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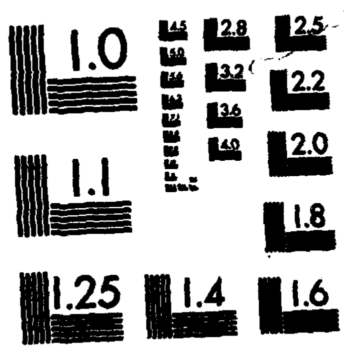

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Special Report 82-32

December 1982

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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Developing a water well for the ice backfilling of DYE-2

John Rand

Prepared for
DEW SYSTEMS OFFICE, U.S. AIR FORCE
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One proposal to extend the useful life of DEW Line Ice Cap Station DYE-2 is to backfill the lower 50 feet of the truss enclosure with ice. This report discusses a method by which 2.8 million gallons of water would be collected and stored by melting ice. Also included is a description of required components, their costs and the logistical requirements to establish such a system.

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PREFACE

This study was conducted by John Rand, Mechanical Engineer, Engineering and Measurement Services Branch, Technical Services Division, U.S. Army Cold Regions Research and Engineering Laboratory. It was prepared for and funded by the DEW Systems Office of the U.S. Air Force, Peterson Air Force Base, MIPR #CS 79-162. This report was technically reviewed by Donald Haynes and Wayne Tobiasson of CRREL.

Contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

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ILLUSTRATIONS

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practice Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	By	To obtain
Btu	1055.056	joules
feet	0.3048*	metres
gallons	0.003785412	metres^3
horsepower (boiler)	9809.50	watts
inches	0.0254*	metres
pounds	0.4535924	kilograms
degrees Fahrenheit	$t_{°C} = (t_{°F} - 32)/1.8$	degrees Celsius

* Exact.

DEVELOPING A WATER WELL FOR THE ICE BACKFILLING OF DYE-2

John Rand

INTRODUCTION

The concept of melting snow or ice and storing the water in place at a considerable depth below the snow surface was developed in the late 1950s for military camps' water supplies in Greenland. Schmitt and Rodriques (1960), Schmitt (1963) and Mellor (1969) described the various methods of developing water supplies on permanent snowfields and summarized the history of the various in-situ water wells in Greenland.

An in-situ water well is simply a hole that is melted through the snow until the vertical advance is intercepted by impermeable ice, where the meltwater ponds. After enough has accumulated in the hole, the meltwater is pumped from the well to a heat exchanger on the surface. The water is then returned to the well, where it is discharged through a spray nozzle. The shape and size of the ponding cavity depend on the amount of energy applied, the amount of water circulated, and the pattern of the spray discharge.

Aside from the obvious benefits of not having to mechanically handle snow for surface melting operations or having to provide large, insulated storage tanks for the meltwater, the in-situ well provides a useful storage area for wastewater after it is pumped dry.

At Camp Century (N 77°10', W 61°08') in northern Greenland (Fig. 1) three in-situ water wells were started (Schmitt and Rodriques 1960, Schmitt 1962, Clark 1965, Russell 1965 and Mellor 1969). The first service well produced approximately 3.5 million gallons over a two-year period. This well was closed down once the depth of the water level exceeded the pumping limits. The second service well reached a depth of 300 feet; the pool diameter was in excess of 100 feet. The total yield of this well over the 2-1/4 years of operation was 5 million gallons. The third well at Camp Century was used as a heat sink for the glycol coolant from the nuclear reactor. Although no water was removed from this well, approximately 20 million gallons of water were ponded after two years of operation.

