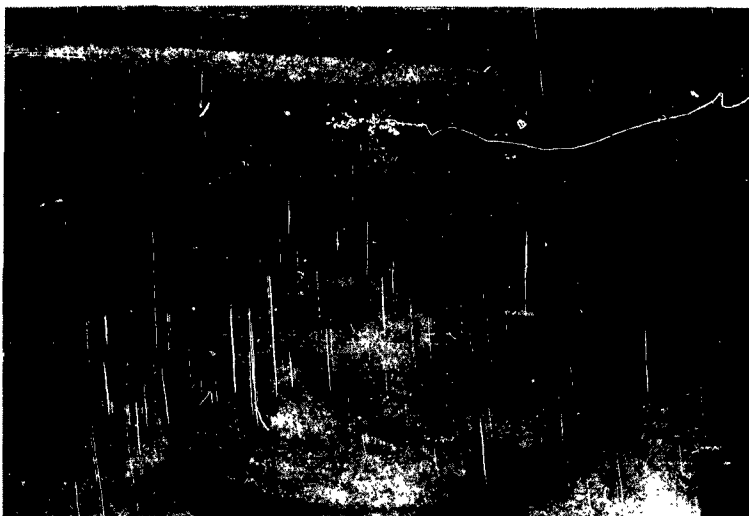


VIEW OF ABLATION AREA AFTER TWO-WEEKS EXPOSURE



VIEW OF THERMOCOUPLE AREA AFTER TWO-WEEKS EXPOSURE

FIGURE 28 PHOTOGRAPHS OF THERMOCOUPLE AREA, CONFINED-FLOODED PLOT-2



VIEW OF THERMO-
COUPLE AREA SHOWING:
1) SET OF ABLATION
STAKES
2) SERIES OF THERMO-
COUPLES USED TO
MEASURE HEAT
FLOW THRU FOAM
LAYER



VIEW FOLLOWING
FOAM APPLICATION



VIEW OF AREA AFTER
TWO WEEKS EXPOSURE

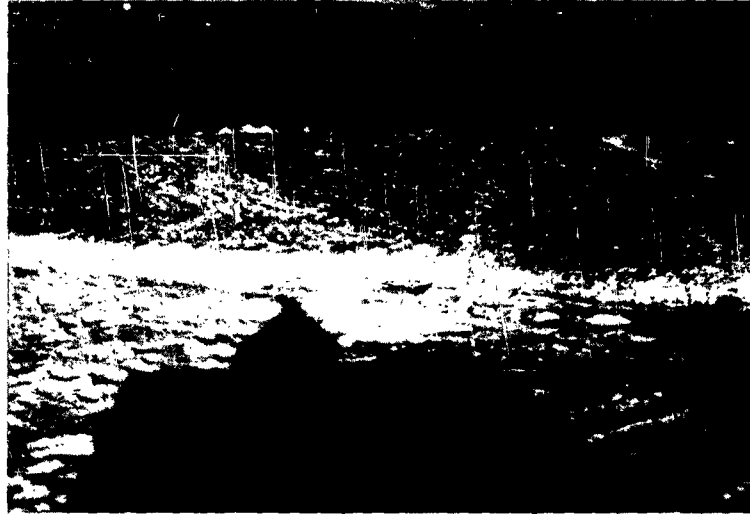
condition that prevailed just prior to application of foam; Middle photograph -- the various expansion-ratio foams generated, seen as different shades of foam; Bottom photograph -- the excellent protection afforded this area by the application of foam after two weeks exposure. Figure 29 shows the ablation area of Plot 2, immediately following the application of foam, and again two weeks later. The "pedestalling" of the ice, approximately 1-1/2 feet, testifies to the excellent insulation value of the foam. These photographs are self explanatory and sum up the results of the field test vividly and concisely.

c) Thermal Conductivity of Foam

The k-value, which is a measure of a materials resistance to heat flow, was determined for the foam used on Plot 2. The k-value of 1.08 $\frac{\text{BTU}/(\text{hr}) (\text{sq.ft.})}{\text{deg F /in.}}$ obtained by collecting heat transfer data over a two week period was well within the experimental values 0.48 to 1.44 (in the above units) calculated and reported in the Final Report AFCRL 827, (see Reference 1). This average k-value was calculated on the assumption that the foam thickness and surface continuity did not change throughout the test period. However, this was not the case, since foam shrinkage and "checking" did result which tends to reduce the resistance of the foam to heat flow. This 1.08 value is higher, i.e. the insulating value is lower, than would be obtained under more normal operating conditions. (See Table XXI for calculations.)

For comparison, the k-values (in the above units) of ice and water at 32°F are 15.6 and 4.1, respectively. The k-values of some of the more common insulatory materials (see Reference 2), are: 0.36 for sawdust, 0.30 for ground cork and 0.44 for corrugated cardboard, also reported in the above units. It

FIGURE 29 PHOTOGRAPHS OF ABLATION AREA, CONFINED-FLOODED PLOT-2



VIEW OF ABLATION AREA
JUST AFTER APPLICATION OF FOAM



VIEW OF ABLATION AREA FOLLOWING
TWO-WEEKS EXPOSURE

should be pointed out that these k-values reported are for dry materials, in contrast to the saturated nature of the aqueous foam when measured. Since these materials would be easily soaked with any melting, the k-values would rise rapidly. Thus, the net effect is not as exaggerated in differences in the insulation values of these materials as might first appear, when compared to the stabilized aqueous foams.

d) Surface Curing of Foam

The low temperatures and high relative humidity encountered at Point Barrow had an adverse effect on foam curing. The surface of the foam did not "heal" as fast, or to the same degree, as those prepared in the laboratory or in the Climatic-Chamber. The resultant slow dehydration (curing) of the foam surface is believed to be the major cause of the foam-shrinkage encountered. This breakdown of structure was further accelerated by increasing the expansion ratio of the foam. Table XXII shows the amount of foam shrinkage encountered in each of the three plots protected, along with the foam expansion ratio (E.R.) and time intervals. It was unfortunate that foam-thickness measurements on plots 2 and 5 were not obtained after approximately one week of exposure, due to the treacherous walking condition of the sea-ice. However, from visual observations it appeared that a foam thickness of about 2 inches prevailed. It was demonstrated during this Field Test, that a foam with an E.R. of approximately 9 was the best compromise for attaining good insulation and foam stability.

e) "Checking" and Cracking of Foam

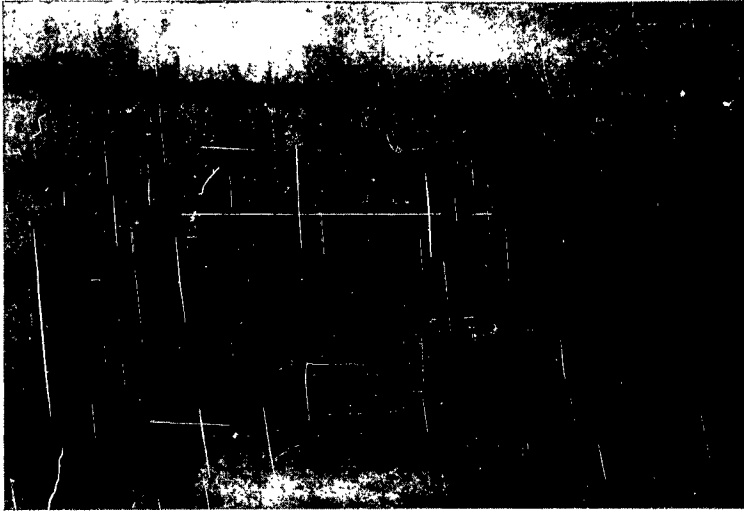
The pulling apart of the foam within itself (best described by comparing it to the "checking" of an old varnished surface), along with the formation of peaks and valleys, was observed less than one week after the foam was applied. As in the case of foam shrinkage, this was not

encountered either in the laboratory or in the Climatic Chamber test. The two variables which influenced the continuity of the foam surface were the method of foam application and the extremely slow dehydration rate encountered at Point Barrow. In all previous applications the areas protected were small enough to permit the working and spreading of the foam with great care. This was not practical with these larger areas, and even with the use of the mechanical spreader, good spreading was only approximated. Also, the curing of the foam has a great influence on its surface characteristics. In the Climatic Chamber test, sun lamps used to simulate the sun rays dried the surface in hours, while at Point Barrow this took days, even though the radiation level was comparable. This difference in curing time combined with the high concentration of cross-linking agent used (aluminum acetate) also accounts for these surface irregularities. Substituting a foam based on a high molecular weight stabilizer, such as CMC 7 HP, would certainly help, if not eliminate, the problem altogether.

