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Technical Report 1737-TR

DEVELOPMENT OF GLACIER SUBSURFACE WATER SUPPLY AND SEWAGE SYSTEMS

Projects 14 and 15
U. S. Army Corps of Engineers

8 February 1963

U. S. Army Engineer Research And Development Laboratories

FORT BELVOIR, VIRGINIA

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U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
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PREFACE

and

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The period covered by this report is April 1958 to September 1961.

The following personnel were responsible for the work covered by this report: Raul Rodriguez, Project Engineer; Richard J. Gainey, Chief, Water Supply Section; Richard P. Schmitt, present Chief, and Harry N. Lowe, Jr., previous Chief, Sanitary Sciences Branch; and Neil K. Dickinson, Chief, Military Department.

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SUMMARY

This report summarizes the data obtained by the Sanitary Sciences Branch, USAERDL, on the development studies of glacier subsurface water supply and sewage systems.

The report concludes that:

a. Drinking water can be obtained from glacier subsurface sources more economically and efficiently than from surface snow melting, and the water produced is normally not contaminated and is acceptable without further treatment.

b. Glacier subsurface wells can be used as heat sinks for the dissipation of waste heat of nuclear reactors.

c. Subsurface cavities which are no longer used for obtaining water can be used for the storage of supplies and fuels and for the disposal of waste products including low-activity waste water from nuclear reactors.

d. The equipment installation and operating procedures contained in Appendix B of this report are a simplified design for future glacial water supply systems using subsurface wells.

e. The discharge of sewage into the subsurface of the glacier is an economical and reliable method for the disposal of liquid wastes.

DEVELOPMENT OF GLACIER SUBSURFACE WATER SUPPLY AND SEWAGE SYSTEMS

I. INTRODUCTION

1. Subject. This report summarizes the research and development studies conducted in Greenland during the summers of 1958, 1959, and 1960 relative to development of a subsurface water source for glacial camps. The summary includes evaluation of the design of the present Camp Century water supply and sewage systems and an improvement of both systems for future glacial camps.

2. Background. The only source of water in glacial camps is the melt obtained from snow or ice. Most of the water produced in small camps has been obtained by melting surface snow that has been manually or mechanically loaded into oil-fired snow melters. The production of water by these methods is inefficient, requires considerable manpower and machinery, and is practically impossible to maintain in operation under adverse winter weather conditions. Also, within the proximity of any glacial camp the surface snow becomes contaminated. Human wastes, carbon, and oil and fuels from machinery are all present. When they are contained in the melted snow, they impair the taste of the water and its bacterial quality. To remove the contaminants, water purification and treatment are required.

When Camp Century, Greenland, was in the planning stage a water requirement of 10,000 gpd was established for the camp. To produce this quantity of melt by former surface snow-melting techniques would have meant the problem of handling approximately 4,000 cu ft of snow per day in addition to all the other problems associated with surface snow melting. A new method that would alleviate or eliminate all the undesirable features connected with snow melting was needed. A concept for a new system was evolved from research studies conducted by the U. S. Army Snow, Ice and Permafrost Research Establishment (now U. S. Army Cold Regions Research and Engineering Laboratories) on the physical properties of the snow of the Greenland Ice Cap. The proposal was made to melt with steam, inside a covered trench, a shaft to the impermeable ice in the subsurface of the glacier, to continue melting the subsurface ice with steam until a reservoir was formed, and then to pump the water to the surface when needed. This technique had distinct advantages over surface snow melting: It would operate in a constant environment not affected by the changing climatic conditions of the surface; it would obtain melt that was protected from contamination by man; and it would eliminate the handling of large volumes of low-density snow in order to obtain equal quantities of water.

This new method was developed and tested on the Greenland Ice Cap during the summers of 1958, 1959, and 1960. A modified permanent system is at present supplying Camp Century with 10,000 gal of water per day.

II. INVESTIGATION

3. Field Studies - Summer 1958. The first studies to determine the feasibility and to establish the criteria for methods and equipment for a glacial subsurface water system were conducted at Camp Fistclench, Greenland, from 18 July to 15 August 1958. Camp Fistclench, located on the ice cap 218 miles east of Camp Tuto, was the base camp of the U. S. Army Polar Research and Development Center (USAPRDC). At the camp, all liquid wastes from the mess hall and latrine were discharged into a single surface hole. These wastes melted a subsurface cavity of undetermined size and shape and infiltrated laterally into the surrounding snow to an unknown distance. For sanitary reasons, the new water system was located 1,200 ft from the sewage discharge.

At this site a trench 80 ft long, 11 ft wide, and 9 ft deep was excavated with a Peter snow miller. The trench was covered with hangar roofing material and a Fiberglas insulating blanket. The equipment required for the water system installed in the trench consisted of the following: Wooden A-frame for support of the melting-pumping bit assembly, 2,000-lb-capacity gasoline-engine-driven winch equipped with 500 ft of 3/8-in.-diameter wire rope for mechanically lowering and raising the bit assembly, melting-pumping bit assembly (Fig. 1) weighing 180 lb, 63 in. in length, and $9\frac{1}{2}$ in. in diameter, with a chamber for distribution of the steam through four 3/4-in. pipes to the nozzles and a $1\frac{1}{2}$-hp, 220-v, 3-phase electric-motor-driven submersible pump capable of delivering 510 gph at 400-ft total dynamic head (TDH). The submersible pump was modified to permit shallow pumping to a depth of 6 in. and was equipped with two electrodes wired so as to permit manual starting and automatic shutoff of the pump, depending on the water level in the melt hole. The melting-pumping bit assembly was for melting a shaft into the glacier ice, subsequent melting of this ice, and pumping the melt to the surface. A 500-lb/hr (500,000 Btu/hr)-capacity oil-fired steam generator was provided as the heat source for melting snow and ice. A snow melter consisting of a 55-gal cylindrical tank equipped with a 35,000-Btu/hr standard Army Quartermaster gasoline-fired immersion heater was installed to provide initial makeup water for the steam

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Fig. 1. Melting-pumping bit assembly.

generator. The melt produced was stored in a 500-gal water tank equipped with a 100-gpm gasoline-engine-driven centrifugal pump for water distribution. Two generators, a 5-kw gasoline-engine-driven unit for providing electric lights in the trench and a 7.5-kw gasoline-engine-driven generator for providing electricity for all other components, were used.

At the intended location of the well a 24-in.-square 6-ft-deep hole was dug in the snow and encased with wood. The melting-pumping bit assembly was placed in the hole and suspended by the free end of the wire rope that was threaded through a pulley supported from the A-frame. Steam hoses to conduct steam from the steam generator to the bit assembly and water from the well to the surface, and the electric power cables were connected and supported from the wire rope by clamps spaced every 10 ft. Sufficient makeup water for the steam generator was produced, the steam generator was started, and the steam was directed to the bit. As the melting of the shaft progressed, the bit was gradually lowered by the winch, and additional hoses and electric cables were connected when required. To determine if the bit was descending freely, the tension on the cable was manually checked intermittently. No appreciable change was noticed in cable tension when the bit was lowered to an estimated depth of 360 ft. At this depth, steam was injected for a few hours, and the submersible pump was started. It was soon determined that because of the nonconductance of the melt the electrodes controlling the pump would not operate. The pump controls were rewired to bypass the electrodes, and the pump was started. It operated for a reasonable time without any water pumpage. The hoses, cables, and bit were pulled out, and a light was lowered into the shaft. Inspection showed that at a depth of 100 ft an ice lens caused the bit to deviate from its vertical path to a lateral undetermined direction for an unknown distance.

Once more the steam bit was assembled for operation, and its rate of descent was decreased to increase the shaft diameter from 12 to 18 in. When a depth of 230 ft was reached, steam was intermittently injected for several hours, and the pump was operated for a reasonable time without any water pumpage. The hoses and pump assembly were removed, a bucket was lowered into the shaft, and water was found at a depth of 125 ft. The water in the shaft apparently was the result of reboring a shaft that was already glazed with ice formed in the first boring. After the second boring test personnel assumed that the melt which could not permeate into the snow collected in the shaft.

Although the results of this test were inconclusive, they indicated that it was feasible to melt and collect water in a subsurface cavity. On the basis of these experiences it was decided that the following changes in procedures should be made:

a. Operations should be conducted on a 24-hr rather than an 8-hr schedule to reduce the starting time and the time lost in drainage of equipment. Every morning 2½ hr minimum were spent in thawing out equipment and in producing sufficient melt to start the steam generator.

b. The steam generator should be installed in a heated shelter. This would facilitate maintenance and operation of the equipment and reduce freezing hazards.

c. The electrode controls for the submersible pump should be replaced with a control that would operate regardless of the conductivity of the water.

d. The diameter of the shaft should be increased to permit visual observation of the drilling and melting progress and also to facilitate lowering a man into the cavity if required.

e. Two separate bit assemblies should be used, one for drilling the shaft and the other for melting ice and pumping the water produced.

f. A tension gage should be provided to indicate pressure on the drilling bit and to facilitate drilling a straight shaft.

4. Field Studies - Summer 1959. The second field study to determine the feasibility of a glacial subsurface well was conducted at the Camp Century construction camp site from 5 July to 20 August 1959. The construction camp was located ½ mile east (downwind-downslope) from the proposed Camp Century location and 138 miles east of Camp Tuto, Greenland.

Equipment changes were made to correct some of the troublesome features of the equipment used in the previous test and to increase the amount of water produced to 10,000 gpd, the water requirement for the proposed Camp Century system. The equipment changes made were as follows:

a. The former melting-pump bit assembly was replaced with two assemblies, a melting-drill bit (Fig. 2) and a melting-pump bit (Fig. 3).

(1) The melting-drill bit assembly consisted of a 36-in.-diameter, 6-in.-high cylindrical chamber for distribution

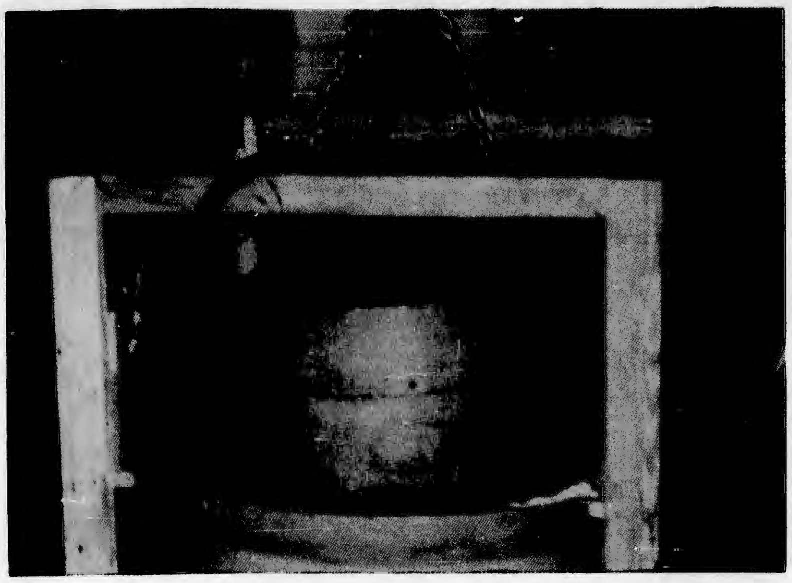

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Fig. 2. Melting-drill bit suspended over well shaft.