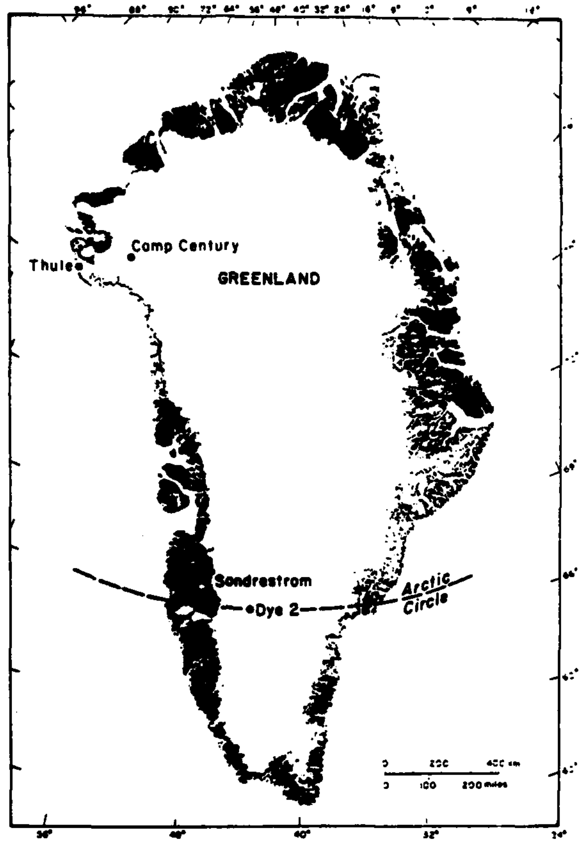

Figure 1. Location of DYE-2.

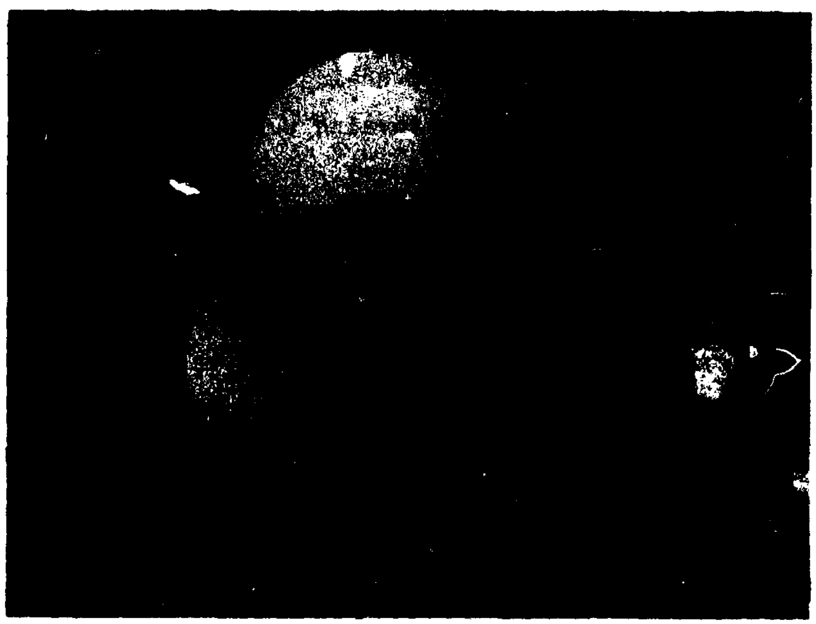

Figure 2. DYE-2.

DYE-2 (N 55°29', W 46°20') is located in southern Greenland (Fig. 1). The station is a four-story steel structure elevated above the snow surface (Fig. 2). Periodically the structure is elevated on its eight legs to keep the building above the snow surface. Eventually the building can no longer be safely raised, and an alternate method has to be used if the station is to operate. Moving the entire building sideways and establishing new stilts is the recommended method; however, an alternate method was considered. This method was to fill the bottom 50 feet of the existing trusses with water, freezing it in layers to cast a new foundation for the building. To do this, 2.8 million gallons of water would be required. This report describes the equipment and procedure to melt that amount of water during a single season.

DEVELOPING THE WATER WELL

The first step in developing the water well is to melt or drill a vertical shaft through the permeable snow to a depth at which the melt water will not permeate into the surrounding material. This depth is referred to as the firn-ice transition. If the hole is melted, water will first start to collect (due to the decreasing permeability) approximately 1/3 of the distance to the firn-ice transition.

Once the firn-ice transition depth is reached (approximately 150 feet below the snow surface), the drilling equipment is removed. A submersible pump and two hoses are attached to an electromechanical cable and winch system. The pump assembly is lowered quickly into the hole and submerged in the water at the bottom of the hole. The water is pumped up one of the hoses to the surface, where a control panel monitors the inlet water temperature, pressure and flow rate. The water passes through a heat exchanger, where the temperature is raised to 160°F, and is returned to the hole through the second hose.

During the melting process the position of the submersible pump must be closely monitored to ensure that the pump inlet stays under water. Initially this task requires constant attention, but as the cavity enlarges, the water level drops more slowly.

When enough water has been melted, the well is ready to use. In previous ice-cap wells, water has been used while the well was being formed. However, for the ice backfill operation the well would be developed in the summer and the water would be used for the spraying operation in the winter.