f) Natural versus Flooded Ice Plots as Foam Bases

The effect of the natural versus flooded ice plots on the aqueous foam layer applied to them, could not be ascertained, since the natural ice plot was inundated and the foam washed away before an evaluation of these plots could be made. Figure 30 shows the ice and foam surfaces prior to and during the break-up and subsequent floating away of the foam. A comparison of the foam layers on the free and confined-flooded plots after two weeks exposure showed no noticeable differences. It is felt, however, that utilizing raised ice

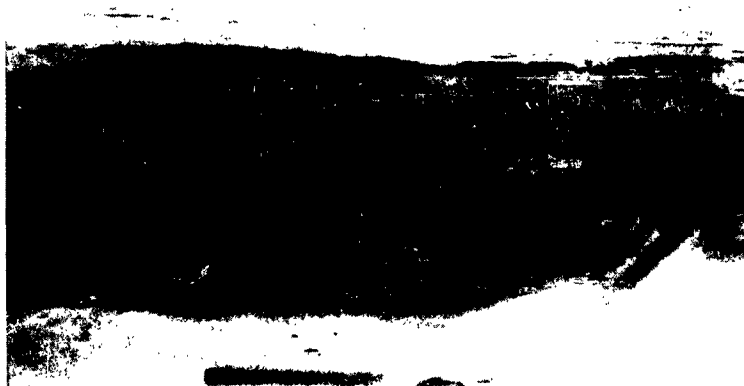
FIGURE 30 PHOTOGRAPHS OF NATURAL SEA-ICE PLOT-6



JUST PRIOR TO
FOAM APPLICATION



CONDITION OF FOAM
AFTER ABOUT ONE
WEEK EXPOSURE



FLOATING-AWAY OF
FOAM

(Approximately three weeks
after application
of foam)

surfaces especially those not subject to easy "break-up", such as ice islands, would permit unlimited observations of the foam, and would eliminate the dangers of working on relative thin sections of ice during the thaw-period.

g) Equipment Limitation

The size and light-duty foam generator used in the Arctic field test prevented full utilization of formulation "know-how". The choice of formulation, as mentioned previously, was limited to the one which afforded the highest generation rate even though it produced the least stable foam. This formulation restriction caused by the limitation of the equipment, points out the dire need for a more commercial-type unit for future field tests. It also indicates an area requiring additional study.

5. General Discussion of Field Test

The primary purpose of the Field Test was to substantiate theories and test results conducted on a smaller scale, and also to show areas requiring additional investigation, both anticipated and not anticipated. Based on this understanding, the field trip to Point Barrow was highly successful. It proved conclusively that a stabilized aqueous foam will protect ice from melting due to solar radiation. It also revealed the limitations of both the equipment and the CMC 7 LT formulation when used under Arctic conditions, and suggested areas of investigation for overcoming these limitations.

E. "Post" Arctic Field Test

Since the results of the Arctic field test indicated the need for a foam based on a high molecular weight stabilizer and a means of generating it, the post Arctic investigation has been in this direction.

1. Formulation

a) CMC Base Foams

The recommended formulation based on CMC 7 HP and its optimum expansion ratio range of 8-12, are listed in Table XXIII. The logistic advantage of this formulation can also be determined from Table XXIII. Based on 50 gallons of foam solution, water comprises 46.5 gallons, leaving an equivalent of 3.5 gallons or 0.47 cubic feet to be transported to the site. Cost figures for foam formulations based on CMC 7 LT and 7 HP are \$0.094 and \$0.075 per square foot respectively, showing no significant cost difference (see Tables XXIV and XXV). Substantial reductions in these costs, however, can be realized in the following areas.

- 1) Bulk purchases of raw materials.
- 2) Reduction in foaming liquid concentration. A 50 percent reduction in concentration will reduce cost by over 25 percent. With the compressed-air system this is a possibility.
- 3) Reduction of foam thickness from 4 to 3 inches would also result in a 25 percent saving in raw material cost. By substituting CMC 7 HP for 7 LT in the formulation, this is a reasonable expectation.

Of course, optimization of the final formulation can only be determined by field tests.

b) Natrosol-CMC Base Foams

A possible means of producing a strong stable foam comparable to CMC 7 HP, but having a substantially lower solution viscosity, was studied by the partial replacement of CMC 7 HP with a high molecular weight, water-soluble polymer which behaves like sand in a slurry and does not

hydrate and foam a stable gel until after the foam has been generated and in place. Exploratory tests in the laboratory with a Natrosol 250/CMC 7 HP stabilizer blend, were encouraging.

2. Generation

Realizing the need for a more rugged and trouble-free prime mover, much thought was devoted to this subject. The sliding vane pump, presently being used and shown schematically in Figure 13, was one that was considered and tested. The initial runs with this pump were very encouraging.

Scheduled for a future foam-generator was a controller device, designed to meter in air and feed solution at a predetermined rate. This in effect would control the expansion ratio and, in general, result in a smoother and more economical operation.

Also contemplated for future study was the development of a technique for post-adding gelling agent. If this could be achieved it would simplify the generation of the high viscosity foam solutions immeasurably.

V CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

Based on actual Arctic field tests it can generally be concluded that stabilized aqueous foams afford good insulation protection for ice-surfaces under a variety of weather conditions; these aqueous foams can be generated in situ utilizing raw sea water under various air and liquid temperatures.

Specific conclusions concerning aqueous foams are detailed below:

1. The most stable and freeze-thaw resistant aqueous foams developed were based on Mearlfoam-Type 5, CMC and Aluminum Acetate.
2. When fully gelled and dehydrated, these foams appear to last indefinitely in the laboratory.
3. The thermal conductivity of foam was not changed by the addition of the CMC stabilizer.
4. Use of higher molecular weight stabilizers from CMC 7 LT to 7 HP resulted in:
 - a) Stronger and more stable foam structures.
 - b) A reduction in the foam generation rate.
5. Increasing the foam-thickness, protected the ice longer by reducing the melting rate. When sufficiently gelled and dehydrated, there was no appreciable improvement beyond a 2-inch thickness of foam, as noted in laboratory investigations.
6. Increasing the expansion ratio of the foam resulted in:
 - a) Improved insulation.
 - b) A more fragile and unstable foam structure.
7. Optimum expansion ratio range determined for formulation utilized in the Arctic field test was 8 to 12.
8. The expansion ratio of foam is dependent on the viscosity of the foam liquid and the energy of generation.

9. Aqueous foams based on CMC 7 LT protected sea-ice surfaces from serious and uneven melting due to solar radiation under Point Barrow conditions. (This observation was limited to two weeks due to break-up of sea-ice.)
10. These insulating foams were generated in situ on Point Barrow sea-ice using raw sea-water obtained at the site.
11. The less stable nature of the CMC 7 LT base foam, accentuated by the high relative humidity, low temperature conditions encountered at Point Barrow, caused cracking and shrinking of the foam layer.
12. During field tests conducted at Point Barrow, the present generation equipment was not capable of sustained high rates of foam generation (2 gpm minimum) even with the low viscosity CMC 7 LT base foam solution.
13. Present generation equipment is only capable of generating foams based on CMC grades 7 LT to 7 HP, for laboratory and small field tests.

B. Recommendations

Based on the results of this investigation it is recommended, generally, that further modification of the CMC 7 HP formulation be studied to meet Arctic and Antarctic conditions, which do not become duplicatable in the laboratory. A full scale generator unit should be designed, built and tested to meet any design criteria of available power and spreading equipment. The formulation and design of generation equipment should be such that nontechnical personnel will have no difficulty processing and applying the foam.

Specific recommendations are detailed below:

1. If cost is a factor, a more economical formulation should be sought.
2. A technique for post-adding the gelling-agent should be developed.

3. The optimum applied foam thickness should be determined, for the CMC 7 HP base foam.
4. The stabilizer blend composed of Natrosol 250 and CMC 7 HP should be more thoroughly investigated.
5. Simulated plane landings on the foam surface should be evaluated.
6. A heavy duty laboratory foam generator should be designed and built to handle CMC 7 HP base foams at a minimum foam liquid rate of 2 gpm (corresponding to 20 gallons of foam based on an E.R. of 10).
7. All future test plots should be of the "confined" or "free-flooded" type.
8. Another field test should be made to evaluate the above recommended studies.
9. A full scale foam generator should then be designed, built and field tested.

APPENDIX

TABLE I
EVALUATION OF POTENTIAL STABILIZERS

Formula: Based on 200 ml. of liquid foam solution
6% Mearlfoam-5* (by volume)
% Stabilizer (by weight) (see below for concentration)
25% Aluminum Acetate (by weight) (based on stabilizer weight)
Water (by volume) (amount necessary to give a final volume of 200 ml.)

Foam Generation: Carried out in a household "Mix-Master" operated at maximum speed.