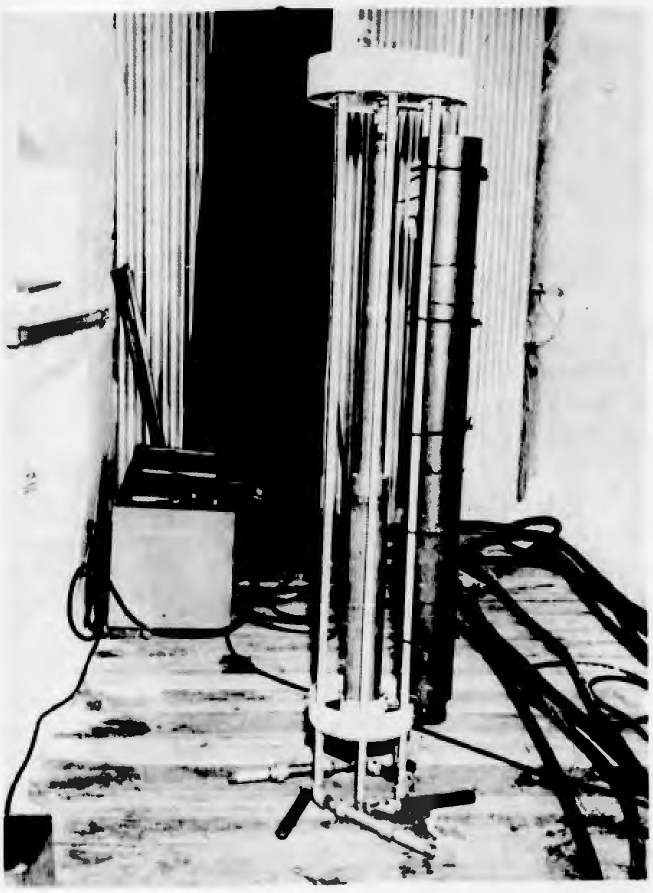

Fig. 3. Melting-pump bit. G2185

of the steam to seven nozzles that extended 1 ft from the bottom of the cylinder. The nozzles were inclosed for protection in a 2-ft-high skirt that was fastened to the chamber. The skirt also facilitated drilling a straight shaft. The new drill bit assembly would melt at least a 36-in.-minimum-diameter shaft.

(2) The melting-pump bit assembly consisted of an 18-in.-diameter, 6-in.-high cylindrical chamber for distribution of steam through six 3/4-in. pipes 82 in. long and each equipped with a horizontal discharge nozzle. On each nozzle a water heater was installed to stimulate recirculation of melt in the well. The chamber also supported an electric-motor-driven submersible pump of 1,700 gph at 200-ft TDH or 1,020 gph at 500-ft TDH capacity. Fastened to the assembly was the pump control consisting of a float riding freely on a rod that would make contact between a high-level and a low-level pair of electrodes. The pump controls permitted manual starting and automatic shutoff of the pump dependent on the water level and independent of water conductivity. The melting-pump bit was used to melt the ice and pump the melt to the surface.

b. The larger steam generator with an output of 800 lb of steam per hour at 165 psi (800,000 Btu/hr) was used as the heat source for melting ice and snow.

c. The wire rope in the winch was replaced with 600 ft of 3/8-in.-diameter nonrotating cable. This cable prevented the coiling of the steam and water hoses around the cable as they were extended.

d. A dynamometer with a deflecting beam of 2,500-lb capacity was fastened to the A-frame for support of the pulley. The dynamometer scale indicated whether the melting-drill bit was resting on the shaft bottom, partially or totally suspended.

The A-frame and winch were installed in a 16-ft-high, 10-ft-wide, 50-ft-long trench cut in the glacier and covered with an arched snow roof. The steam generator was installed in a 12-ft-long Jamesway that was located on the surface 25 ft from the trench end wall. The Jamesway was equipped with a fuel oil space heater for maintaining above-freezing temperatures and quick startup of the steam generator. A 400-gal-capacity snow melter tank also used as a water makeup tank for the steam generator, and the standby 15-kw electric generators were also located in the Jamesway. A 2-in.-aluminum-insulated pipeline was installed to conduct steam from the steam generator to the snow melter tank and into the trench, and electrical power lines were connected to the standby generator and to the camp's 100-kw electric generator.

To start drilling operations about 100 gal of water were produced in a snow-melting tank by melting surface snow with two standard Army gasoline-fired immersion heaters. This amount of water was sufficient to start using the steam generator. Thereafter, melting snow with steam to produce makeup water for the steam generator was repeated intermittently while the shaft was being drilled. The melting-drill bit was suspended from the cable over a 4-ft-square, 6-ft-deep hole that had been previously dug in the snow and encased in wood. The steam hose was connected to the drill bit and steam was directed into the bit, which was gradually lowered until the dynamometer reading indicated that the bit was partly resting on the bottom of the shaft. This procedure was repeated intermittently while the shaft was being drilled. Simultaneously, close attention was given to maintaining a 40-in.-diameter shaft so that the bit could be freely raised and lowered. As the shaft sank deeper, the rate of penetration decreased with the increased density of the snow. Also, ice lenses which were periodically encountered markedly reduced the rate of penetration. Under these conditions, the operators were careful to keep the drill bit practically in free suspension to prevent sideward deviation and the start of a slanting shaft. As the shaft descended, the snow melt produced permeated into the porous snow. After 30 hr of drilling when a depth of 130 ft had been attained, the snow was sufficiently dense for water to start forming a pond. The drilling was continued for another 5 hr to a depth of 139 ft. At this depth, sufficient melt had accumulated in the shaft bottom to warrant replacement of the melting-drill bit with the melting-pump bit. Table I shows the drilling information.

Table I. Drilling Data for Subsurface Water Source

Date	Drilling Time (hr)	Total Drilling Time (hr)	Depth Drilled (ft)	Total Depth from Snow Surface (ft)	Average Rate of Descent (ft/hr)
20 Jul	2.8	2.8	20	36	7.1
21 "	5.1	7.9	45	81	8.8
22 "	1.5	9.4	18	99	12.0
23 "	7.4	16.8	12	111	1.6
24 "	4.5	21.3	15	126	3.3
25 "	4.5	25.8	7	133	1.6
26 "	4.2	30.0	6	139	1.4

The drilling of the shaft was not continuous because of periodic malfunctioning of the steam generator when Fiberglas particles were accidentally introduced into the generator's makeup water. The Fiberglas inactivated the generator controls and required frequent disassembly for cleaning. To melt the shaft, 2,874 gal of water were used by the steam generator. This water was obtained by melting 1,281 cu ft of surface snow. Initially, 100 gal of melt were produced in 2.1 hours with the two Quartermaster heaters.

With the new melting-pump bit, melt was pumped to the surface while steam was simultaneously injected into the well for melting purposes. Surface snow melting was no longer required; makeup water for the steam generator was obtained from subsurface ice melt. As the melting progressed and water was pumped to the surface for consumption or discharge to waste, the water level in the cavity dropped sufficiently to close the low-level circuit in the melting-pump bit float control mechanism and to activate an indicating light on the control panel board at the surface. The melting-pump bit was then lowered until the float closed the high-level circuit light on the panel board, indicating that the bit was submerged. During the melting operation, this procedure was repeated intermittently, and additional hoses and electric cables were added when they were required. The melting-pumping operation was continued for approximately 298 hr to form a hole of a total depth of 171 ft. Table II shows the data collected during this operation.

A total of 138,666 gal of water were intermittently pumped at a rate of about 25 gpm and received at the surface at temperatures varying from 35° F to 49° F. Of the 138,666 gal of water pumped, 30,150 gal were used to produce steam, leaving a net amount of 108,516 gal for drinking and other uses. Of this net amount 12,000 gal were sufficient to satisfy all the requirements of the temporary camp for drinking, cooking, and personnel use; the other 96,453 gal overflowed to waste 200 ft from the subsurface well. It should be noted that near the end of the test period almost 48,000 gal of water were stored in the subsurface pool, thus revealing that the reservoir was good for storage of liquid products. From the results, personnel also calculated that 8,700 gal of water could have been pumped to the surface each 24-hr operating day. Two water samples from the melt hole were bacteriologically examined with a millipore bacterial filter by a Medical Corps Officer. No coliform organisms were found in the samples examined, and the water was considered safe for drinking with addition of chlorine only for protection against subsequent contamination.

Figure 4 shows the location of the Camp Century construction camp sanitary facilities in relation to the water well. The wastes from the showers, laundry, and washtubs were discharged into the snow closer to the water well (about 160 ft) than were other

Table II. Melting Data for Subsurface Water Source

Date	Melting Time (hr)	Total Melting Time (hr)	Total Depth of Hole (ft)	Melt Pumped (gal)	Water Used by Construction Camp (gal)	Water Used to Produce Steam (gal)	Water Pumped to Waste (gal)	Average Temperature of Melt (^{o}F)	Fuel Used (gal)*
27 Jul	3.1	3.1	-	1,868	-	-	1,868	-	21.1
28 "	17.3	20.4	149.0	3,937	1,150	1,784	1,003	49	117.6
29 "	19.0	39.4	152.7	4,893	716	1,603	2,574	48	129.2
30 "	16.5	55.9	153.5	4,607	647	1,502	2,458	47	106.2
31 "	18.7	74.6	156.1	5,784	427	1,643	3,714	46	127.2
1 Aug	12.1	86.7	157.1	3,651	378	1,191	2,081	46	82.3
2 "	5.9	92.6	156.7	2,021	761	754	506	39	34.1
3 "	14.2	106.8	158.2	3,945	582	1,389	1,974	45	96.6
4 "	13.7	120.5	160.8	3,261	555	1,228	1,478	45	93.2
5 "	15.8	136.3	162.3	5,692	456	1,736	3,500	44	107.4
6 "	15.1	151.4	164.7	7,407	518	1,642	5,247	43	102.7
7 "	3.4	154.8	165.7	1,030	634	396	-	40	23.1
8 "	9.8	164.6	166.9	2,641	481	1,111	1,049	42	66.6
9 "	8.9	173.5	166.9	2,948	606	745	1,597	42	60.5
10 "	16.9	190.4	167.4	5,177	349	1,689	3,139	43	114.9
11 "	16.0	206.4	168.7	5,723	798	1,564	3,362	42	102.8
12 "	19.3	225.7	168.8	5,770	669	1,721	3,380	43	131.2
13 "	15.1	240.8	170.3	5,398	682	1,731	2,985	42	102.7
14 "	17.3	258.1	170.5	5,517	390	1,832	3,295	42	117.6
15 "	10.3	268.4	171.3	4,877	512	1,380	2,985	42	70.0
16 "	7.7	276.1	171.9	4,503	662	944	2,897	40	52.4
17 "	22.5	298.6	172.1	26,766	-	2,565**	24,201	41	147.0
18 "	0.0	298.6	171.5	21,250	-		21,250	35	-
	298.6			138,666	11,973	30,150	96,543	-	2,006.4

* Gallons fuel used obtained.