A small amount of ice would form on the surface of the pool between operations. An electric cartridge heater would be installed to keep an access hole open to the center of the cavity so that the pumps for the spraying operation could be lowered into the water.

Energy demands for melting ice

The energy required to produce 1 pound of water from ice is defined by the equation

$$Q = L + \left(C_{pi}\ \Delta T_1\right) + \left(C_{pw}\ \Delta T_w\right)$$

where

Q = total energy required (Btu/lb)

L = latent heat of fusion of ice (144 Btu/lb)

C_{pi} = specific heat of ice (0.5 Btu/lb °F)

ΔT_1 = difference between the ambient ice temperature and the melting point of ice (°F)

C_{pw} = specific heat of water (1.0 Btu/lb °F)

ΔT_w = difference between the freezing point of water and the final water temperature (°F).

The estimated temperature at the firn-ice transition at DYE-2 is 0°F. The ambient pool temperature is assumed to be 34°F. Therefore

$$Q = 144 + \left[0.5\ (32-0)\right] + \left[1.0\ (34-32)\right]$$

$$Q = 162 \text{ Btu/lb.}$$

The heating value of arctic-grade diesel fuel (DFA) is about 19,500 Btu/lb. If the melting process was perfectly efficient, the ratio of water produced to fuel consumed would be

$$\frac{19500 \text{ Btu/lb}}{162 \text{ Btu/lb}} = 120.4 \text{ lb of water per lb of fuel.}$$

Schmitt and Rodriques (1960), Mellor (1969) and Russell (1965) recommend, respectively, that 66, 60 and 59 lb of water per lb of fuel be used to account for the inefficiencies and thermal losses. Mellor also noted that the ratio for surface snow melting should be reduced to 25 lb of water per lb of fuel. Thus, it is at least twice as efficient thermally to use the water well.

Tobiasson et al. (1975) estimated that 2.8 million gallons (23.4 million lb) of water would be required for the DYE-2 backfill. If we use Mellor's ratio of 60 lb of water per lb of fuel, the energy Q_T required to produce 2.8 million gallons of water is

$$Q_T = \frac{23{,}366{,}000 \text{ lb of water}}{60 \text{ lb of water/lb of fuel}} \times 19{,}500 \text{ Btu/lb of fuel}$$

$$= 7.6 \times 10^9 \text{ Btu.}$$

The largest commercially available water-tube boilers that have indirect heat exchangers installed in the top shell and that are transportable by C-130 aircraft are in the 125- to 140-bhp range. Two 125-bhp units combined in a parallel loop would be of reasonable size and would generate 8,380,000 Btu/hr. If a 250-bhp package was used, 2.8 million gallons could be produced in about 38 days.

Components of the water well

The primary components of the DYE-2 water well proposed for the backfill operation include 1) the equipment to drill the initial hole, 2) the boiler and heat exchangers, 3) the submersible pump assembly, and 4) the miscellaneous support equipment (Fig. 3). In this section each component will be identified, its function described, and its size determined.

Drilling equipment. An initial hole is required for penetrating the upper layers of porous snow to the level where water will not permeate into the surrounding material. Several kinds of drills are possible, such as an electromechanical ice-coring auger (Rand 1974) or a thermal drill (Rand 1980). The method proposed here is a hot-water drill, which would be used to melt a vertical shaft to the firn-ice transition. An initial quantity of water (500 gallons) could be obtained from the DYE-2 water system and stored in insulated tanks near the operation site. This water would be circulated through the boiler and heat exchanger until its temperature reached 160°F. Then it would be routed through a hose to the drill (Fig. 4), which would be suspended on a cable and winch assembly. As the drill is lowered, the snow below melts. At a depth of about 60 feet, water will