Expansion Ratio: Volume of foam divided by the volume of liquid required to generate the foam.

Non-Frozen Sample: Evaluated after over night conditioning at room temperature.

Frozen Samples: Evaluated after being frozen at 0°F for 2 hours, and then subjected to 100°F for an additional 2 hours.

Run No.	Formulation	Non-Frozen Sample	Frozen Sample	Expansion Ratio
1	6% Mearl + 1.5% Gelatin	Fair strength-slight shrinkage	Failed	20.8
2	6% Mearl + 2.0% Gelatin	Quite strong	Broke down rapidly.	21.9
3	6% Mearl + 2.25% Gelatin	Quite strong	Cell structured weakened noticeably	22.8
4	6% Mearl + 2.0% Gantrez 4621	Formed a good protective skin, very soft below this skin layer.	Some breakdown after thawing.	14.7
<u>Remarks:</u> a 2% Solution of this material produced a very viscous liquid.				
5	6% Mearl + 2.0% Alkogum AN-25	Formed a very weak foam	Failed	15.0
6	6% Mearl + 2.0% Protein (Bone-Glue)	Would not foam	Would not foam	----
<u>Remarks:</u> Bone Glue dissolved very poorly and inhibited foaming action of Mearl-5.				
7	6% Mearl + 2.0% Carbose VL	Failed	Failed	12.4
8	6% Mearl + 2.0% Carbose D	Formed a skin layer.	Failed	11.3
9	6% Mearl + 2.0% Carbose IM	Formed a skin layer.	Some breakdown after thawing.	
<u>Remarks:</u> Carbose IM produced strongest foam of the series, however still not up to CMC.				

TABLE I Cont'd.

Run No.	Formulation	Non-Frozen Sample	Frozen Sample	Expansion Ratio
10	6% Mearl + 2.0% CMC(7LP)	Failed	Failed	14.8
11	6% Mearl + 2.0% CMC(7MP)	Weak foam	Shrunk very badly.	12.2
12	6% Mearl + 2.0% CMC(7HP)	Weak foam	Shrunk badly	10.35
<u>Remarks:</u> Of all stabilizers tested, CMC-7HP withstood the freeze-thaw cycle best.				
13	6% Mearl + 1.0% CMC 7HP + 25% Al. Acetate	No drainage; noticeable increase in bubble size.	Foam Surface collapsed	10.8
14	6% Mearl + 1.5% CMC 7HP + 25% Al. Acetate	No drainage; stronger than 1% CMC 7HP.	Very noticeable shrinkage.	7.9
15	6% Mearl + 2.0% CMC 7HP + 25% Al. Acetate	No drainage; good bubble strength.	Noticeable shrinkage	7.1
16	6% Mearl + 2.5% CMC 7HP + 25% Al. Acetate	No drainage; excellent bubble strength	Slight shrinkage No collapse after two freeze-thaw cycles.	6.8
<u>Remarks:</u> Under these severe freeze-thaw conditions it appears that a concentration of CMC-7H between 2.0 and 2.5% is necessary to produce an acceptable foam.				
17	6% Mearl + 4.0% ET-460-4	Drained after 2 hrs. no cell strength.	Foam surface collapsed.	9.2
<u>Note:</u> Runs No. 13 thru 17 were run as a series. Master batch of CMC was used in Runs No. 13 thru 16.				
18	1.5% Myverol + 1.5% CMC 7HP	No drainage; no noticeable cell change.	Cracked on freezing. Collapsed after a freeze-thaw cycle.	7.8
19	2.0% Myverol + 1.5% CMC 7HP	Formed a vapor seal.	Shrunk quite badly.	7.3
20	2.0% Myverol + 2.0% CMC 7HP	Same as 1.5% CMC 7HP	Some shrinkage after freeze-thaw cycle.	8.1
<u>Remarks:</u> Aluminum acetate gelling agent could not be used due to its adverse effect on foaming property of the Myverol solution. Dehydration of this foam is extremely slow, a thin skin forms on the surface and acts as a vapor barrier.				

* Except where otherwise noted.

TABLE II
REFINEMENT OF FOAM FORMULATION BASED
ON CMC 7HP STABILIZER

<u>Formula:</u>	See formulations below.
<u>Foam Generation:</u>	Carried out in a household "Mix-Master" operated at maximum speed.
<u>Expansion Ratio:</u>	Volume of foam divided by the volume of liquid required to generate the foam.
<u>Non-Frozen Sample:</u>	Evaluated after over-night conditioning at room temperature.
<u>Frozen Sample:</u>	Evaluated after being frozen at 25°F for a minimum of two hours followed by over-night conditioning at room temperature.

VARYING CONCENTRATION OF CMC 7HP

- 1) 6% Mearl + 1.25% CMC 7HP + 25% Al. Acetate -- Expansion Ratio = 14.5
- 2) 6% Mearl + 1.50% CMC 7HP + 25% Al. Acetate -- Expansion Ratio = 12.5
- 3) 6% Mearl + 1.75% CMC 7HP + 25% Al. Acetate -- Expansion Ratio = 11.5

OBSERVATION OF NON-FROZEN SAMPLES NO. 1 to 3.

- a) No drainage in any of the samples.
- b) No apparent effect on bubble size due to decrease in CMC concentration.
- c) Strength of foam increased as CMC concentration increased.

OBSERVATION OF FROZEN SAMPLES NO. 1 to 3.

- a) Same as non-frozen samples.
- b) Same as non-frozen samples.
- c) Same as non-frozen samples.
- d) Shrinkage is inversely proportional to CMC concentration, the greater the concentration the less the shrinkage.

Remarks:

CMC-7HP concentrations of 1.5% and below produce foams with weak structures which shrink noticeably when subjected to the above freeze-thaw cycle.

TABLE II Cont'd.

VARYING CONCENTRATION OF ALUMINUM ACETATE

- 4) 6% Mearl + 2.0% CMC 7HP + 10% Al. Acetate -- Expansion Ratio = 11.5
- 5) 6% Mearl + 2.0% CMC 7HP + 15% Al. Acetate -- Expansion Ratio = 11.6
- 6) 6% Mearl + 2.0% CMC 7HP + 20% Al. Acetate -- Expansion Ratio = 11.5
- 7) 6% Mearl + 2.0% CMC 7HP + 25% Al. Acetate -- Expansion Ratio = 10.8
- 8) 6% Mearl + 2.0% CMC 7HP + 50% Al. Acetate -- Expansion Ratio = 9.5

OBSERVATION OF NON-FROZEN SAMPLES NO. 4 to 8

- a) No drainage in any of the samples.
- b) 10 and 15% samples showed noticeable increases in bubble size with 10% being noticeably worse than 15%. The 20, 25 and 50% samples were equivalent and showed no noticeable increase in cell structure.
- c) All displayed equal strength and resiliency.

OBSERVATION OF FROZEN SAMPLES NO. 4 to 8

- a) Same as non-frozen samples.
- b) All increased in bubble size over corresponding non-frozen samples. However, the 25 and 50% samples were equivalent and showed the least cell expansion.
- c) Same as non-frozen samples.
- d) All samples shrunk. The 25 and 50% samples displayed the least shrinkage.

VARYING CONCENTRATION OF MEARLFOAM-5

- 9) 3% Mearl + 2.0% CMC 7H + 25% Al. Acetate -- Expansion Ratio = 5.0
- 10) 6% Mearl + 2.0% CMC 7H + 25% Al. Acetate -- Expansion Ratio = 10.1
- 11) 7.5% Mearl + 2.0% CMC 7H + 25% Al. Acetate -- Expansion Ratio = 11.1

OBSERVATION OF NON-FROZEN SAMPLES NO. 9 to 11

Note: Samples of 6 and 7.5% Mearl were comparable and better than the 3.0% Mearl sample in the following respects:

- a) The foams were much tougher.
- b) The bubble size was much smaller.
- c) The entire foam structure was more rigid.

OBSERVATION OF FROZEN SAMPLES NO. 9 to 11

The frozen and non-frozen samples were identical except for a slight shrinkage observed in the frozen samples.

TABLE III

COMPOSITION OF SALT WATER PREPARED IN LABORATORY

COMPOSITION	CONCENTRATION
Na Cl	2.70%
K Cl	0.07
Ca Cl ₂	0.14
Mg So ₄	<u>0.59</u>
	TOTAL = 3.50%

TABLE IV

MELTING AND TEMPERATURE PROFILE DATA FOR FIGURE

(Foam Layer Thickness = 1.25 inches - Ice Volume = 500 ml.)