** Estimated.

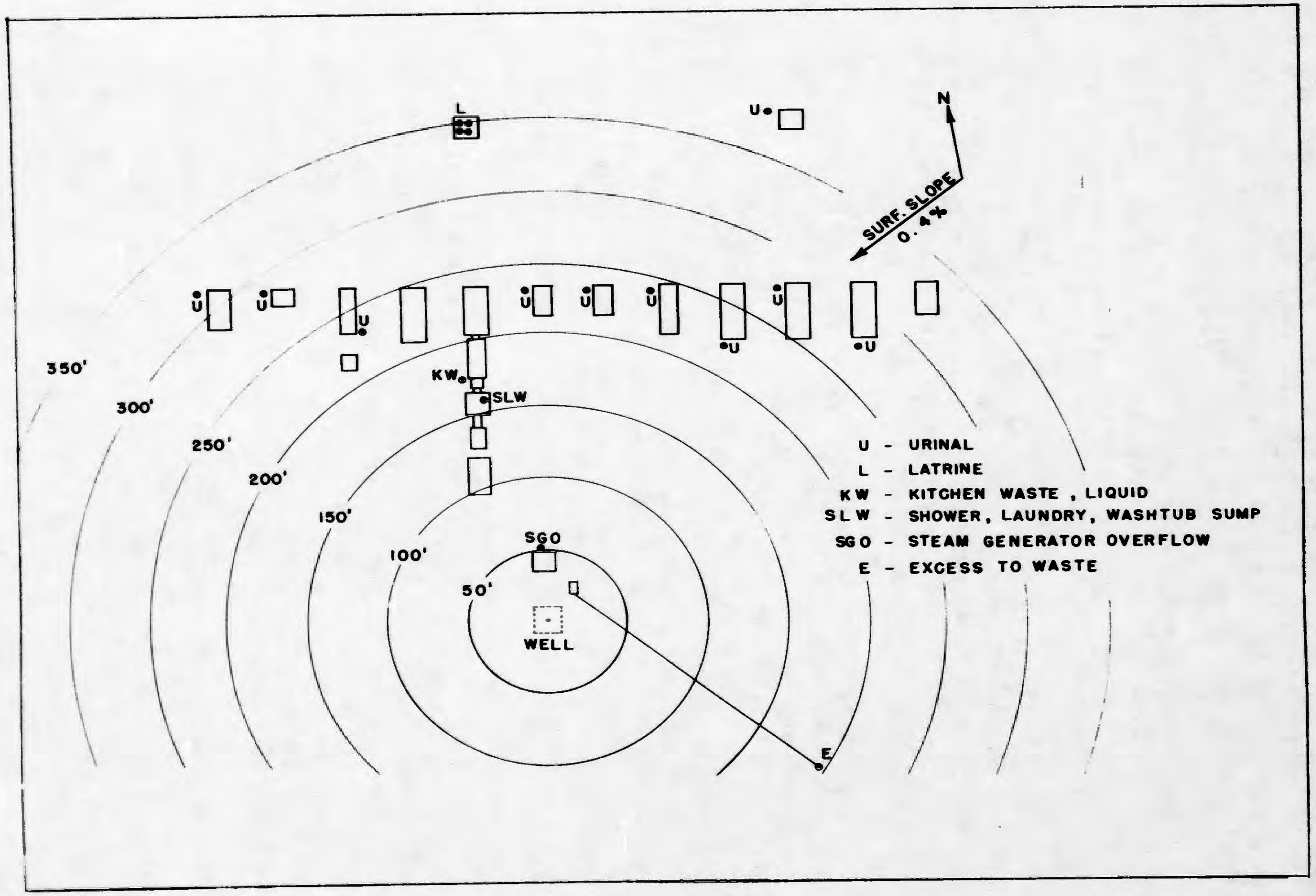

Fig. 4. Location of sanitary facilities at Camp Century temporary camp.

wastes. Because these wastes also constituted the largest amount of liquid wastes they were chemically tagged daily with a fluorescein dye that would reveal seepage of the wastes into the water well. During the test, the presence of fluorescein was checked and never found in the water produced.

In this operation, the amount of steam used for other surface purposes could not be accurately measured. However, the quantity of fuel required to operate the steam generator and the amount of feed water consumed in the production of steam were calculated. To produce 108,516 gal of water 2,006 gal of fuel were used giving a water-to-fuel ratio of 66 lb of water/lb of fuel. The system had a calculated thermal efficiency of 84 percent based on fuel consumed, 65 percent based on steam produced for 23 days of intermittent operation, and delivery of the melt to the surface at an average temperature of 42° F.

Sufficient information obtained during the test period revealed that it was technically feasible to obtain water in quantity from a subsurface source. With an increase in steam production capacity to 1,000,000 Btu/hr of heat, the required 10,000 gal of water could be produced in 14.5 hr each day.

At the conclusion of the 298-hr test period, all equipment was withdrawn from the well so its interior physical characteristics could be examined. A television camera was lowered into the hole to observe the features of the cavity on a screen located at the surface, but the similarity of color or lack of contrast precluded any identifiable pictures on the television screen. The television camera was removed, and a man in a rope harness was lowered into the cavity by the winch. A large symmetrical bell-shaped cavity was found to be approximately 50 ft high with a maximum diameter of 40 ft that gradually tapered into a smaller cylindrical-shaped entrance shaft. The bottom of the cavity was somewhat irregular tapering into a smaller depression where the melting bit had apparently been last located. The bottom and side walls were lined with an impermeable ice coating. The bottom of the cavity had a smooth ice-covered circular floor-like surface. After test personnel broke through the 2-in.-thick ice cover, they found a pool of water 5 ft in diameter and 7 ft in depth. The pool of water was melt which had not been pumped from the cavity, and $6\frac{1}{2}$ days after the introduction of heat was discontinued was still in the liquid state. The heat loss through the liquid ice interface was calculated at a rate of about 18 Btu/sq ft/hr. This is an extremely low heat loss rate compared to water stored in surface reservoirs. The subsurface reservoir was lined with an almost infinite thickness of ice which because of its low thermal conductivity (1.28 Btu/sq ft/hr/°F/in.) served as excellent insulation.

From the measurements obtained, a cross-sectional drawing of the cavity and the vertical shaft was prepared (Fig. 5). The lateral dimensions inside the cavity were difficult to make, but the volume of the cavity calculated from these measurements was not much greater than the volume measured by metering the quantity of water pumped to the surface. Assume an average ice density of 50 lb/cu ft. A total of 18,200 cu ft of ice had been melted. This amount compared favorably with the 21,300 cu ft determined from the measured dimensions indicated in Fig. 5. The difference in these figures substantiates the contention that once the cavity is formed the melt is retained, and little or no liquid is lost to the surrounding glacial deposits.

Another observation made in inspection of the cavity was the features of the vertical entrance shaft (Fig. 6). The shaft was tapered from 3½ ft in diameter at the top to approximately 5 ft in diameter at its exit. The full depth of the shaft was sheathed with an ice casing much like a pipe or rigid casing placed in wells of ground water supplies. This ice lining could provide an important barrier to external contamination or introduction of undesirable liquids from the upper porous snow layers. The shaft was larger near the bottom, and it is probable that the increase was the result of melting caused by the upward movement of warm air as the drilling operation became continuous in the lower cavity. If the shaft becomes larger and forms a new ice casing, the aforementioned ice barrier loses all its utility by melting contamination contained behind the original barrier. A summary of the 1959 test results follows:

Water Pumped from Cavity (gal)	138,666
Water Used for Steam (gal)	30,150
Water for Service, Net (gal)	108,516
Total Melting Time (hr)	298
Water Production Rate (gpd)	8,736
Average Water Temperature at Surface (°F)	42
Calculated Volume of Cavity (cu ft)	21,300
Metered Volume of Cavity (cu ft)	18,200
Fuel Consumed (gal)	2,006
Water-Fuel Ratio	66-1
Melting Efficiency (23 days, 42° F water at surface)	
On Fuel Consumed (%)	83.8
On Steam Produced (%)	64.8

The information obtained in this test of a glacial subsurface water system and the conclusions drawn were based on intermittent operation. The period of steam injection into the melt hole

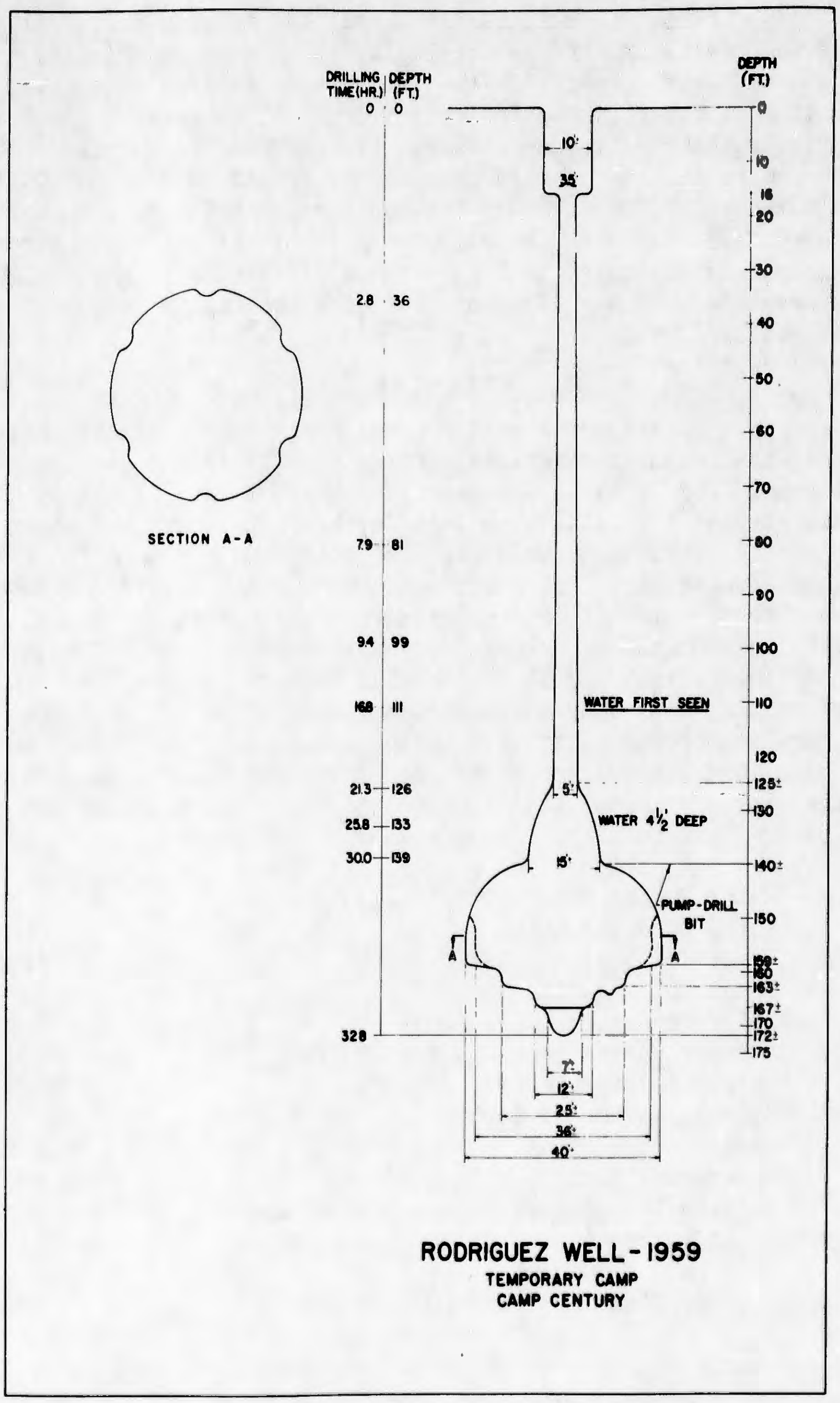

Fig. 5. Cross-sectional drawing of cavity and shaft - summer 1959.