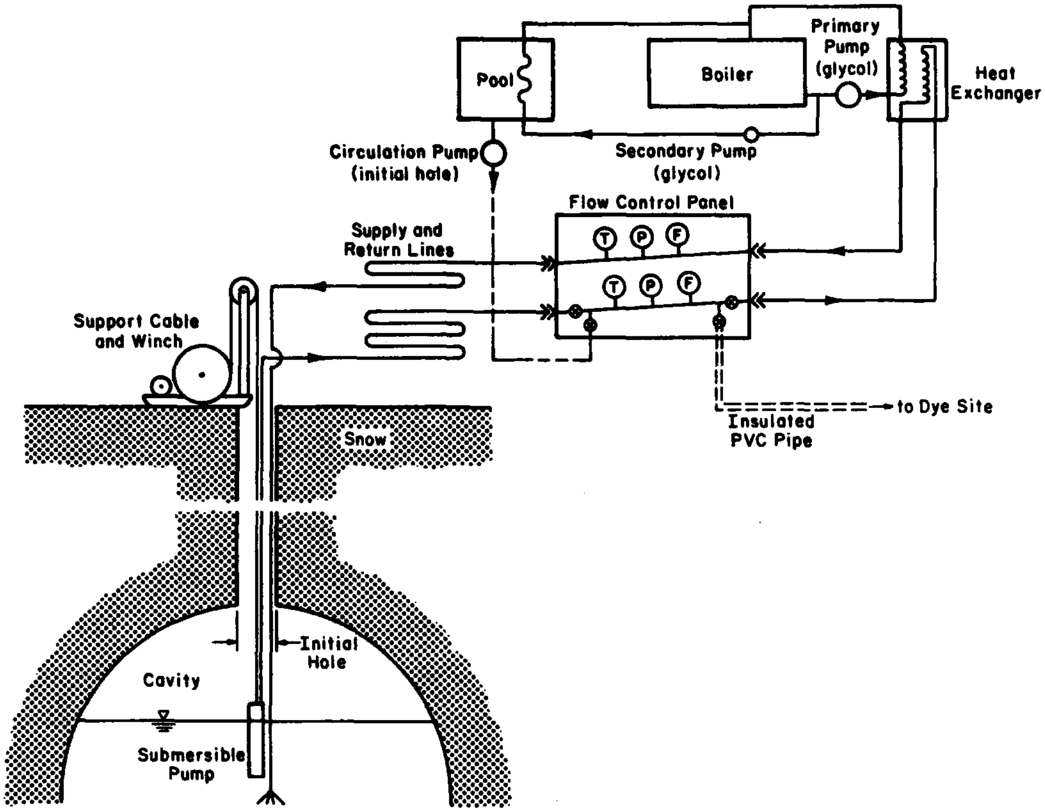

Figure 3. Components of the water well system.

start to collect in the hole. When the water level reaches the sensor above the submersible pump inlet housed in the drill, the pump turns on automatically. Once the water begins to circulate out of the hole, the initial surface water supply is no longer required.

The diameter of the vertical shaft is determined by the physical size of the component to be lowered through it. For this operation 12 inches is sufficient; the hole can be enlarged later if necessary. The smaller the hole, the safer it is for the crew working around it.

Table 1. Estimated drill performance rates.

	Depth (ft)			
	0-50	50-100	100-150	Total
Density (lb/ft^3)	18.7	31.2	43.6	
Volume of hole (ft^3)	39.3	39.3	39.3	117.9
Weight of snow (lb)	734.4	1226.2	1713.5	3674.1
Drilling time (min)	10.25	17.12	23.92	51.3
Average penetration rate (ft/min)	4.8	2.9	2.1	