	Protected Ice Sample				Unprotected Ice Sample		
	Melting Data	Temperature Profile - °F			Melting Data	Temp. Profile - °F	
Run Time hours	Volume of Liquid Drained Ml.	Center of Ice	Inter-face	In Foam 3/4 in. from surface	Directly Over Foam surface	Volume of Liquid Drained Ml.	Freezer Temp. Over Ice Surface
Start		24	25	33	52	-----	21
1		22	23	30	52	10	13
2		21	22	30	52	30	15
3		21	21	28	52	54	14
4		20	20	27	53	65	13
5		24	24	30	56	112	21
6	3	26	26	32	58	159	23
7	10	26	26	35	60	239	24
11	120	31	31	39	68	450	30
12	145	30	30	38	68	450	27
13		30	30	38	68		26
22		31	31	40	70		29
23	432	31 1/2	31 1/2	41	70		29
24	435	33	33	43	71		30
							28
							30
							30
							29
							29
							35
							35
							35
							47
							45
							45
							45
							46
							47

MELTING AND TEMPERATURE PROFILE DATA FOR FIGURE

		Protected Ice Sample				Unprotected Ice Sample			
	Run Time Hours	Melting Data	Temperature Profile - °F			Melting Data	Temperature Profile °F		
		Volume of Liquid Drained-ml.	Center of Ice	Inter- face	In Foam 1 1/2" From Surface	Directly Over Foam Surface (Thermo- couple shielded)	Volume of Liquid Drained-ml.	Freezer Temp.	Cabinet Air Temp. (Thermo- couple not shielded)
Start			28	28	29	47		24	57
1		2	29	29	31	55	18	27	62
2		8	30	30	33	58	90	29	64
3		13	31	29	31	57	237	23	62
4		30	30	30	33	56	373	22	62
5		59	30	30	32	54	402	25	59
6		62	30	30	33	55	418	27	60
7		62	30	30	33	55	424	26	60
8		62	30	30	32	56	425	27	61
9		63	30	30	32	57	426	27	61
10		63	30	30	32	57	430	27	62
11		63	30	30	32	57	430	28	62
17		83	31	31	33	60		26	64
20		95	31	31	34	62		27	66
24		155	31	31	34	63		23	66
25		163	30 1/2	30 1/2	33 1/2	62		23 1/2	65
26		170	31	31	33 1/2	63		24	66
40			31	31	33 1/2	63		27	67
41			31 1/2	31 1/2	34 1/2	64		27	68
42			31 1/2	31 1/2	34 1/2	64		27	68
44			32	32	35	66		29	69
48		284	32	32	37	69		31	71

TABLE VI
EVALUATION OF FOAM SOLUTIONS BASED ON EQUIVALENT CONCENTRATIONS
OF CMC TYPE STABILIZERS

Formula: Based on 200 ml. of liquid foam solution

6% Mearlfoam-5 (by volume)

2% CMC (by weight)

25% Al. Acetate (by weight) (based on weight of CMC)

Water - (by volume) (amount necessary to give a final volume of 200 ml.)

Foam Generation: Household "Mix-Master" operated at maximum speed.

Viscosity Determination of Foam Solutions

Brookfield Synchro-electric Model LVT, 8 speeds, 4 spindles
Range 0 to 400,000 centipoises.

Expansion Ratio:

Volume of foam divided by volume of liquid required to generate the foam.

Run No.	CMC Type	Non-Frozen Sample (Evaluated after over-night conditioning at room temperature)	Frozen Sample (Evaluated after being frozen at 25°F for a minimum of 2 hrs. followed by an over night conditioning at room temperature.)	Brookfield Viscosity. Centipoises	Expansion Ratio
1	7HP			20,500	7.2
2	12HP			720	10.7
3	7MP			720	11.1
4	7LP			66	17.0

OBSERVATIONS OF NON-FROZEN SAMPLES NO. 1-4

Property Observed	7HP	12HP	7MP	7LP
Drainage	none	none	none	none
Bubble size	slight increase	slightly more than 7HP	very slight increase	very slight increase
Foam strength	tough flexible skin	not quite as tough as 7HP	not quite as tough as 7HP more brittle skin	not as tough as 12HP

OBSERVATIONS OF FROZEN SAMPLES NO. 1-4

The frozen samples were similar to the non-frozen ones as regards drainage, bubble size and foam strength. However, both the 7MP and 7LP samples displayed less shrinkage than the others, with the 12HP showing the largest amount of shrinkage.

TABLE VII

FORMULATION AND GENERATION DETAILS - CLIMATIC CHAMBER TEST

- Formula: Based on 20 pounds or 9,100 ml of liquid foam solution
 % Mearlfoam-5 (by volume)
 % Stabilizer (by weight) (see below for type and concentration)
 % Aluminum Acetate (by weight) (based on stabilizer weight)
 Salt Water (by volume) (amount necessary to give a final volume of 9,100 ml.) (see Table VIII for analysis).
- Foam Generation: See Figures 4 and 5 for schematic and an actual view of generator.
- Expansion Ratio: Volume of foam divided by the volume of liquid required to generate the foam.
- Non-Frozen Sample: Evaluated after over-night conditioning at room temperature.
- Frozen Sample: Evaluated after being frozen at +25°F for a minimum of two hours followed by over-night conditioning at room temperature.

Formulations	Expansion Ratio	Appx. & Relative Generation Times -- Min.
1) 6% Mearlfoam-5 + 1.75% CMC 7HP + 25% Al. Acetate	6.0	30+
2) 6% Mearlfoam-5 + 2.00% CMC 12HP + 25% Al. Acetate	8.7	7
3) 6% Mearlfoam-5 + 3.00% CMC 7LP + 25% Al. Acetate	8.3	7
4) 6% Mearlfoam-5 + 4.00% ET-460-4 + 25% Al. Acetate	13.0	4

TABLE VIII

ANALYSIS OF SALT WATER* USED IN CLIMATIC CHAMBER TEST

Total Chlorides as NaCl	3.13%
Undissolved Solids (Mostly Organic)	118 PPM
Approximate Amount of Sand (Microscopic)	60 Grains/liter
pH	7.97
Specific Gravity	1.026
Freezing Point	28°F

* The sample was obtained approximately 2 1/2 miles off-shore in the Gulf of Mexico.

TABLE IX

INITIAL EVALUATION OF FOAMS - CLIMATIC CHAMBER TEST
 (SEE TABLE VII FOR FORMULATION AND GENERATION DETAILS)

OBSERVATION OF NON-FROZEN FOAM SAMPLES

	CMC-7 HP	CMC-12 HP	CMC-7 LP	ET-460-4
Drainage	None	None	None	Some
Cell Size	Very little expansion.	Sl. larger than 7HP	Same as 7HP	Noticeable increase.
Surface Shrinkage	Very little	None	Same as 7HP	Surface expanded.
Foam Strength	Strong	Half as strong as 7 HP	Between 12 HP and 7 HP	Weak and fragile

OBSERVATION OF FROZEN FOAM SAMPLES

	CMC-7 HP	CMC-12 HP	CMC-7 LP	ET-460-4
Drainage	None	None	None	Some
Cell Size compared to Non-Frozen Samples	Sl. expansion	Noticeable expansion	Same as 7HP	Very large expansion
Surface Shrinkage	Some	Some	Some	Noticeable
Foam Strength compared to Non-Frozen Samples	Not quite as tough	Same as 7HP	Between 12 HP and 7 HP.	Very weak and fragile.

TABLE X

PERCENTAGE OF ICE-SAMPLE MELTED AFTER EXPOSURE TESTS IN STRATO-CHAMBER(MEASUREMENTS AND CALCULATIONS BASED ON FIGURE 18.)

STRATO-CHAMBER							
Average Solar Radiation Level gm.cal/sq.cm-min.	0.75						
	CMC 7 HP		Unprotected Ice	CMC 12 HP			
	Length	Width		Length	Width		
	Average Depth of Water - ft.	0.187		0.183	100% of ice	0.175	0.156
	Ave. Width of Water Section-ft.	0.239		0.392	melted after	0.275	0.187
Length of Water Section - ft.	4.0	2.0		two days	4.0	2.0	
Volume of Water - cu ft.	0.19(0.24)4= 0.18 0.18(0.39)2= 0.14		exposure.	0.18(0.28)4= 0.19 0.16(0.19)2= 0.06			
Volume of Ice - cu. ft.	4.0			4.0			
Approx. Amount of Ice Melted -- Percent	$\frac{0.32}{4.0} \times 100 =$ 8.0		100.0	$\frac{0.25}{4.0} \times 100 =$ 6.0			

TABLE XI

PERCENTAGE OF ICE-SAMPLE MELTED AFTER EXPOSURE TESTS IN ALL-WEATHER CHAMBER
(MEASUREMENT AND CALCULATIONS BASED ON FIGURE 19)

ALL-WEATHER CHAMBER			
Average Solar Radiation Level gm.cal/sq.cm-min.	0.37		
	CMC 7 LP	Unprotected Ice	ET-460-4
Average Depth of Water - ft.	0.15	0.30	0.23
Ave. Width of Water Section - ft.	0.167		0.33
Length of Water Section - ft.	4.0		4.0
Volume of Water - cu. ft.	$0.15(0.167)4 = 0.1$		$0.23(0.33)4 = 0.28$
Volume of Ice - cu. ft.	$2(4)0.5 = 4.0$		4.0
Total Depth of Ice - ft.		0.48	
Approx. Amount of Ice Melted -- Percent	$\frac{0.1}{4.0} \times 100 = 2.5$	$\frac{0.30}{0.48} \times 100 = 64$	$\frac{0.28}{4.0} \times 100 = 7.0$

TABLE XII

SOLAR RADIATION MEASUREMENTS AND TEMPERATURE PROFILES
(STRATO-CHAMBER SAMPLES)

Temperature Measuring Device: Daystrom-Weston Multiple Station Recorder
 Model 6702. Temperature Range Minus 50 to
 Plus 100°F.