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Fig. 6. Looking into shaft.

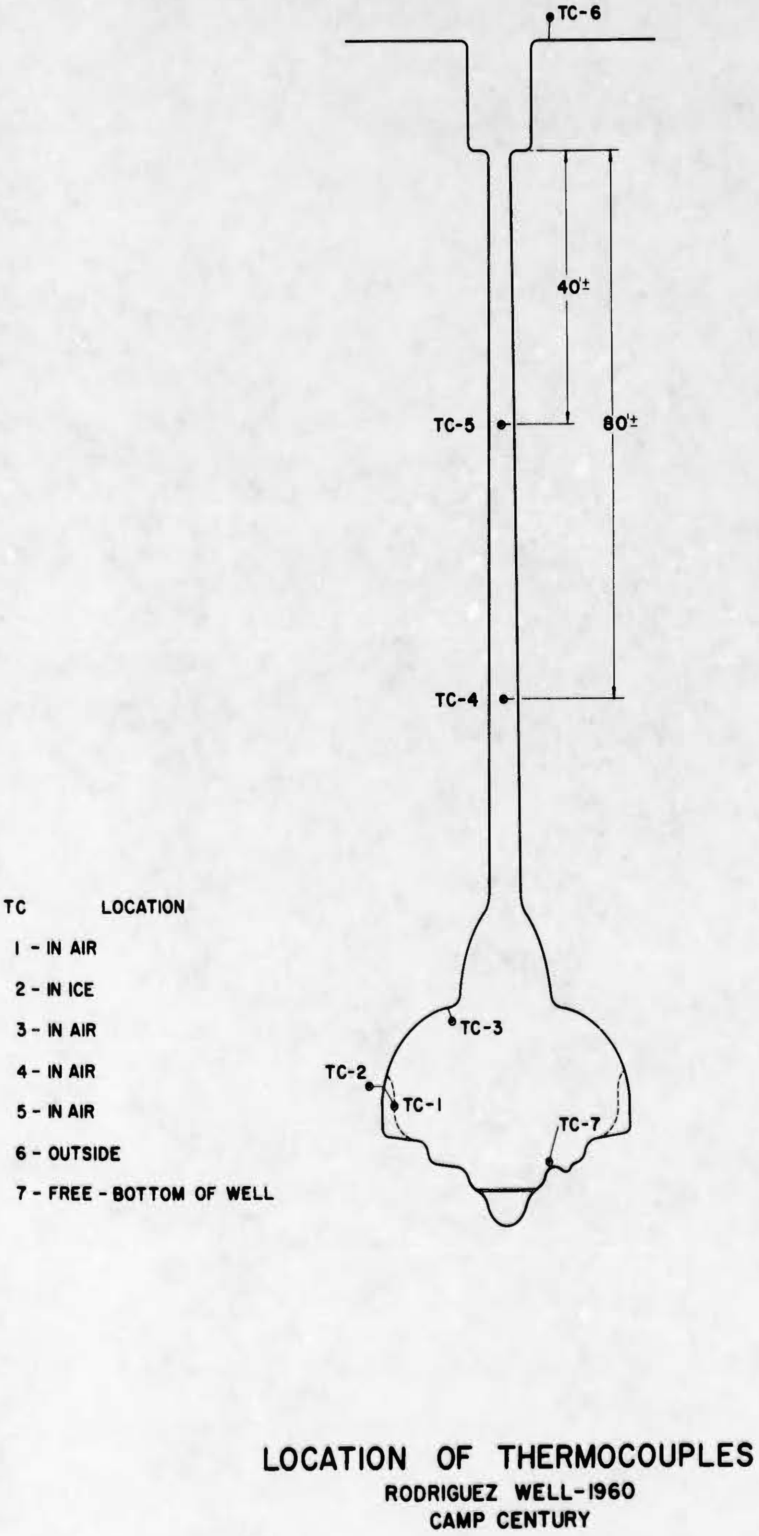

Fig. 7. Location of thermocouples.

varied from day to day. Some operations were almost continuous or about 22 hr long, whereas other operations were no longer than 3 hr with 21 hr of shutdown. The shape of the hole and the thermal efficiencies might be somewhat different if a continuous 24-hr-day schedule were maintained.

5. Field Studies - Summer 1960. The third field study in the development of a glacial subsurface water well was conducted from 15 May to 5 October 1960 at the location used in the previous year. Only one major modification was made to the equipment. The melting-pump bit float controlled high- and low-level electrode assembly was replaced with two diaphragm-operated level control switches.

Before the drilling operation was started, the well was instrumented with thermocouples to measure the temperatures in the cavity shaft and the water. Figure 7 shows the location of the seven thermocouples, and Table III shows the thermocouple readings.

Table III. Thermocouple Readings - Summer 1960

Date		Temperature (°F)						
		Air	Ice	Ice	Ice	Ice	Air	Water
		1	2	3	4	5	6	7
21 May	Maximum (daily average)	14	-1	17	57	24	14	38
to	Minimum (daily average)	6	-6	10	12	16	-2	35
31 May	Average (monthly)	9	-3	13	19	20	5	37
1 Jun	Maximum (daily average)	17	7	27	73	36	28	38
to	Minimum (daily average)	11	0	17	21	24	10	32
30 Jun	Average (monthly)	15	4	22	38	32	19	33
1 Jul	Maximum (daily average)	25	17	34	79	41	31	43
to	Minimum (daily average)	17	8	29	52	33	20	34
31 Jul	Average (monthly)	23	15	32	68	40	26	40
1 Aug	Maximum (daily average)	24	22	39	45	45	35	45
to	Minimum (daily average)	19	10	29	35	37	7	32
31 Aug	Average (monthly)	22	15	33	39	40	23	36
1 Sep	Maximum (daily average)	22	18	34	52	40	26	42
to	Minimum (daily average)	18	10	28	32	32	-14	32
30 Sep	Average (monthly)	20	13	31	39	38	8	32

To start the melting operation, the procedure used the year before was followed. Sufficient steam generator makeup water was obtained from surface snow melt, the steam generator was started, and the steam was directed to the melting-drill bit that was already installed and located in the bottom of the cavity. Melting of snow to produce steam and steam injection into the cavity was continued intermittently for 16 hr. After this period, the drill bit was replaced with the melting-pump bit. The melting of ice and pumping of water to the surface was continued for 144 days for a total of 2,448 hr. The steam generator was operated for an additional 273 hr for purposes other than melting ice. During the total 2,721 hr of operation, the steam generator consumed 21,634 gal of fuel oil. Of this amount, a net of 19,647 gal were used to produce water.

During the test period, a total of 877,307 gal of water were pumped from the well and received at the surface at temperatures ranging from 32° F to 45° F. Of the 877,307 gal pumped, 252,695 gal of water were converted into steam at 150 psi, 228,531 gal were consumed by the construction camp personnel, and 291,081 gal were pumped to waste. A summary of the results follows:

Water Pumped from Cavity (gal)	877,307
Water Used for Steam (gal)	252,695
Water for Service, Net (gal)	624,612
Total Melting Time (hr)	2,448
Calculated Water Production Rate (gpd)	9,285
Average Water Temperature at Surface (°F)	36
Calculated Volume of Cavity (cu ft)	109,533
Metered Volume of Cavity (cu ft)	104,380
Fuel Consumed (gal)	19,647
Calculated Water-Fuel Ratio	59-1
Melting Efficiency (144 days, 36° F water at surface)	
On Fuel Consumed (%)	60
On Steam Produced (%)	60

Table IV presents operational data of a subsurface water well.

During the test, several water samples were collected in plastic bottles and shipped to the Sanitary Sciences Branch for analysis. The samples were analyzed for resistance with a conductivity meter and for concentration of electrolytes with a flame spectrophotometer. Table V presents the results of the analysis. Table VI shows the specific conductance in micromhos of distilled and deionized water. It should be noted that the ice melt was better in quality than water obtained by triple distillation in glass.

Table IV. Operational Data of Subsurface Water Well - 15 May to 5 October 1960

Date	Hours of Operation		Fuel (gal)	Water Pumped from Well			
	Steam to Well (hr-min)	Steam Bypass (hr-min)		Makeup Steam Generator (gal)	Water to Camp (gal)	Water to Waste (gal)	Total (gal)
15 May to 31 May	251-22	28-36	1,911	19,904	15,189	-	35,093
1 Jun to 30 Jun	524-33	41-25	4,554	49,408	47,195	51,058	147,661
1 Jul to 31 Jul	542-45	44-16	5,165	61,332	55,081	202,922	319,335
1 Aug to 31 Aug	517-53	74-8	5,000	59,628	55,084	61,144	175,856
1 Sep to 30 Sep	520-30	74-30	4,453	55,525	49,403	56,389	161,317
1 Oct to 5 Oct	90-15	9-45	551	6,898	6,579	24,568	38,045
Totals	2447-18	272-40	21,634	232,695	228,531	396,081	877,307

Water samples were also analyzed on site for pH, dissolved CO_2 and O_2. The samples were collected and analyzed according to the Standard methods for the Analysis of Water, AWWA, Tenth Edition, 1955. Table VII shows the results of these analyses, which indicate that the well water was not saturated with dissolved oxygen. The pH of the samples analyzed at Camp Century was lower than those analyzed in the USA, because of loss of CO_2 in the samples that were shipped.