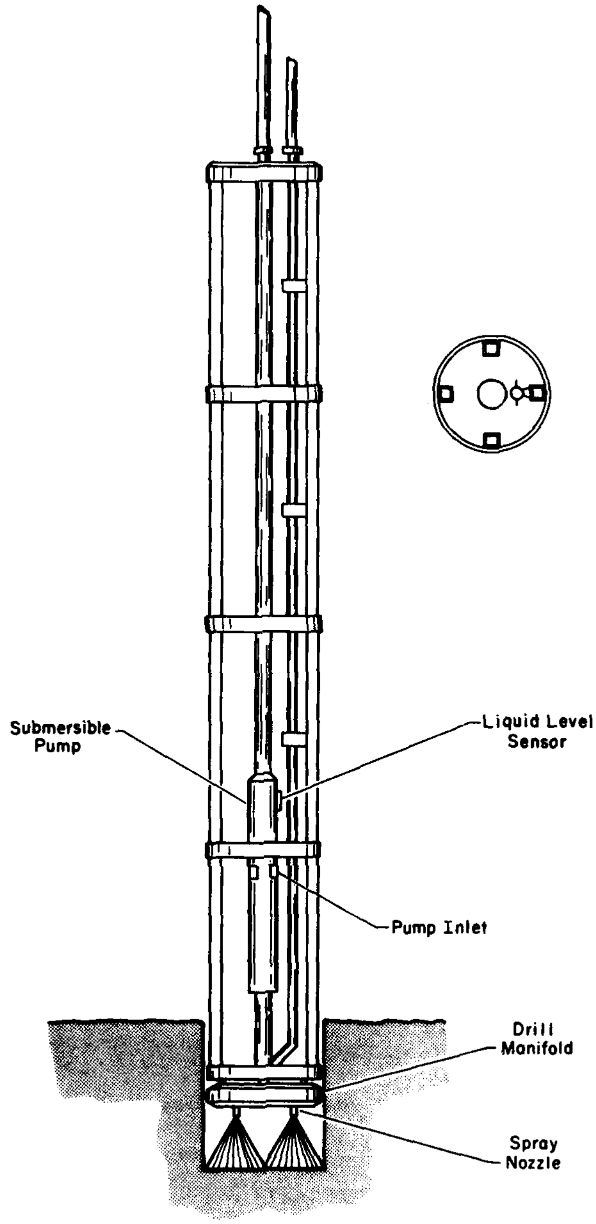

Figure 4. Hot-water drill.

The rate that snow is melted can be estimated using Mellor's ratio of 60 lb of water per lb of fuel and the heating value of 19,500 Btu/lb of fuel. The energy required to melt the snow, then, is 325 Btu/lb of water. The rate at which the snow is being melted is equal to the available energy divided by 325 Btu/lb of water.

If one of the boilers was used at a third of its rated output (1.396 million Btu/hr), then the rate at which the snow is melted would be

$$\text{Rate of melting} = \frac{1{,}396{,}000 \text{ Btu/hr}}{325 \text{ Btu/lb} \times 60 \text{ min/hr}}$$

$$= 71.6 \text{ lb/min.}$$

The amount of snow to be melted can be estimated from the density profile, as shown in Table 1. With this and the melting rate the penetration rates in each of the depth increments can be estimated.

The surface pump and the submersible pump used in this initial operation must be large enough to maintain the flow of water required to transfer the available energy to the drill head.

$$Q = W\,C_{pw}\,\Delta T$$

$$W = \frac{Q}{C_{pw}\,\Delta T}$$

$$W = \frac{1{,}396\ 000}{1 \times 128} = 10{,}906 \text{ lb/hr} = 21.8 \text{ gal./min}$$

where

Q = available energy (Btu/hr)

W = amount of water (lb/hr)

C_{pw} = specific heat of water (1.0 Btu/lb °F)

ΔT = difference in water temperature (160°-32°F) = 128°F.

Both the initial surface pump and the submersible pump enclosed in the drill, then, should be able to pump 20-25 gal./min.

The pumps use water from the surface storage tanks until water begins to pool in the hole, about 10-12 minutes after the drilling begins. At a pumping rate of 25 gal./min, 250-300 gallons will have been used. Since ample water should be available in case of unexpected problems, 500 gallons should be stored on the surface.

Boiler and heat exchanger. Three sizes of boilers would be suitable for melting enough water within a reasonable time (30-50 days); they are 200, 250 and 300 bhp (Fig. 5). Smaller units would extend the field season. Units larger than 300 bhp present transportation and logistical problems, since all equipment must be airlifted to DYE-2 in C-130 aircraft.

The two packaged boilers selected are hot-water units with indirect heat exchangers having a combined output of at least 250 bhp (8,380,000 Btu/hr). Appendix A outlines the boiler specifications. Two smaller units

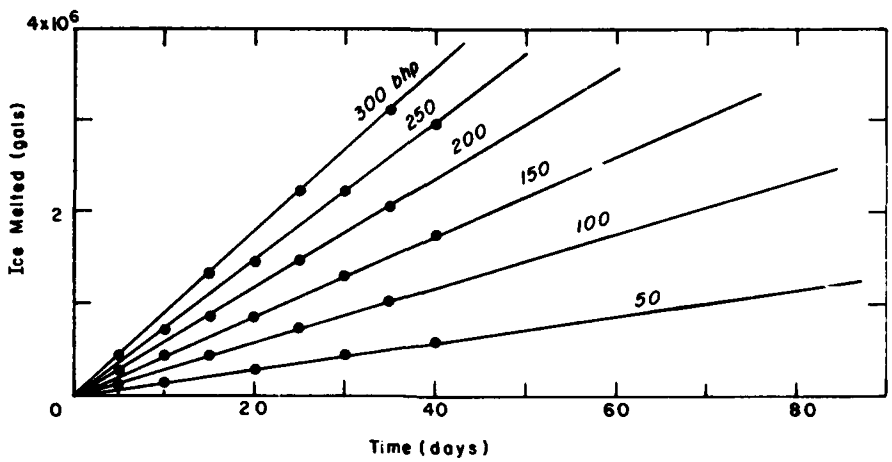

Figure 5. Melting rates for various size boilers.