Solar Radiation Measuring Device: Eppley Pyrheliometer No. 2435

Chamber Temperature: Maintained at +25°F

Date	Solar Radiation*	Temperature Profiles - °F							
	3-17	3-16 (start)	3-16	3-17	3-18	3-19	3-20	3-21	3-22
Thermocouple Position									
Pan 1 (CMC-7HP)	0.88								
Ice Center		26	27	29	30	31	31	30	32
Ice-Foam Interface		27	28	31	32	34	36	33	35
3/4" Below Foam Surface		30	57	61	60	60	60	61	61
Pan 2 (Unprotected Ice)	0.78								
Ice Center		27	32	32	36	--	--	--	--
Ice Surface		30	32	32	38	--	--	--	--
Pan 3 (CMC-12HP)	0.60								
Ice Center		26	27	29	30	31	31	31	32
Ice-Foam Interface		26	27	30	32	32	32	32	32
3/4" Below Foam Surface		32	60	65	64	68	70	66	60
Miscellaneous									
Over Foam (Not Shielded)		57	62	65	60	64	63	62	60
Over Foam (Shielded)		45	50	52	50	53	50	46	45
Under 12 HP Pan		25	28	29	29	31	31	31	30

* gm.cal./sq.cm-min.

TABLE XIII

SOLAR RADIATION MEASUREMENTS AND TEMPERATURE PROFILES
(ALL-WEATHER CHAMBER SAMPLES)

Temperature Measuring Device: Daystrom-Weston Multiple Station Recorder
 Model 6702. Temperature Range Minus 50 to
 Plus 100°F.

Solar Radiation Measuring Device: Eppley Pyrheliometer No. 2435

Chamber Temperature: Maintained at +25°F

Date	Solar Radiation*	Temperature Profiles - °F							
	3-17	3-16 (start*)	3-16	3-17	3-18	3-19	3-20	3-21	3-22
Thermocouple Position									
Pan 1 (CMC-7LP)	0.33								
Ice Center		26	26	29	29	29	30	30	30
Ice-Foam Interface		26	27	30	31	32	33	33	32
3/4" Below Foam Surface		29	52	55	54	54	57	57	57
Pan 2 (Unprotected Ice)	0.41								
Ice Center		28	32	32	36	45	45	42	41
Ice Surface		31	32	32	32	41	44	38	37
Pan 3 (ET-460-4)	0.38								
Ice Center		26	27	30	30	31	31	31	31
Ice-Foam Interface		27	29	30	31	33	34	33	32
3/4" Below Foam Surface		33	50	52	52	52	55	52	51
Miscellaneous									
Over Foam (Not Shielded)		39	44	45	45	50	47	45	43
Over Foam (Shielded)		35	40	42	41	46	45	40	43
Under Unprotected Ice Pan		25	27	28	28	29	29	29	29

* gm.cal/sq.cm-min.

TABLE XIV

FORMULATION DATA

<u>Formula - 50 Gallons of Foam Solution</u>			
<u>Ingredient</u>	<u>Density</u> (LBS/GAL)	<u>Amount</u> Percent	<u>Weight Basis</u> Pounds
Mearlfoam - 5	9.6	6.7	29.2
CMC - 7LT(1)		3.0	13.1
Aluminum Acetate (2)		25.0	3.3
Sea Water (3)	8.55		390.0
			Total - 435.6 lbs.

Sp.G. of above solution = 1.04

- (1) The "T" designation of CMC 7LT refers to the technical grade, which was determined in the laboratory to be a satisfactory replacement for the more expensive pure grade (7LP).
- (2) Percent of aluminum acetate based on CMC weight.
- (3) Sea water was obtained at the site by drilling a hole through the ice to the water below and pumping the amount needed.

TABLE XV

RATE AND COVERAGE MEASUREMENTS WITH MODIFIED FOAM-GENERATOR
(UNDER CONTROLLED CONDITIONS)

DATA

Foam solution used - 20 gallons
Time required - 23 minutes
Size Plot covered with foam
7 ft. wide, 10 ft. long and 4.5 inches thick

CALCULATIONS

$$\text{Generation rate of foam solution} = \frac{20 \text{ gal}}{23 \text{ min}} = 0.87 \text{ gpm.}$$

$$\text{Volume of foam laid down} = 7 \text{ ft.} \times 10 \text{ ft.} \times \frac{4.5}{12} \text{ ft.} = 26 \text{ cu.ft.}$$

Area of foam laid down (Based on 3-inch thickness) =- sq. ft.

$$\left(\frac{1}{4}\right) \text{ ft. (x) sq. ft.} = 26 \text{ cu. ft.}$$

$$x = 104 \text{ sq. ft.}$$

$$\frac{\text{area of foam generated (3-in. thick)}}{\text{gallon of foam solution}} = \frac{104 \text{ sq.ft.}}{20 \text{ gal.}} = 5.2 \text{ sq.ft./gal.}$$

TABLE XVI

DAILY WEATHER DATA

DATE	TIME	TEMPERATURE F		SHADED Air Temp.	WIND (mph)	WIND Dir.	SKY COVER - REMARKS
		Min.	Max.				
May 10		-1	+9				Overcast
May 11	0830	-4	+4	+1 F	14-16	NE	Overcast
	1000				20	NE	
	1600			+5	16-20	NE	50% Cloudy
May 12	0930		+12	+7	20	NE	Hazy-clear
	1030			+5	19	NE	Hazy-clear
	1100			+8	19	NE	Hazy-clear
May 13	1300	+5	+15	+17	19	NE	Sunny early, 1" snow, Hazy by noon snowing by early Aft. cont. past 2200.
May 14	0850	+12	+20	+23	0-3	NE	Overcast
	0920			+24	8	NE	Sunny
	1420				0-2	NE	Overcast, occ. Sun
	1630						
	1830			21.5	7-9	NE	Cloudy
	1900			21.5	7-9	NE	
May 15	0830	+20	+25	+25	16	E	Overcast
	0900			25	20-22	E	w/Blowing
	1638			23.5	20-25	E	Snow
May 16	0820	+13	+28	25	16	E	Overcast (1" snow in
	1525			30.5	10-12	E	Overcast the evening.)
May 17	0820	+18	+28	25.0	5-8	SW	Clear-Sunny
	0900			25	8-10	SW	Clear-Sunny
	1500			30.0	8-10	SE	Clear-Sunny
	1600			25	9-10	SE	Clear-Sunny
May 18	0815	23	36	30	4-6	S	Sunny
	1609			35	12	SE	Overcast
May 19	0810	22	39	36	5	S	Cloudy with some sun
	1653			36	10	W	Some fog with sun

TABLE XVI Cont'd.

DAILY WEATHER DATA

DATE	TIME	TEMPERATURE F		SHADED Air Temp.	WIND (mph)	WIND Dir.	SKY COVER - REMARKS
		Min.	Max.				
May 20	0815 1839	+30	+38	34.0 +36	7-9 8-9	NE NE	Sunny (Rained about- Partly Cloudy 2200 for 1 hour).
May 21	0817 1635	+28	+43	+38 36	6-7 10	SE SW	Cloudy (Snowing shortly Cloudy after 12 Mid- night. Still snowing at 0930 -- about 1" total.)
May 22	0816 1630	+20	+39	38 35	7-8 3-5	N NW	Cloudy Snow Cloudy --(Snow flurries- about 2" total snow fall.)
May 23	0811 1633	+22	30	26 30.5	3-5 7-9	SE NE	Cloudy Clear at Noon
May 24	0830 1650	+22	32	32 28	10 10	S SE	Cloudy Snowing - (lightly at 1800, did not continue all night.)
May 25	0837 1930	+24	32	27.5 28.0	16 0-4	E SE	(Snowing at 1800) (Snowing still)
May 26	0800 1650	20	35	30.0 32.0	10	N	Cloudy Overcast
May 27	0830	20	35	29	10-15	N	Overcast
May 28	0815 1900	22	35	26 24	9 9	NE NE	Overcast Overcast (Snow flurries during afternoon.)
May 29	0825 2100	10	33	25.5 24	8-10 7-8	NE NE	Overcast with lt. snow Overcast with lt. snow (Snowed all day.)
May 30	1130 1700	16	40	42 27	5-6 0-8	N N	Sunny--Some Clouds Sunny--Clear
May 31	0825	22	33	25 28	7-10 10-20	E E	Hazy Overcast and Hazy

TABLE XVI Cont'd.