The test was concluded on 5 October 1960. The cavity was inspected on 9 August 1961, and an interior survey of the cavity was

Table V. Well Water Analysis Performed at Fort Belvoir, Virginia - 1960

Sample	Date Taken	Depth of Well (ft-in.)	Temperature of Water in Well (°F)	pH	Resistance (ohm)	Specific Conductance at 25° C (micromho/cm)	Concentration (mg/ l) Na	K	Ca	CL	SO_4	NO_3
1	21 May	174-10	42	6.1	600,000	0.17	0.02	0.04	0.1	-	-	0.02
2	28 "	176-4	41	6.1	590,000	0.17	0.02	0.02	0.1	0.10	-	-
3	11 Jun	183-0	35	6.1	680,000	0.15	0.01	0.02	0.1	-	<0.1	-
4	18 "	185-0	34	6.1	720,000	0.14	0.02	0.02	0.1	-	-	0.04
5	25 "	185-11	32	6.1	680,000	0.15	0.02	0.04	0.1	0.02	-	0.03
6	2 Jul	191-6	46	6.0	700,000	0.14	0.01	0.03	0.1	-	<0.1	0.02
7	9 "	194-6	40	5.8	750,000	0.13	0.01	-	-	0.03	-	0.03
8	16 "	197-5	39	5.8	700,000	0.14	0.02	-	-	0.03	-	0.03
9	23 "	199-8	34	5.8	700,000	0.14	0.02	-	-	0.03	<0.1	0.00
10	30 "	203-6	39	5.8	720,000	0.14	0.01	-	-	-	-	0.00
11	6 Aug	207-0	40	5.9	850,000	0.12	0.02	-	-	0.04	-	0.00
12	13 "	208-8	39	6.0	800,000	0.12	-	-	-	-	<0.1	0.00
Average			38	6.0	708,000	0.14	0.02	0.03	0.1	0.04	<0.1	0.03

Table VI. Conductivity of Water Obtained from Various Sources

Type of Water	Quality (micromho)
Theoretical Maximum Quality	0.038
Water Distilled 28 Times in Quartz	0.043
Water Deionized with Amberlite Ion Exchange Resins	0.056
Water Triple Distilled in Glass	1.0
Water Single Distilled in Glass	2.0
U.S.P. Grade Distilled Water	2.0 to 5.0

Table VII. Well Water Analysis Performed at Camp Century, Greenland - 1960

Date	CO_2 (mg/l)	D. O. (mg/l)	pH	Temperature (^oF)
7 August	2.0	6.2	5.2	48
9 "	1.0	6.8	5.1	48
21 "	0.5	6.2	5.0	36
Average	1.2	6.4	5.1	44

made to establish a central bench mark and a system of points. Inspection showed another large symmetrical bell-shaped cavity approximately 47 ft high with a maximum diameter of 66 ft (Fig. 8). The floor was round and was practically level for about 9 ft from the wall. The center of the floor was cone shaped with an elevated height of about 2 ft 5 in. The floor showed cracks created by the ice pressure when the large circular pond of water left in the well froze. The walls were ridged horizontally at regular intervals, and at the top of the cavity five black rings could clearly be seen. From the measurements obtained, a cross-sectional diagram was prepared (Fig. 9). The cavity was accurately surveyed to a height of about 15 ft from the floor. From the drawing, a calculated volume of 109,533 cu ft was obtained.

Assume an average ice density of 50 lb/cu ft. A net amount of 655,440 gal of water was pumped from the well. This figure compares with the 624,612 gal actually pumped from the well. To determine the overall thermal efficiency of the system test personnel assumed that the shape of the cavity left under water was a

J7354

Fig. 8. Surveying cavity.

cylinder 7 ft high and 65 ft 8 in. in diameter with the bottom of the cavity as a spherical segment and a height of 10 ft 10 in. The volume of the cylinder and the spherical segment was calculated at 322,478 gal of water. The amount added to the net amount pumped from the well made a total of 947,090 gal of water produced. The system had a calculated thermal efficiency based on fuel consumed of 60 percent and on steam produced 60 percent.

After the survey of the cavity was completed, core samples were collected from the floor and wall by Chester C. Langway, Jr., U. S. Army Cold Regions Research and Engineering Laboratories, Hanover, New Hampshire. Thin sections of the samples were photographed with transmitted and crossed polaroid light to study ice crystal structure (Figs. 10 through 13). Also, density measurements were made for 16 increments of 2.81 m of horizontal core taken approximately 1 m above the cavity ice floor. To obtain the density measurements, the hydrostatic method was used with 2,2,4 trimethylpentane as the immersion fluid. Density values were corrected to -25° C., the near annual temperature of Camp Century. Table VIII gives the results of the density measurements.

From the thin section analysis Langway concluded that there does not appear to be any physical alteration to the ice structure beyond the shallow skin ice layer of 0.5- to 3.0-cm thickness

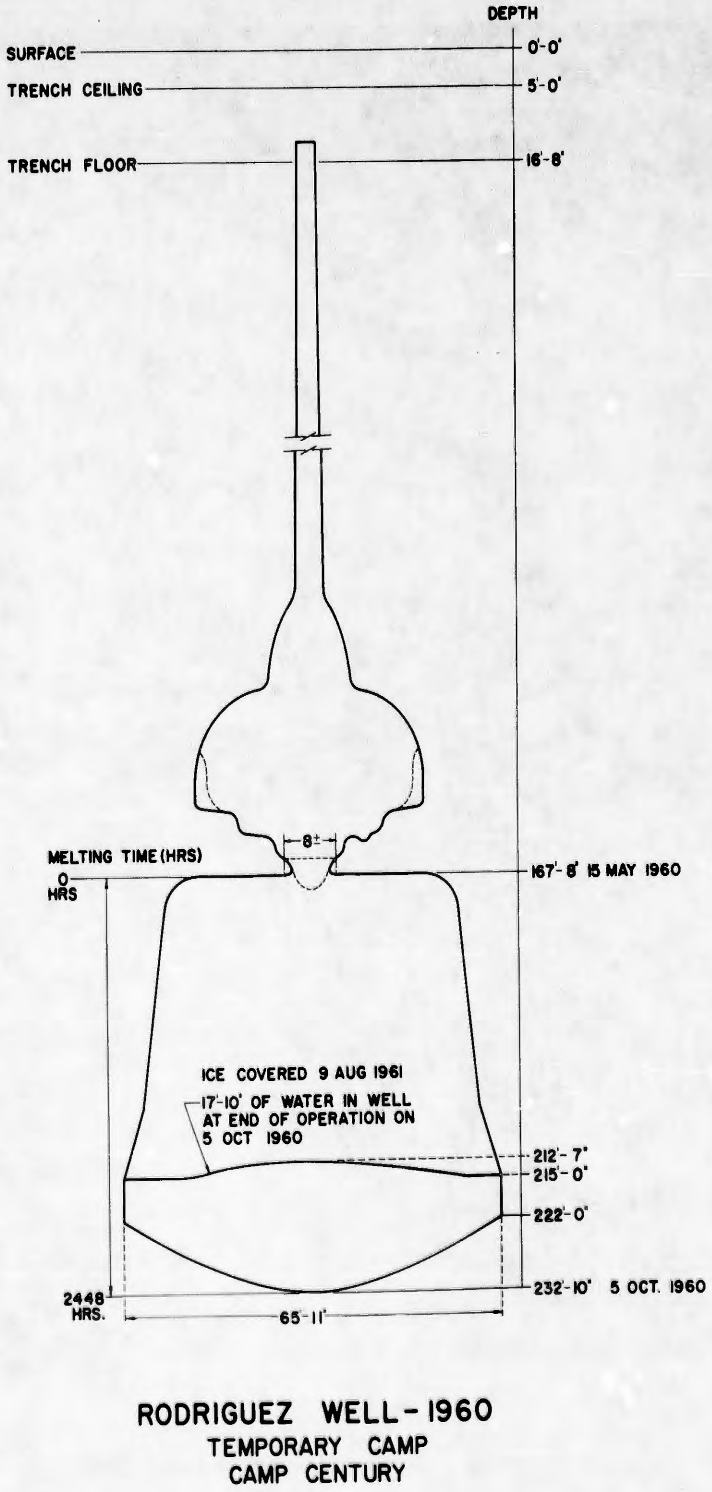

Fig. 9. Cross-sectional drawing of cavity and shaft - Summer 1960.

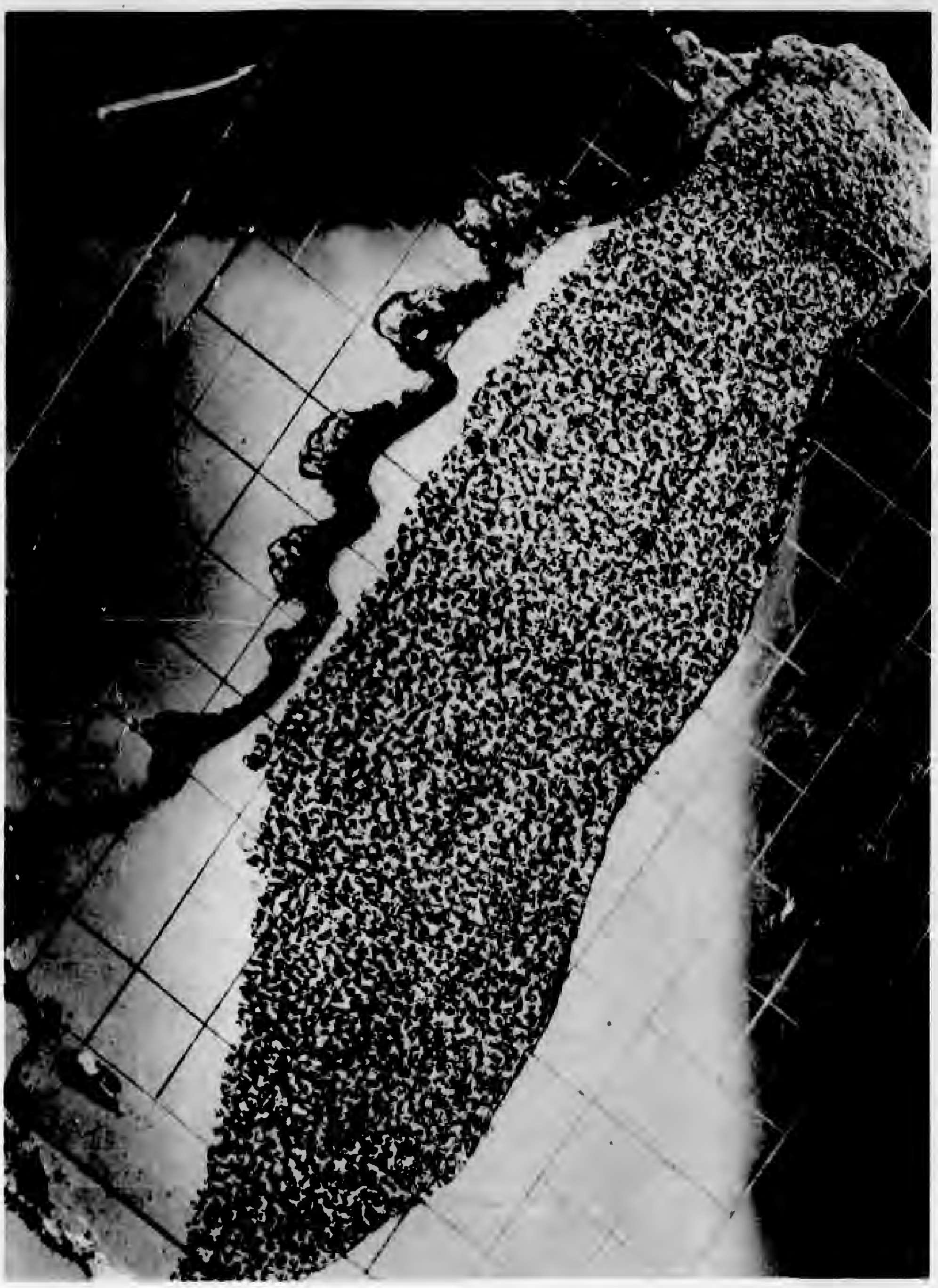

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Fig. 10. Thick ice section examined under transmitted illumination (linear scale - centimeter grid).