were chosen instead of one large one to provide the ability to produce only the reduced amount of energy required during the start-up period and to add redundancy to the system in case of breakdown. If only one of the boilers operated, it would take over 2 1/2 months to produce the water needed, but it could be done.

The fuel consumption for the boilers is estimated to be 66,000 gallons for a 38-day operating time and a 25% allowance for unexpected delays. Fuel would be pumped through a 2-inch hose from the station's tanks to a 2000-gallon storage tank near the boilers. A flow meter in the fuel line would monitor the amount of fuel consumed.

The boilers would be supported on an insulated wood pad and would be covered with an arched frame shelter. The boilers should be positioned within 50 feet of the vertical shaft to reduce heat loss in the water lines.

Submersible pump assembly. Three submersible pumps are required for the various operations related to this project. The first pump is lowered in the drilling equipment. The second is used during the melting operation to circulate the well water to the surface, through the boiler and heat exchangers, and back down the hole. The third pump is used during the spraying operation to pump water out of the well to the spraying system in the truss enclosure of the DYE site.

The size of the second pump is determined by its ability to transfer the energy from the boilers to the hole. For a 250-bhp boiler the energy available Q_a is 8,380,000 Btu/hr. The temperature difference between the pool water (32°) and the discharge water (160°F) is 128°F. The rate W at which the pump must be able to circulate water is

$$W = \frac{Q_a}{C_{pw}\Delta T}$$

$$= \frac{8,380,000 \text{ Btu/hr}}{(1 \text{ Btu/lb °F})(128°\text{F})} = 65,468 \text{ lb/hr}$$

$$= 130 \text{ gal./min.}$$

The pool develops downward from the firn-ice transition, which at DYE-2 is approximately 150 feet below the surface. If the pool is a sphere storing 2.8 million gallons of water at 34°F, then its volume V is

$$V = \frac{w \cdot \omega}{\rho \cdot k}$$

$$= \frac{(2,800,000)\ (8.34)}{(62.4)\ (1.09)} = 343,330 \text{ ft}^3$$

where

w = amount of water (gallons)

ω = weight of water (8.34 lb/gal.)

ρ = density of water (62.4 lb/ft^3)

k = expansion factor (1.09).

Its diameter D_s is

$$D_s = \frac{\sqrt[3]{V_s \cdot 6}}{\pi}$$

$$= \frac{\sqrt[3]{343,330 \cdot 6}}{3.14}$$

$$= 86.5 \text{ ft.}$$

The depth to the bottom of the pool would be 150 + 86.5 = 236.5 ft.

If the shape of pool is a paraboloid, then the height of the pool h is

$$V = \frac{\pi r^2 h}{2}$$

$$h = \frac{2V}{\pi r^2}$$

$$= \frac{2 \cdot 343,330}{3.14\ r^2}$$

$$= \frac{218,682}{r^2}$$

where r is the radius of the paraboloid. If r is 40 feet, then h equals 136.6 feet; if r is 50 feet, then h is 87.4 feet; if r is 60 feet, then h is 60.7 feet. The 40-foot-radius pool has the deepest pumping requirement; the total depth of the pool would be 286.6 feet.

During the melting period the pump should not have to go below 250 feet. Only during the spraying operation would a submersible pump need to go to the bottom of the cavity to pump out all the water. The pump used for the melting operation should be capable of providing 130 gal./min with a discharge pressure of 40 psi while operating from a depth of 150-250 feet.

The electrical cable required for this pump and used for all pumping operations down the hole should be three-conductor #8 AWG. The maximum cable length should be 350 feet.

This operation and all other operations down the hole should use an SAE 100 R-5 hydraulic-base hose. It is made up of a synthetic rubber tube, a textile miner braid, a high-tensile steel braid, and a polyester braid cover. It is capable of withstanding a working pressure of 200 psi and a temperature between -40° and 300°F. The inside hose diameter is 1 13/16 inches and its outside diameter is 2 1/4 inches. The hose weighs 0.94 lb/ft and is available in 50-foot lengths.