DAILY WEATHER DATA

DATE	TIME	TEMPERATURE F		SHADED Air Temp.	WIND (mph)	WIND Dir.	SKY COVER - REMARKS
		Min.	Max.				
June 1	0900	28	32	30	16-20	NE	Overcast Hazy Overcast-(lt. snow falling by 1645.)
	1547			30	16-20	N	
June 2	1950	26	36	40.5	6-8	NW	Overcast-foggy Overcast-foggy
				38	4-5	W	
June 3	0815	16	31	33.5	5-7	W	Overcast--snow Overcast--occ. sunshine.
	1645			36	10	N	
June 4	0845	20	27	31.5	7	N	Sl. overcast with sun Sl. overcast with sun
	1635			39	10-12	N	
June 5	0845	22	29	27	10-14	NW	Cloudy Cloudy--little sun
	1635			33	20-22	NW	
June 6	0830	23	35	36	8	NW	Broken clouds with sun- shine. Overcast-snowed all afternoon & evening.
	1900			29	6-8	N	
June 7	0900	22	40	45	3-5	W	Cloudy & hazy Cloudy--little sun
	1700			40	4-5	NW	
June 8	0945	28	37	35	7-10	S	Cloudy Clear
	1915			33	7-10	SE	
June 9	0815	34	44	38.5	6-10	SE	Overcast
June 10	1145	36	48	55	0-1	SE	Sunny with few clouds Same as above with fog
	2100			36	9-11		
June 11	1100	32	48	55	3-4	SE	Partly cloudy with sun Sunny with scattered clouds.
	2000			42	8-10	NE	
June 12	0900	32	38	37.5	5-6	NE	Partly cloudy-hazy Cloudy-hazy
	1700			34	10-16	NE	
June 13	0845	32	39	42	6-10	N	Sunny-scattered clouds Sunny-few clouds
				34.5	7-9	N	
June 14	0845	32	44	43	5-7	W	Overcast with little sun Sunny and hazy
				36	2	SW	
June 15	0815	30	49	49.5	5-7	S	Clear--few clouds
June 16	1125	32	46	35	8-12	W	Hazy fog Clear
	1830			39	6	W	

TABLE XVI Cont'd.

DAILY WEATHER DATA

DATE	TIME	TEMPERATURE F		SHADED Air Temp.	WIND (mph)	WIND Dir.	SKY COVER - REMARKS
		Min.	Max.				
June 17	0800 1615	34	52	51 40	7-8 Calm	S	Slightly overcast Clear few clouds
June 18	0820 1630	34	47	46 40	3-4 4-5	S SW	Overcast, occ. rain Overcast, occ. rain
June 19	0900	32	39	40.5	12-16	SW	Clear
June 20	0900	30	41	38	10-12	W	Partial cloudy, sunny
June 21	0100	28	34	33.5	8-10	NE	Overcast
June 22	0912	26	32	31	9	NE	Sunny but foggy
June 23	0945	26	34	35	8-10	E	Sunny, scattered clouds
June 24		No reading Sunday, No Eskimo Guide.					
June 25	1030			33	10-12	NE	Clear

TABLE XVII

DAILY AVERAGE, TOTAL SOLAR INCIDENT RADIATION

(Supplied by the U. S. Weather Bureau, Pt. Barrow, Alaska)

DATE	gm-calories/sq. cm-min	DATE	gm-calories/sq. cm-min
May 14	0.39	June 7	0.47
May 15	0.42	June 8	0.45
May 16	0.35	June 9	0.43
May 17	0.51	June 10	0.55
May 18	0.45	June 11	0.42
May 19		June 12	0.39
May 20	0.47	June 13	0.53
May 21	0.37	June 14	0.45
May 22	0.33	June 15	
May 23	0.45	June 16	
May 24		June 17	0.53
May 25	0.69	June 18	0.22
May 26	0.31	June 19	0.40
May 27	0.38	June 20	
May 28	0.31	June 21	
May 29	0.38	June 22	
May 30	0.40	June 23	
May 31	0.40	June 24	0.39
June 1	0.35		
June 2	0.32		
June 3	0.34		
June 4	0.51		
June 5	0.44		
June 6	0.35		

TABLE XVIII

TEMPERATURE PROFILES OF SEA WATER, ICE AND FOAM

TEMPERATURE READINGS -- ° F														
PLOT NUMBER AND TIME OF READING														
DATE:		June 10				June 11				June 12				
Thermocouple No.	Depth (In)*	2		3		2		3		2		3		
		1145	2100	1145	2100	1100	2000	1100	2000	0900	1700	0900	1700	
1	In Water	34	28	32.5	29.5	35	29.5	32	30	31	30	31	30	
2	-48	35	28	34	28	37	28	31	29	30.5	28	31	29	
3	-36	36	27.5	35	28	38	28	33	29	30.5	27.5	31	29	
4	-24	36	27	36	28	39	27	34	29	30	27.5	31	29	
5	-12	37	28	37		40	27			31	28			
6	0	39	29	42	32	45	32	37	31.5	36	32	34	32	
7	+3	39	32	35.5	32	39	35	35	34	33	32.5	34	33	
8	+6	40	32	38	33	42	34	36	35	34	32	35.5	34	
9	+9	42	32	44.5	34	42	34	41	37	35	32	45	39	
7F	0										32			
8F	+1/2										36			
9F	+1										40			
10F	+2										35			

* LEGEND + Above original natural ice surface -- inches
 - Below original natural ice surface -- inches
 F Above ice surface in foam layer ----- inches
 TC1 Located 12 inches in sea water.

TABLE XVIII Cont'd.
TEMPERATURE PROFILES OF SEA WATER, ICE AND FOAM

		TEMPERATURE READINGS -- °F											
DATE:		June 13				June 14				June 15			
Thermocouple No.	Depth (In)*	2		3		2		3		2		3	
		0845	1630	0845	1630	0845	1830	0845	1830	0815	1815	0815	1815
1	In Water	35	30	34	30	30	30	31	32.5	31	32	32	32
2	-48	35	29	32	28	29	28	28	31	31	28	31	28
3	-36	35	28	31	26	28.5	27	28	31	31	28	31	28
4	-24	36	28	30	27	28.5	27	27	31	31	27	31	27
5	-12	37	29			28.5	27.5			32			
6	0	40	31	33	31	31.5	30	31	35	35	30		30
7	+3	36	32	37	36.5	33	33	31.5	35	33	33		33
8	+6	38	31	38	41	33	33	39.5	40.5	35	38		38
9	+9	39	30.5	45	47	34	32	39	42	35	44		44
7F	0	39	31			35	33			38			
8F	+1/2	42	35.5			39	36.5			42			
9F	+1	41	40			41	40.5			43			
10F	+2	39	34			36	37			38			
DATE:		June 16				June 17				June 18			
		2		3		2		3		2		3	
		1125	1830	1125	1830	0800	1615	0800	1615	0820	1630	0820	1630
1	In Water	30.5	31	30	33	31.5	30	31	35	31	31	32	
2	-48	30	30	29	33	31	28	28.5	34	29.5	30	30	
3	-36	29.5	29	28.5	33	31	27.5	28	34	29	29	29	
4	-24	29.5	28	29	33.5	31	27.5	28	37	29	30	29	
5	-12	30	28			32	28			29.5	30		
6	0	33	30	33.5	39	35	29.5	32		32	33		
7	+3	34	34	38	37	34	32	37.5		33	33		
8	+6	34	34			35	30.5			33	33		
9	+9	34	34			35	30.5			33	34		
7F		38	38			39	38			38	42		
8F		41	40.5			43	46			42	46.5		
9F		42.5	42			45	57.5			46	46		
10F		43	39			40	44.5			40	43		