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Fig. 11. Thick ice section examined under crossed polaroid illumination (linear scale - centimeter grid).

J5377

Fig. 12. Thin ice section examined under transmitted illumination (linear scale - centimeter grid).

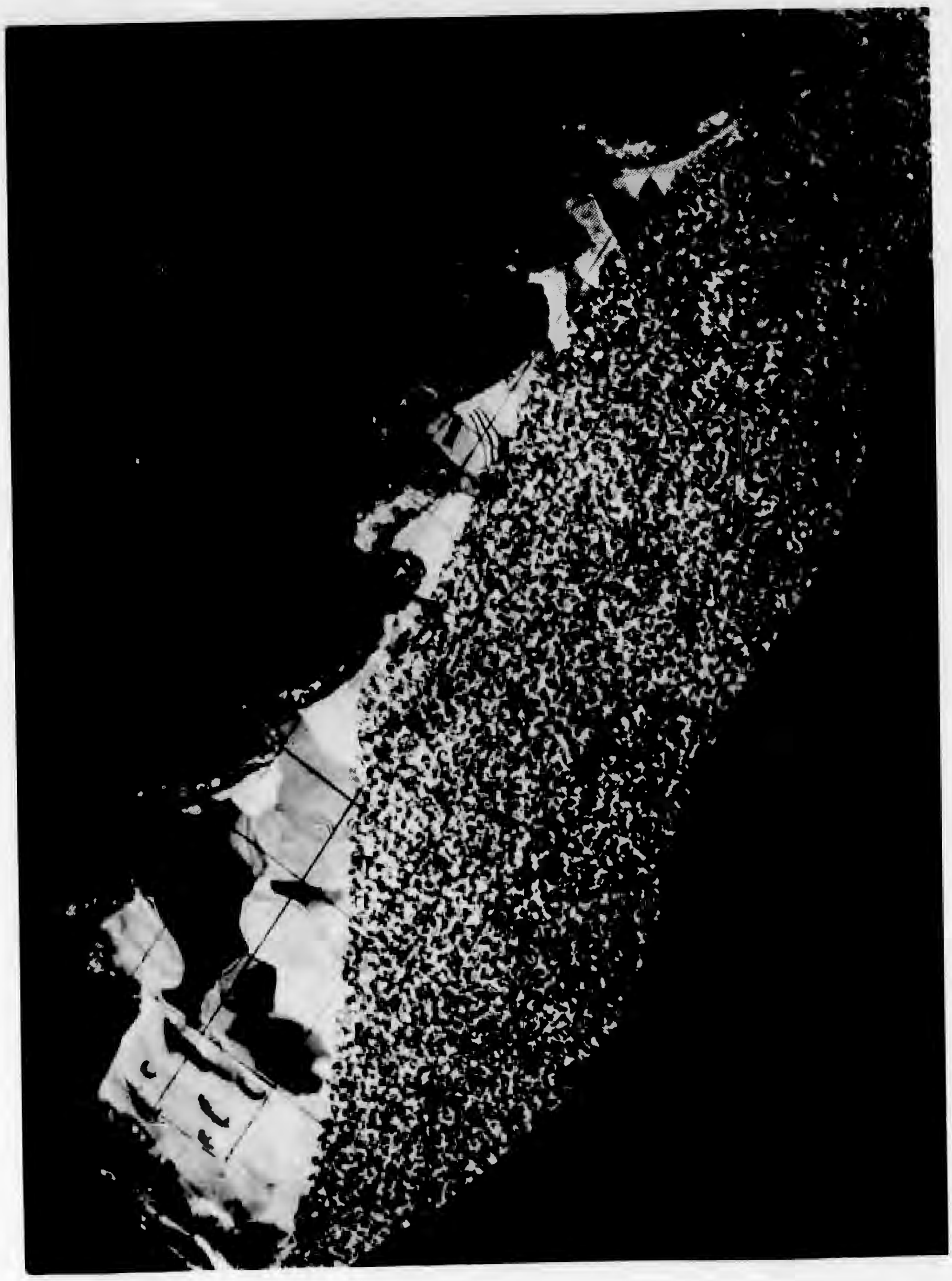

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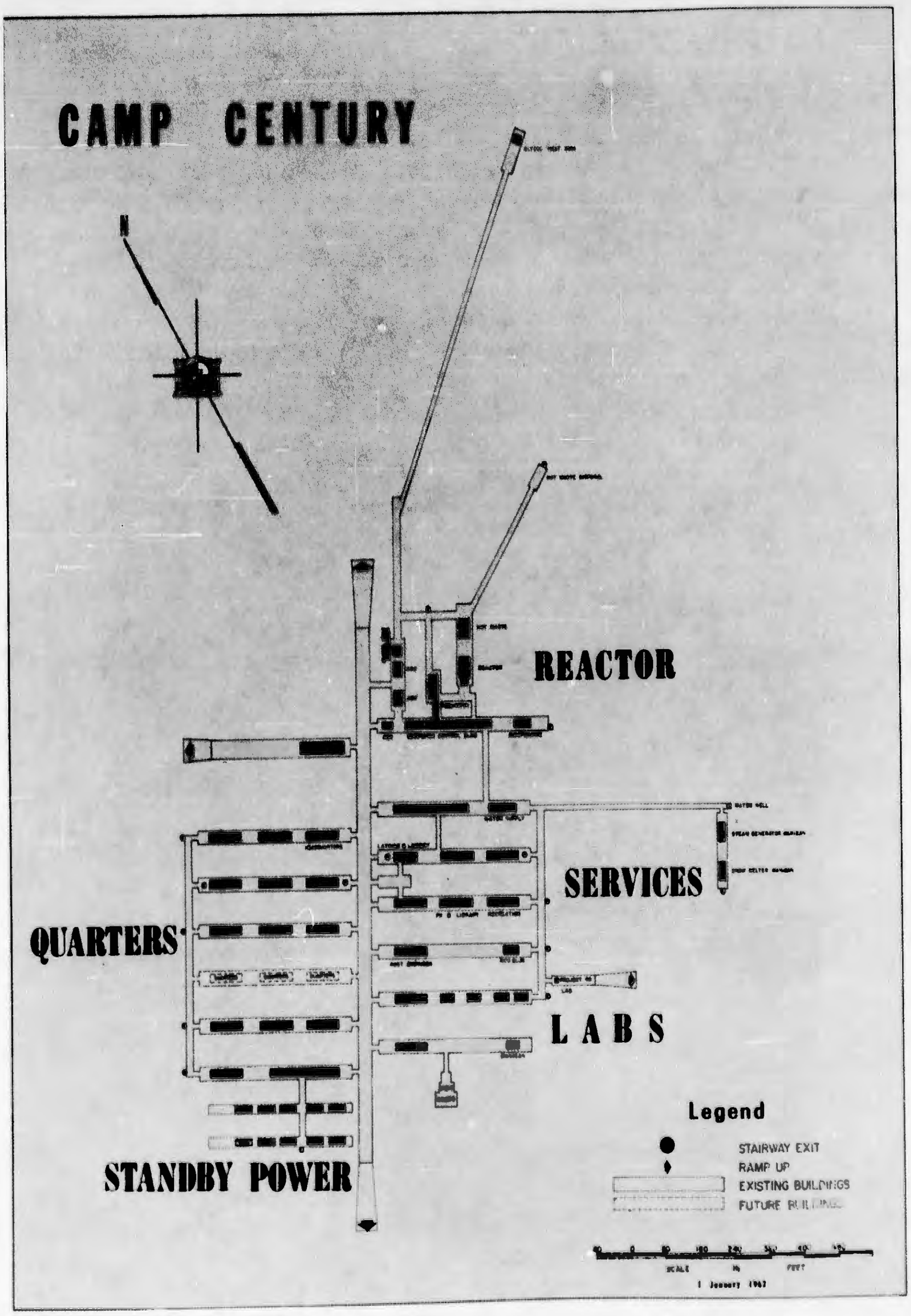
Fig. 13. Thin ice section examined under crossed polaroid illumination (linear scale - centimeter grid).

Table VIII. Ice Density Measurements Made at Camp Century - 1961

Piece No. Sample: 1	Horizontal Distance from Face Wall to End of Core Piece (cm)	Density (Temperature Corrected to -25.0° C) (g/cm^3)
1	11	None
2	29	0.8204
3	46	0.8221
4	65	0.8226
5	83	0.8283
6	101	0.8369
7	120	0.8384
8	138	0.8434
9	155	0.8402
10	174	0.8370
11	191	0.8376
12	208	0.8390
13	226	0.8429
14	244	0.8456
15	262	0.8471
16	281	0.8467

that encases the cavity which is a direct result of ice melting. Also, the reflection of the lowering of the melting-pump bit can be seen as serrated projections on the surface of the wall. From the density data, it was concluded that there is a trend of increasing density into the cavity wall. (A tentative explanation is that the stress release attendant to the production of the cavity affects the structure closer to the wall to a greater extent.)

An interesting phenomenon happened while a core sample was being taken about 6 ft from the center of the cavity floor. Drilling through $5\frac{1}{2}$ ft of ice caused water under pressure to push the core drill out. The depth of the water was measured at 9 ft and the temperature, at 28.4° F. This water was the remainder of the 17 ft 10 in. of water left in the well at the close of operations on 5 October 1960 and still in its liquid state after 11 months of storage.



J3010

Fig. 14. General plan of Camp Century.