The spray-system pump size is determined from estimates done by Hanamoto et al. (1976) for acceptable methods of spraying the water in the enclosures to form ice. It is estimated that 20,000 gal./day can be sprayed; this would raise the ice surface in the truss enclosure about 5 in./day. To operate at that rate for 12 hours each day, the pump must be able to move 30 gal./min from a depth of about 300 feet.

Miscellaneous support equipment. The flow control panel is a preassembled unit consisting of valves, gauges and meters that monitor the inlet and discharge pressures, temperatures and flow rates. It is from this panel that all water is diverted to and from the well.

The winch assembly raises and lowers the electromechanical cable and the components going down hole. The winch should be capable of lifting

2,000 lb. It must also have a variable speed control, so the rate of descent can be varied from 5 ft/min to 0.5 ft/min. An electromechanical cable should be used to provide the mechanical support for the pumps and the signal leads for the sensors in the hole.

A small compressor is required to dry the hoses after they have been used to circulate water, so that they do not freeze. A hose reel is needed that is capable of handling two 2-1/4-inch, 350-foot hoses simultaneously. This reel should have a variable speed control. Swivel joints at each end of the reel shaft will allow water to flow continuously as the hose is being raised or lowered.

A similar electric cable reel is required to store the electric leads to the submersible pump. A slip ring should be included to allow the pump to operate continuously as it is raised or lowered. The reel must be capable of storing 350 feet of three-conductor #8 AWG cable.

One fuel tank is required to store enough fuel for one day's operation. A skid-mounted, 2000-gallon tank 64 inches in diameter by 12 feet long would be large enough. There must be enough fuel hose to connect the existing fuel storage at DYE-2 to the day tank about 400 feet away. A booster pump may be required to pump fuel to the tank.

Insulated water pipes are required during the spraying operation. Approximately 400-500 feet of insulated, 2-inch, schedule 40, PVC pipe with heat-trace tape, 3 inches of fiberglass insulation and a metal jacket is required.

The water well components will require a 30-kW, 230-V, three-phase, four-wire electrical line. This power would be available from the DYE-2 site. A four-wire service line would run from the DYE-2 generator room to the well site; about 500 feet of cable will be required. This cable should be at least #00 AWG, based on a 5% voltage drop in the line. A master distribution box will be required at the water well for distributing power to the various components.

DISCUSSION AND CONCLUSIONS

The in-situ water well system has been used successfully in Greenland for producing large quantities of water. This system is the best alternative for obtaining the water required for the DYE-2 ice backfill. The benefits gained by using this method are:

1. It is at least twice as efficient as melting surface snow.
2. It can be accomplished during the summer months.
3. It provides its own container for storage.
4. The water is available prior to the start of the winter spraying operation.
5. The cavity produced when the water is pumped out would be usable for wastewater storage.

The only disadvantages to this type of operation are the possibility of freeze-up problems and the need to carefully monitor the equipment in the hole. These are typical cold regions problems and can be readily solved.

All the equipment selected for this operation could be transported by three C-130 aircraft from Sondrestrom Air Base (Appendix B). The 66,000 gallons of fuel required for the boilers would be scheduled into the DYE-2 fuel resupply in the spring. This quantity of fuel will require 22 flights, assuming 3,000 gallons are transported on each flight.

The cost of the project (not including transportation or fuel) is estimated to be $320,000. A budget is outlined in Appendix C. The melting operation can be accomplished in 38 days; however, a two-month period should be scheduled to compensate for any unforeseen delays.

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APPENDIX A. SPECIFICATIONS FOR BOILERS

Two packaged, hot-water boilers with indirect heat exchangers must have a combined rated output of at least 250 bhp (8,380,000 Btu/lb), a water-heating capacity of 6,000 Btu/hr, and a 128°F temperature rise. These boilers will be manufactured in strict accordance with ASME codes for pressure-heating boilers and will have a design pressure rating of 125 psi, with a safety valve setting at the same pressure. They will be subjected to a hydrostatic test of 2,000 psi. The boilers are made of steel. The heating medium within the boiler itself is to be a 50% concentration of ethylene glycol.

The boilers will be furnished with one or more indirect heat exchangers installed in the upper drum of the boilers. The heat exchangers, which will be constructed of heavy copper, seamless fin tubing attached to an appropriate heater, will be capable of absorbing 100% of the boiler's output. The heat exchangers must be attached in a way that allows them to be easily removed for inspection.