TABLE XVIII Cont'd.
TEMPERATURE PROFILES OF SEA WATER, ICE AND FOAM

		TEMPERATURE READINGS -- °F									
DATE:		PLOT NUMBER AND TIME OF READING									
Thermocouple No.	Depth (In)*	6-19		6-20		6-21	6-22	6-23	6-25		
		2	3	2	3	2	2	2	2		
1	In Water	0900	0900	0900	0900	1000	0912	0945	1030		
2	-48	30	34	30.5	30.5	31	30	30	32		
3	-36	29.5	31.5	30	31	30	29	29.5	30		
4	-24	29	31.5	29.5	31	30	28.5	29.5	30		
5	-12	29	31.5	30	32	29.5	29	30	30		
6	0	30		31		30.5	30	30	31		
7	+3	32		33		33	33	32	33		
8	+6	32		32.5		33	32	33	32		
9	+9	33		33		33	31.5	33	32		
7F		33		33		33	31.5	33	32		
8F		38		38		37	39	41	39		
9F		42.5		41		40	46	48	43		
10F		44		40		41	45	47	39		
		40		38		38.5	43	45	41.5		

TABLE XIX

ABLATION READINGS - PLOT 2

DATE & TIME	ABLATION STAKE NO'S.	HEIGHT FROM ICE SURFACE TO TOP OF ABLATION STAKES -- INCHES									
		10-11	11-12	12-10	13-14	14-15	15-13	16-17	17-18	18-16	
9 April		11 6/8	11 6/8	11 7/8	12 3/8	12 6/8	11 6/8	11 6/8	11 7/8	12	
12 May 1100	Ice Loss Ave. Loss	11 7/8 1/8	12 2/8 5/24	12 1/8 2/8	12 6/8 3/8	12 6/8 0 5/24	12 2/8	11 7/8 1/8	11 7/8 0 3/24	12 2/8 2/8	
17 May 1500	Ice Loss Ave. Loss	11 6/8 0	11 7/8 1/8 2/24	12 1/8	12 3/8 0	12 5/8 -1/8	No. 13 Broken	11 6/8 0	11 7/8 0 1/24	12 1/8 1/8	
28 May 1900	Ice Loss Ave. Loss	11 7/8 1/8	12 2/8 4/8 6/24	12 1/8		13 3/8 5/8 15/24		12 6/8 8/8	12 2/8 3/8 15/24	12 4/8 4/8	
1 June 1620	Ice Loss Ave. Loss	11 4/8 2/8	11 6/8 -4/24	11 5/8 -2/8		13 2/8 -4/8 -12/24		12 4/8 6/8	12 1/8 2/8 12/24	12 4/8 4/8	
7 June 1700	Ice Loss Ave. Loss	11 -6/8	11 1/8 -5/8 -12/24	11 1/8 -6/8		13 2/8 6/24		12 2/8 4/8	12 1/8 2/8 8/24	12 2/8 2/8	
11 June 1100		14 (Foam Applied)	15	14 4/8							
13 June 1600					(Foam Applied)	19		Stakes 16, 17 & 18 were surrounded by water.			
17 June 1615	Ice Loss Ave. Loss							25 4/8 13 6/8	25 6/8 13 7/8 13 7/24	25 7/8 13 7/8	
21 June 1000	Ice Loss Ave. Loss								29 4/8 17 5/8 17 15/24		
25 June 1030	Ice Loss Ave. Loss	16 2	16 4/8 1 4/8 1 18/24	16 2/8 1 6/8		19 4/8 4/8 12/24			30 6/8 18 7/8 18 21/24		

ABLATION READINGS - PLOT 3

DATE & TIME	ABLATION STAKE NO'S.	HEIGHT FROM ICE SURFACE TO TOP OF ABLATION STAKES - INCHES									
		10-11	11-12	12-10	13-14	14-15	15-13	16-17	17-18	18-16	
9 April		11 7/8	11 7/8	12	11 7/8	11 6/8	11 6/8	12	12	12	
12 May 1100	Ice Loss Ave. Loss	12 1/8	12 1/8 2/8 4/24	12 1/8 1/8	12 1/8 2/8	12 2/8 6/24	12 2/8	12 1/8 1/8 0	12 0 3/24	12 2/8 2/8	
17 May 1500	Ice Loss Ave. Loss	11 6/8 -1/8	11 5/8 -2/8 -6/24	11 5/8 -3/8	11 6/8 -1/8	11 6/8 0 -1/8	11 6/8 0	11 6/8 -2/8 -6/24	11 6/8 -2/8	11 6/8 -2/8	
28 May 1900	Ice Loss Ave. Loss	12 1/8	12 1/8 2/8 5/24	12 2/8 2/8	12 2/8 3/8	12 1/8 3/8 9/24	12 1/8 3/8	12 2/8 2/8 6/24	12 2/8 2/8	12 2/8 2/8	
1 June 1620	Ice Loss Ave. Loss	12 1/8 2/8	12 2/8 3/8 7/24	12 2/8 2/8	12 2/8 3/8	12 2/8 4/8 11/24	12 2/8 4/8	12 2/8 2/8 7/24	12 3/8 3/8	12 3/8 3/8	
7 June 1700	Ice Loss Ave. Loss	12 2/8 3/8	12 2/8 3/8 9/24	12 3/8 3/8	12 4/8 5/8	12 2/8 4/8 14/24	12 3/8 5/8	12 3/8 3/8 9/24	12 3/8 3/8	12 3/8 3/8	
12 June 1700	Ice Loss Ave. Loss	14 6/8 3/8	15 3/8 3	15 3/8	5/8	4/8 39/24	15 1/8 5/8	14 6/8 3/8 26/24	14 6/8 3/8	14 6/8 3/8	
17 June 1615	Ice Loss Ave. Loss	22 5/8 10 6/8	23 2/8 11 3/8 11 2/24	23 1/8 11 1/8		11 18/24	23 4/8 11 6/8	23 2/8 11 2/8 11 3/24	23 6/8 11 6/8	23 6/8 11 6/8	
19 June 0945	Ice Loss Ave. Loss	26 4/8 14 5/8	26 6/8 14 7/8 14 12/24	26 14		26 12/24	26 4/8				
21 June 1000	Ice Loss Ave. Loss	29 3/8 17 4/8	29 1/8 17 8/24	29 4/8 17 4/8		28 4/8 16 4/8 16 18/24	28 4/8 16 4/8				
25 June 1030	Ice Loss Ave. Loss	30 7/8 19	19								

TABLE XIX Cont'd.

ABLATION READINGS - PLOT 5

DATE & TIME	ABLATION STAKE NO'S.	HEIGHT FROM ICE SURFACE TO TOP OF ABLATION STAKES-- INCHES										
		10-11	11-12	12-10	13-14	14-15	15-13	16-17	17-18	18-16		
9 April		11 6/8	12	12	11 6/8	12	12	12 5/8	11 5/8	11 6/8		
12 May 1100	Ice Loss Ave. Loss	11 7/8 1/8	12 6/8 6/8 11/24	12 4/8 4/8	11 4/8 -2/8	12 1/8 1/8 3/24	12 2/8 2/8	12 1/8 1/8	11 6/8 1/8 4/24	12 2/8		
17 May 1500	Ice Loss Ave. Loss	12 1/8 3/8	12 1/8 1/8 5/24	12 1/8 1/8	11 1/8 -5/8	11 5/8 -3/8 -10/24	11 6/8 -2/8	11 7/8 -1/8	11 7/8 2/8 3/24	11 6/8 0		
28 May 1900	Ice Loss Ave. Loss	12 4/8 6/8	12 4/8 4/8 15/24	12 5/8 5/8	11 7/8 1/8	12 0 3/24	12 2/8 2/8	Stake # 17 Broken	12 2/8 4/8			
1 June 1620	Ice Loss Ave. Loss	12 4/8 -2/8	13 1 1 6/24	12 4/8 4/8	Remaining Stakes Broken							
7 June 1700	Ice Loss Ave. Loss	12 4/8 6/8	12 4/8 4/8 17/24	12 7/8 7/8								
10 June 2200		15 1/8	15	14 7/8								
(Foam Applied Following These Readings.)												
25 June 1030	Ice Loss Ave. Loss	16 3/8 1 2/8	16 2/8 1 2/8 1 5/24	16 1 1/8								

TABLE XX

EFFICIENCY OF FOAM PROTECTION - CALCULATIONS

(Data Abstracted From Table XIX)

	ICE PLOTS TYPE AND NUMBER		
	PROTECTED		UNPROTECTED
	Plot 2	Plot 5	Plot 3 (Control)
Average ice ablation from 6-11 to 6-25-INCHES	1.75	1.21	19.00

$$\text{Efficiency of foam protection Plot No. 2} = \frac{19-1.75}{19} \times 100 = 90.8\%$$

$$\text{Efficiency of foam protection Plot No. 5} = \frac{1.9-1.21}{19} \times 100 = 93.5\%$$

$$\text{Average efficiency (Plots 2 and 5)} = \frac{90.8\% + 93.5\%}{2} = 92.2\%$$

TABLE XXI

THERMAL CONDUCTIVITY OF PLOT 2 FOAM

(Average k-value for period 6-12 to 6-25, data taken from Tables XVIII and XIX)

 $q = -ka \frac{dt}{dx}$ Equation for heat transfer by steady unidirectional conduction.

where:

DEFINITIONS AND UNITSVALUES

q = Steady rate of heat flow BTU/hour	
k = Thermal conductivity at temp. t , $\frac{(\text{BTU})/(\text{hr})(\text{sq. ft.})}{\text{deg. F/ft}}$	
A = Area through which heat flows at right angles - square feet.	1 sq. ft.
dt = Thermometric temperature - degrees F	4°F
dx = Length of conduction path - feet	0.0416 ft. (0.5 inch)

Basis: Calculations based on 1 square foot of surface area.