6. Camp Century Water Supply System. The 10,000-gpd water requirement of Camp Century is obtained from a subsurface water well. The well is located 430 ft from the water supply building (Fig. 14) and at the end of the mess kitchen trench (Fig. 15). This well was developed using the same methods and similar equipment as those employed at the temporary camp. One significant equipment modification was the replacement of the hoses leading from the surface into the well with two strings of $1\frac{1}{4}$-in. aluminum pipe. The pipelines were supported from the wire rope in a manner similar to the hoses. The steam line was insulated with 1-in. thickness of insulation to reduce heat losses and prevent excessive enlargement of the shaft. The replacement of the hoses with pipe was mainly to eliminate an objectionable rubber taste imparted to the water.

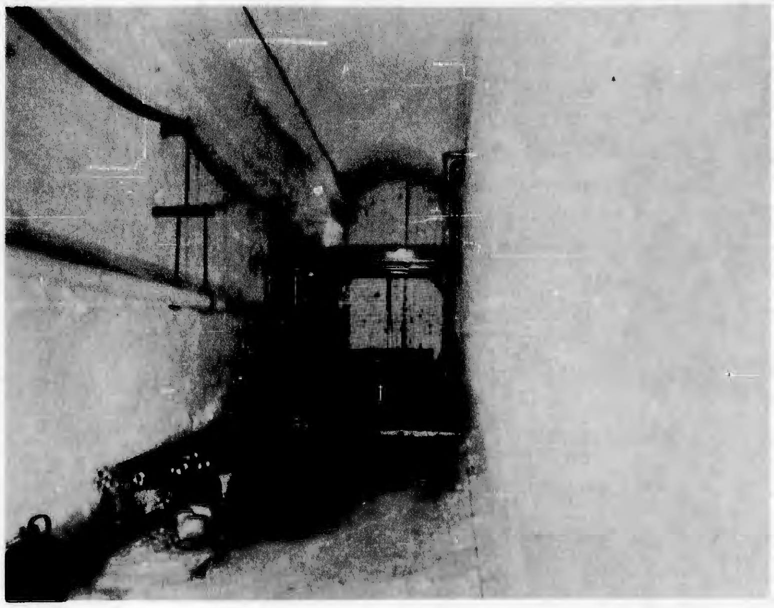


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Fig. 15. Camp Century water well trench.

Steam for melting subsurface ice in the well is obtained from two sources. When the nuclear plant is in operation, steam is obtained from the secondary loop of the reactor. The steam is transmitted to the well through 700 ft of 2-in. pipe. The pipeline is covered with 2 in. of insulation to reduce heat losses by conduction. A flexible steam hose is provided to connect with the pipe string into the well.

The other source of steam is located at the well site. A 1,000,000-Btu/hr diesel-fired steam generator installed in a wanigan is located in a special trench adjacent to the well. A 15-kw diesel-engine-driven electric generator is also installed in the same wanigan. This generator is of sufficient capacity to power all the electrical components located at the well site in the event of camp power failure.

An alternate method to produce water is also provided at the well site. A snow melter installed in a wanigan is located adjacent to the steam generator. The snow melter is essentially a rectangular aluminum tank with a snow capacity of 1,670 cu ft. The melter can produce 5,000 gal of water from each loading; thus, two loadings per day are required to satisfy the camp's requirements. The tank is equipped with steam jets for melting snow and can be loaded through hatches that cover the entire top of the tank. Steam from the nuclear plant or the steam generator can be used for melting snow.

The snow melter and the steam generator were installed in wanigans to make them transportable and to facilitate relocation if required. When the Camp Century water supply system was designed, the studies in the development of a subsurface water source were not completed, and it was not conclusively known whether water could be satisfactorily obtained from a subsurface source, nor was the production period for a single well established. If water had to be produced from surface snow the equipment could be moved to the surface and operated as a surface melting water point. However, as the subsurface source proved adequate to satisfy the Camp Century water requirements, the wanigan-mounted snow melter was used only for additional water storage.

Water from the well is pumped into the snow melter for temporary storage. The stored water is maintained at 40° F by automatic steam injection. From the melter it is pumped to the water supply building through a 430-ft-long, 2-in. pipeline. The pipeline is covered with $1\frac{1}{2}$-in. thickness of insulation. It is also electrically heated with thermostatically controlled mineral-insulated cable. The thermostats are adjusted to maintain a temperature of 40° F.

The water treatment, storage, and pumping equipment is housed in the water supply building. The building is a 52-ft-long, 16-ft-wide, and 12-ft-high T-5-type building located next to the mess kitchen. The building contains two separate storage and pumping systems. One provides untreated water to the nuclear plant. The other provides treated water for camp consumption and fire fighting.

Water for the nuclear plant is stored untreated in a bolted storage tank of 4,200-gal-capacity. From the tank the water is pumped to the nuclear plant by a Moyno-type pump of 15 gpm at 250-psi TDH. A similar pump is provided as a standby. The water to the reactor is continuously recirculated through a 400-ft-long, $1\frac{1}{4}$-in. pipeline loop. The pipeline is covered with $1\frac{1}{2}$-in. thickness of insulation and is also electrically heated with thermostatically controlled mineral-insulated cable. On the return end of the pipe loop a back pressure valve adjustable from 100 to 200 psi controls the pressure in the waterline. The water pressure delivered to the nuclear plant heat exchanger determines the pressure of the steam supplied to the water well.

The water supplied to the nuclear plant is untreated, as the addition of any chemicals, especially calcium hypochlorite, would be detrimental to nuclear power equipment. The water supplied to the nuclear plant is used for the production of steam for melting subsurface ice, for the sanitary facilities and for reactor makeup supply.

Water to Camp Century other than the Nuclear Power Plant, for the latrines, mess hall, dispensary, and laboratory is stored in two bolted storage tanks of 4,200-gal-capacity. Before the water is discharged into the tanks, it is treated with calcium hypochlorite (1-mg/l residual) to prevent subsequent contamination and 2-mg/l sodium hexa-meta phosphate (Calgon) for corrosion control purposes. Also, the water can be filtered through a pressure sand filter, if required. The filter was installed in the system in the event that the Camp Century water might be obtained from surface snow melt. To pump the water through the distribution system each tank is equipped with a 50 gpm at 100 psi TDH-capacity centrifugal pump. The pumps are alternated daily, but if required for fire fighting, they can be operated simultaneously in parallel. If the tanks are full, a fire-fighting water flow of 100 gpm can be maintained for 84 min. In the distribution system, the water is continuously recirculated through a 2,300-ft-long, 2-in. pipe loop. The pipeline is covered with a $1\frac{1}{2}$-in. thickness of insulation and is also electrically heated with thermostatically controlled mineral-insulated heating cable. The serviced buildings are all in the return side of the pipe loop. This way, high-water velocities are maintained in the longest section of the pipeline. This condition helps to prevent freezing in the line and also insures adequate flow of water for fire fighting. Entrance into the serviced buildings is made with 4-ft-long sections of hose to prevent damage that could be caused by differential settlement.

Some of the pipelines at Camp Century are supported from buildings and the cross arms of the power system. The bulk of the distribution system is supported from channel iron driven into the snow walls, and the pipelines are suspended from the channel iron by threaded rods that terminate in circular pipe hangers to permit adjustment. All pipe hangers are spaced 10 ft apart.

To prevent the water from freezing in the distribution pipelines, four methods are used:

a. Continuous circulation of water at 4.8-fps rate through the pipe loops.

b. Sufficient insulation thickness is provided on all pipelines to retard freezing for approximately 2 hr even if no water flow or heat input exists.

c. All pipelines are heated with mineral-insulated heating cable thermostatically controlled to maintain temperatures of 40° F.

d. Automatic injection of steam to the water stored in the water supply building where water temperatures are maintained at 40° F.

These four methods to prevent water from freezing in the pipeline proved satisfactory during the 1960 winter. In the main corridor, an 800-ft section of the 2-in. pipe loop was exposed to -60° F ambient for several weeks. No interruptions of water service caused by frozen waterlines took place during that period.

7. Camp Century Waste Disposal System. At Camp Century, a water-borne sewage system is used for the disposal of liquid wastes from the latrines, laundry, mess hall, dispensary, and water supply building. The wastes from all the buildings (except wastes from the water supply building which are pumped) flow by gravity through 4-in. victaulic pipelines to a central collection tank of 1,500-gal capacity. The tank is suspended in a 10-ft cube pit in the floor of a special trench located between the latrines. The tank is insulated and electrically heated with thermostatically controlled strip heaters. The liquid stored in the tank is maintained at a temperature of about 50° F. When the tank is full, the sewage is automatically pumped to a subsurface sewage sump by a 100-gpm at 100-ft-TDH sewage pump. The sewage is pumped to the sump through 500 ft of 4-in. victaulic pipeline.

All the pipelines from the buildings to the collection tank and from the tank to the sewage outfall are covered with 1½ in. of insulation and are also electrically heated with thermostatically controlled mineral-insulated heating cable. The pipelines are sloped 6 in. per 100 ft to improve drainage and prevent the deposition of solids. Some pipelines are supported from wooden posts driven into the trench floors; most of them are supported from the trench walls in a manner similar to the waterlines.

The subsurface sewage sump was formed by the warm sewage discharged from the outfall line. As the sewage poured downwards, it melted a shaft to the more impermeable ice layers, and additional sewage formed into a pond at the bottom of the shaft. The shape of this sewage sump cavity or the extent of lateral infiltration of the sewage into the surrounding snow is not known.

In 1954 at Site II Greenland, observations of the sewage sump were made by Bader and Small.[1] They concluded that the discharged sewage begins by rapidly melting out a vertical pit until solids accumulate to form an impermeable bottom. Melting then spreads sideways, with spillover producing new vertical holes. It appears likely that the repeated processes of vertical and horizontal penetration take place in a conical volume, with the axis inclined in the direction of inclination of the snow layers. Depth of penetration is limited by the permeability of the snow, which at Site II approaches zero at a depth of 200 ft. The apex of the cone lies at a depth of 70 ft. A state of near equilibrium will be reached after many years, when the surface area of the cone becomes large enough to permit escape of all heat input of the sewage, which then freezes. In the meantime, an extremely large volume of snow is honeycombed by cavities, saturated with water, and made more plastic than its surroundings as a result of higher temperature. The increased plasticity of the snow will be counteracted by less plastic masses of ice. It is considered certain that no serious collapsing of cavities will occur, the only possible consequences being increased settlement of the overlying snow surface.

In another study made by the U. S. Army Medical Corps at another camp site, core drillings were made from the surface around the sewage sump area to determine the extent of contamination. Figure 16 shows the probable shape of the contamination as obtained from the core samples. The shape is conical with the apex 38 ft below the pipe outfall and the base between 80 to 120 ft in diameter.

At present, personnel of the Office of the Surgeon General are completing a study to determine the size and shape of the Camp

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[1] H. Bader and F. A. Small, Sewage Disposal at Ice Cap Installations (Greenland: Snow, Ice, and Permafrost Research Establishment, October 1954).