The boiler package will be insulated with a minimum of 1 1/2 inches of Styrofoam insulation and will be covered with a metal jacket. All exterior surfaces will be painted with a heat-resistant paint. The boiler will be mounted on a large, reinforced-steel, flat-plate sled. The sled should extend 3 feet in front of the boiler, 1 foot in the rear of the boiler and 6 inches from each side. Welded eyes are to be provided at each corner of the sled for tying down cargo.

Heater trim

Each boiler will be furnished with the following fitting and trim:

1) Aquastat for boiler water-temperature control.
2) Aquastat for boiler high-limit control.
3) Properly sized expansion tank and fitting.
4) Combination thermometer and pressure gauge.
5) ASME-rated, hot-water, safety relief valve for boiler (125 psi).
6) ASME-rated, hot-water, safety relief valve for heat exchanger (125 psi).
7) Low-water cutoff with an audio alarm in the burner control cabinet.
8) Piping-flow-sensing switch with an alarm in the burner control cabinet.

9) Stainless steel stack at least 8 feet high, with a manual-locking, quadrant-type damper that clearly indicates the position of the damper blade.

10) Stack thermometer.

11) Completely plumbed circulation loop with properly sized pumps for glycol loop.

12) Drain valves and fittings installed on the boiler.

Burner and controls

Each boiler shall be furnished with an integral, forced-draft, flame-retention, pressure-atomizing-type oil burner suitable for arctic-grade diesel fuel. The burner will have a motor and blower capable of supplying sufficient combustion air at an altitude of 7,000 feet. The following controls will be furnished with the burner and its control cabinet:

1) Combustion control with a flame-detector system.

2) Direct spark ignition system.

3) Minimum of two main oil shut-off valves.

4) Low-fire startup with a high-low-operating-type fuel system capable of low fire at a third of its rated capacity.

5) Fuel-oil pressure gauges.

6) Integral factory-piped, basket-type section filter.

7) Electric preheater on the burner capable of heating the fuel to a proper temperature from an ambient temperature of -30°F.

8) Fuel-oil pump with the burner system capable of removing oil from an outside tank located within 50 feet of each burner.

9) Signal lights to indicate low water, flame failure, low heat, power, ignition, fuel, and low water flow. The cabinet will also be provided with a gasketed, dust-tight, key-locking cover.

10) Switches for power, fuel-pump purge, alarm-silencing, low-fire hold, and circulation pumps.

11) Circuit breakers for burner motors.

12) Circulation pump interlocked with burner.

Boiler package and weight

Each boiler package must be capable of fitting inside a military C-130 cargo plane, which limits the height to 96 inches and the width to 88 inches. The length of the boiler should be limited to 20 feet. The maximum cargo load that a ski-equipped C-130 aircraft can carry from DYE-2 is about 25,000-30,000 lb. It is estimated that each boiler will weigh between 8,000 and 10,000 lb.

APPENDIX B. LOGISTICAL SUMMARY.

Description	Quantity	Weight (lb)	Size (ft^3)
130-gal./min submersible pump	2	640	12
25-gal./min submersible pump	2	200	10
20-gal./min surface pump	2	200	12
Hose with reel	1	1000	64
Support winch with cable	1	2500	80
125-bhp boilers	2	16000	1000
2,000-gallon fuel tank	1	1500	80
Fuel hose	500 ft	2000	160
Insulated water pipe	500 ft	1000	400
Hot-water drill		200	12
Electric cable with reel	1	2000	80
Power cable (#00 AWG)	1	4000	160
Miscellaneous electronic equipment	500 ft	2000	80
Shelter supplies		5000	1200
Miscellaneous equipment		4760	590
Estimated totals		43000	3940

APPENDIX C. COST SUMMARY.

1.	Material and supplies	
	Boiler	$ 100,000
	Fuel tank	6,000
	Hose with reel	11,000
	Pumps	12,000
	Control panel	4,000
	Pump components	5,000
	Support winch	16,000
	Electrical supplies	12,000
	Flow control panel	4,000
	Shelter	14,000
	Insulated pipe	15,000
	Miscellaneous	21,000
	Total	$ 220,000
2.	Engineering and fabrication	40,000
3.	Field work (labor, per diem travel)	60,000
	Estimated total	$ 320,000

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