Cu. ft. of ice melted/14 days $-1.75 \text{ in.} \times \frac{\text{ft}}{12 \text{ in.}} \times 1 \text{ ft}^2 = 0.146 \text{ ft}^3$
 (amount of ice ablated -1.75 inches)

Pounds of ice melted in 14 days. $0.146 \text{ ft}^3 \times \frac{62.4 \#}{\text{ft}^3} \times 0.915 = 8.32\#$
 (Sp.G. of ice = 0.915)

Steady heat flow - $q \frac{8.32\#}{14 \text{ days}} \times \frac{144 \text{ BTU}}{\#} \times \frac{\text{day}}{24 \text{ hrs.}} = 3.57 \frac{\text{BTU}}{\text{hr}}$
 (Heat of fusion of ice = 144 BTU/#)

dt (Temp. readings taken on 6-12-62)
 $t_2 - t_1$ (1 in. - 0.5 in. above ice surface in Foam)

$$(40 - 36)^\circ\text{F} = 4^\circ\text{F}$$

 $A = 1 \text{ sq. ft.}$ (taken as a basis)

$$k = \frac{q}{A(dt/dx)} = \frac{q(dx)}{A(dt)} = \frac{\text{BTU}}{(\text{hr})(\text{ft})(^\circ\text{F})}$$

$$k \text{ (for } dt \text{ of 6-12)} = 3.57 \frac{\text{BTU}}{\text{hr}} \times (0.0416 \text{ ft}) \left(\frac{1}{4^\circ\text{F}}\right) = \frac{3.57(0.0416)}{(4)}$$

$$= 0.0372 \frac{\text{BTU}}{(\text{hr})(\text{ft})(^\circ\text{F})}$$

TABLE XXI CONT'D.

AVERAGE k-VALUE FOR 14 DAY PERIOD

DATE AND TIME OF READING	dt	k-value	DATE AND TIME OF READING	dt	k-value
6-12 PM	4	0.0372	6-17 PM	11.5	0.0128
6-13 AM	1	0.1488	6-18 AM	4	0.0372
6-13 PM	4.5	0.0331	6-18 PM	0.5	0.2970
6-14 AM	2	0.0744	6-19 AM	1.5	0.0992
6-14 PM	4	0.0372	6-20 AM	1	0.1488
6-15 AM	1	0.1488	6-21	1	0.1488
6-16 AM	1.5	0.0992	6-22	1	0.1488
6-16 PM	1.5	0.0992	6-23	1	0.1488
6-17 AM	2	0.0744	6-25	4	0.0372

GRAND TOTAL = 1.7309

$$\begin{array}{l} \text{Average k-value} \\ \text{(from 6-12 to 6-25)} \end{array} \quad \frac{1.730}{18} = 0.0964 \quad \frac{\text{BTU}}{(\text{hr})(\text{ft})(^{\circ}\text{F})} = 1.08 \frac{\text{BTU}}{(\text{hr})(\text{in})(^{\circ}\text{F})}$$

TABLE XXII

FOAM SHRINKAGE - PLOTS 6, 5 AND 2

NATURAL SEA-ICE PLOT NO. 6

PLOT AREA and FOAM E.R.	DATES				REMARKS
	5-20	5-21	5-25	6-3	
	Average Foam Thickness - Inches				
Thermocouple Area (E.R.-9.5)	3		2	1	After about one-week exposure, the E.R.-12.0 foam began to "check" and shrink badly. The E.R.-9.5 foam held up for about two weeks. The foam applied to this plot was washed away approximately three-weeks after its application due to the thawing and draining of the surrounding ice.
Ablation Area (E.R.-12.0)		3	1		
FREE-FLOODED SEA-ICE PLOT NO. 5					
	DATES				
	6-10	6-14	6-16		
Thermocouple Area (E.R.-10)	4 1/2	1 1/2	1 1/4		After approximately four-days of exposure the foam pulled away from the thermocouples located in it. Surface cracks were also evident. However, foam was still protecting ice surface after two-weeks exposure.
Ablation Area (E.R.-8)	5 1/2		3		
CONFINED-FLOODED SEA-ICE PLOT NO. 2					
	DATES				
	6-11	6-13	6-16	6-17	
Thermocouple Area (E.R.-9)	5		3 1/2		As in Plot 5, approximately four days after application of foam, surface cracks were evident. However, foam was still protecting the ice after two-weeks exposure.
Ablation Area (E.R.-9)		4 1/2	4 1/2	3 1/2	

TABLE XXIII

RECOMMENDED FORMULATION

INGREDIENTS	Wt. - % (Range)	Source
1. Mearlfoam - 5	6.7	Mearl Corporation Roselle Park, New Jersey
2. CMC - 7 HP	1.5 - 2.0	Hercules Powder Company Wilmington, Delaware
3. Aluminum Acetate	10 - 25 (Based on CMC)	Mallinckrodt Chem. Works New York, New York
4. Water	Balance	Salt or Fresh Water

Optimum Expansion Ratio Range 8 - 12

TABLE XXIV

COST FIGURES FOR CMC 7 LT BASED FORMULATION

BASIS: 50 GALLONS OF FOAM SOLUTION					
Ingredients	Density lbs/gal.	Amount - Wt. Basis		Raw Material Cost/ lb.	Cost/50 Gals.
		%	lbs.		
Mearlfoam - 5	9.6	6.7	29.2	\$0.338	\$ 9.86
CMC - 7 LT		3.0	13.1	0.50	6.55
Aluminum Acetate (Based on CMC Weight)		10	1.3	1.85	2.41
Sea Water	8.55		392.0		
			435.6 Lbs.		\$18.82

COST PER SQUARE FOOT FOR 4-INCH THICK FOAM LAYER

BASIS: EXPANSION RATIO OF 10.0	
Calculations:	
50 gals. of foam solution (E.R. 10) = 500 gals. of foam.	
500 gals. of foam $\left[\frac{\text{ft}^3}{7.48 \text{ gals.}} \right] = 66.8 \text{ ft}^3$ of foam.	
66.8 ft^3 of foam $\times \frac{1}{4 \text{ in.}} \times \frac{12 \text{ in.}}{\text{ft}} = 200 \text{ ft}^2$ of 4-inch foam.	
$\frac{\$ 18.82}{50 \text{ gals of foam sol.}} \left[\frac{50 \text{ gals of foam sol.}}{200 \text{ ft}^2 \text{ of 4-inch foam}} \right] = \frac{\$0.0941}{\text{ft}^2 \text{ of 4-inch foam}}$	

TABLE XXV

COST FIGURES FOR CMC 7 HP BASED FORMULATION

BASIS: 50 GALLONS OF FOAM SOLUTION					
Ingredients	Density (lbs/gal)	Amount - Wt. Basis		Raw Mat. Cost/lb.	Cost/50 gals.
		%	lbs.		
Mearlfoam - 5	9.6	6.7	29.2	\$0.338	\$ 9.86
CMC 7 HP		1.75	7.6	0.50	3.80
Aluminum Acetate (Based on CMC Weight)		10.0	0.8	1.85	1.48
Sea Water	8.55		398.0		
			435.6 lbs.		\$14.94

COST PER SQUARE FOOT FOR 4-INCH THICK FOAM LAYER

BASIS: EXPANSION RATIO OF 10.0	
Calculations:	
(For calculation details see Table XXIV).	
$\frac{\$0.0941}{\text{ft}^2 \text{ of 4-inch foam}} \times \frac{14.94}{18.82} = \frac{\$0.0747}{\text{ft}^2 \text{ of 4-inch foam}}$	

REFERENCES

1. Aidun, A. R., et al, "Development of Foam Insulation for Protection of Arctic Airfields", AFCRL Final Report 827 (1961).
2. McAdams, W. H., "Heat Transmission", McGraw-Hill Book Company, Inc. (1954).