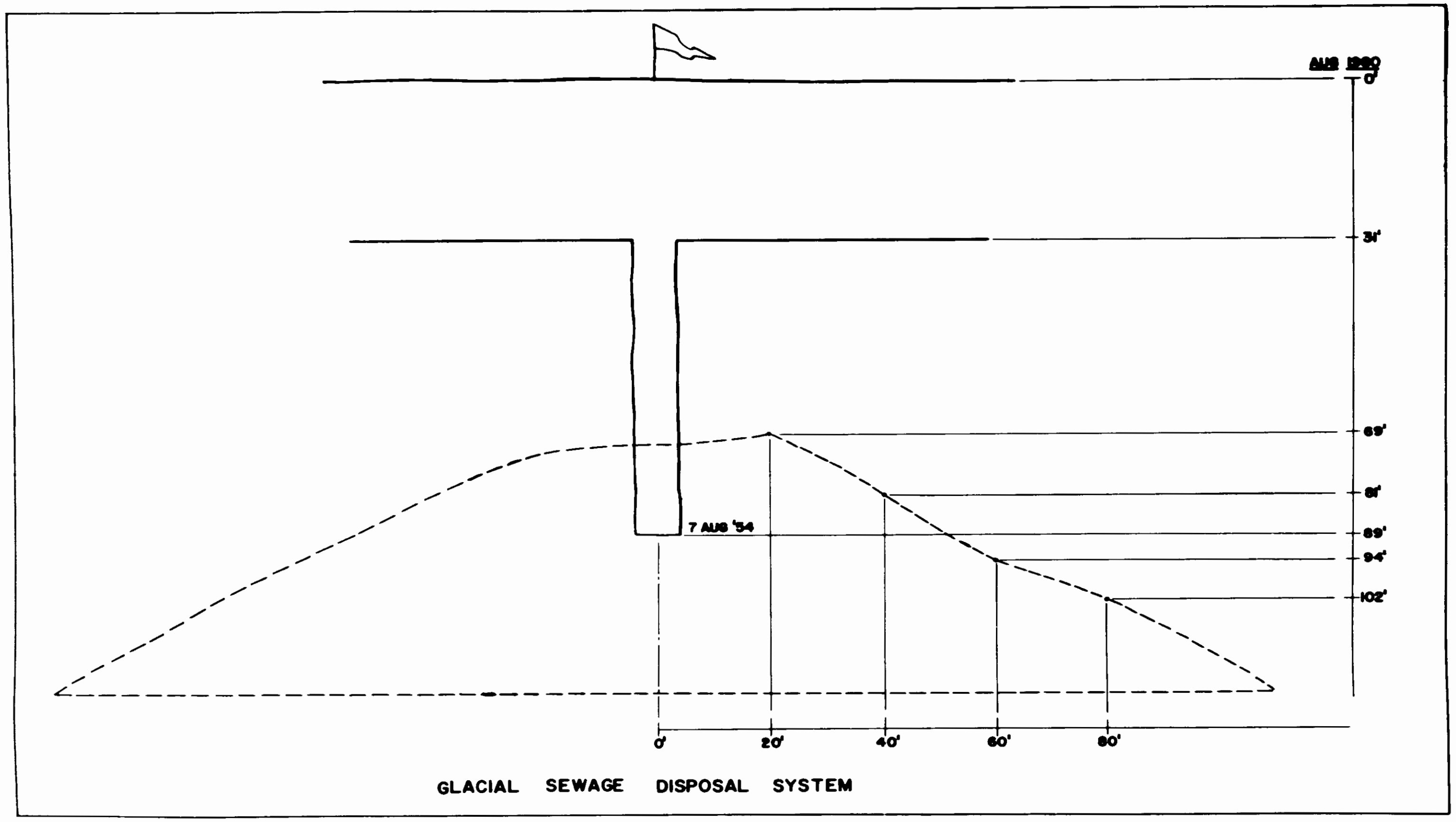

Fig. 16. Probable shape of sewage sump contamination.

Century sewage sump. Preliminary information indicates that the Camp Century sewage sump cavity is shaped much like a subsurface water well cavity. The bottom of the bulb is 160 ft below the trench floor, and the cavity which is 120 ft in diameter has a sewage depth of 46 ft. Several factors such as the amount of sewage discharged daily, the heat content of the sewage, and the year-round operation of Camp Century could be responsible for the differences in shape of the Camp Century sewage sump and that of the sewage sump observed at other locations.

III. DISCUSSION

8. Proposed Design for Future Glacial Installations. The design of the Camp Century water supply and sewage systems had to be operational, and time and funding did not permit detailed development of new equipment. Because of the absence of similar installations from which to obtain design criteria, maximum use was made of conventional sanitary engineering practices and readily available commercial equipment. Careful consideration was given to design systems that would be functional under the unusual and adverse conditions encountered in the ice cap and to the ease of installation, operation, and maintenance by troops in a remote area. For example, to facilitate installation of the systems, the main components were preassembled and each part was marked prior to shipment to Greenland. The installation of the systems at Greenland required 8,494 man-hours, and the costs including the equipment, building, and installation labor were $154,804.[2]

Since the systems became operational in October 1960, there have been on-site observations, revealing certain deficiencies and areas of improvement. Sufficient information has been obtained to develop design criteria for future camps in glacial areas. The future camp systems will cost less, as unnecessary items of equipment can be eliminated. Use of more reliable equipment will reduce the man-hours spent in operation and maintenance, and water conservation practices will reduce operational costs by reducing water consumption.

The Camp Century water well equipment was functionally similar to the equipment used in test at the temporary camp. The equipment was satisfactory for well-supervised tests of short duration; however, it is now evident that for extended operations like

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[2] The water supply and waste disposal systems that were installed at Camp Century are described in detail in the drawings and purchase specifications listed in Appendix A of this report.

Camp Century, equipment with greater reliability factors, easier to maintain and operate will be required (Appendix B). At Camp Century, on several occasions, the well pump motors burned out and the pump limit switches became inoperative. Replacement of these items required considerable time and labor because the two pipe strings into the well had to be removed and reinstalled. During this period, steam could not be injected into the well, and this condition resulted in a reduction of the volume of water in the cavity by refreezing.

In new water well equipment, the wooden A-frame will be replaced with a well-servicing unit (Fig. 17). The well-servicing unit will consist of a four-leg angular mast mounted on an I-beam skid frame base. The mast will be of sufficient height to permit the handling of 20-ft lengths of 2-in. coupled pipe. The unit will be equipped with three winches, each of 10,000-lb capacity. Two of the winches will normally be used to raise and lower two independent pipe strings leading from the surface to the well. This arrangement will permit the removal of a damaged pump while steam injection into the well is continued. The third winch could be used to lower another pipe string with pump into the well prior to the removal of a damaged pump. To install or remove coupled pipe sections, the unit will be equipped with well-drilling spiders and slips to support the pipe strings while a pipe section is being added. The pipe string for steam will be equipped at the lower end with a melting bit. The melting bit will consist of a cylindrical chamber for distribution of the steam to six nozzles. The pipeline will be covered with $1\frac{1}{2}$ in. of insulation to reduce heat losses and minimize well shaft enlargement. To maintain a relative position between the melting bit and the water surface, two sonar-type limit switches will be used. These switches are completely sealed and are not affected by freezing. The pipe string for water service will be equipped at the lower end with a well pump of larger capacity than the one in use at Camp Century. This will permit the filling of storage tanks faster. The pump also will be equipped with two nonfreezing-type limit switches, such as inexpensive sonar switches, to indicate the position of the pump relative to the water surface. The limit switches will also control the pump operation; they will permit pumping when the pump is immersed, and they will automatically shut off the pump when the water level drops.

Structurally, the well-servicing unit will support three independent pipe strings with a combined weight of 18,300 lb. The new equipment will be capable of operation to a depth of 600 ft.

In future camps, all the buildings with water service should be located in a single trench or, at the most, in two adjacent

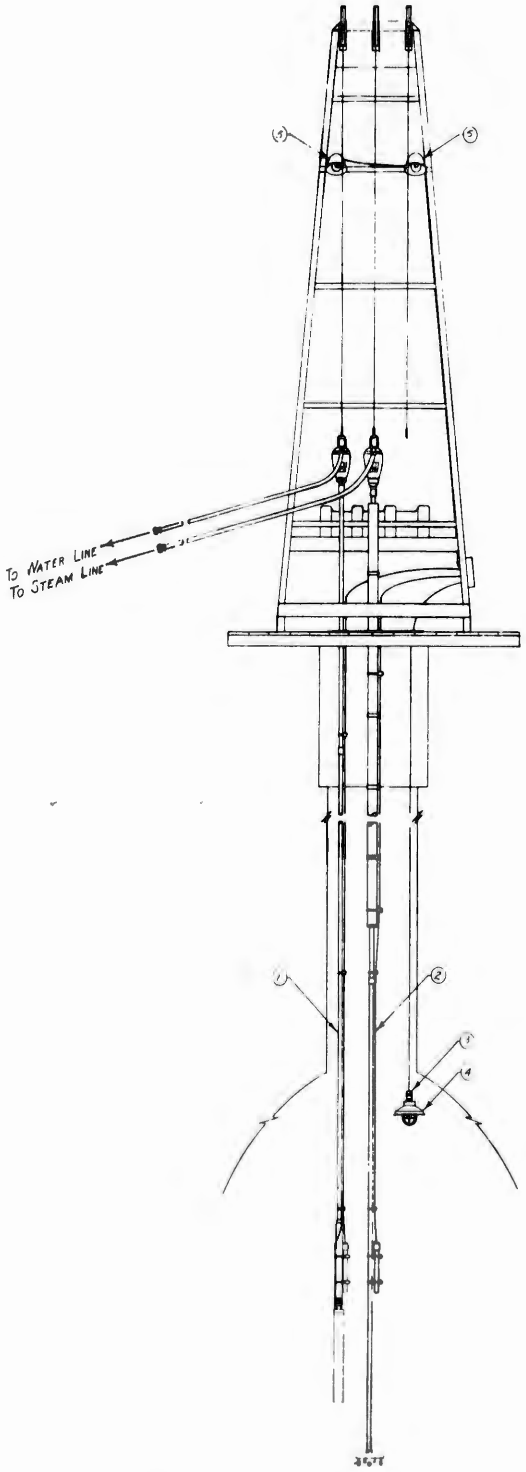

Fig. 17. Water well-servicing unit.

trenches. This would considerably shorten the distribution pipelines. All cold water pipelines should be of aluminum to reduce corrosion problems. The coupling of these pipelines should be of the victaulic type to prevent damage caused by differential settlement. All the pipelines should be suspended from wooden poles on the trench floors rather than from the snow walls. The insulation for all the pipelines should be of glass type with an outside metal cover. This insulation is easier to install and is not affected by water. For fire fighting, other methods that do not use water should be investigated. This would shorten the distribution pipelines by more than 1,000 ft. If water is to be used for fire fighting, a separate pipeline should be used. This pipeline should be kept empty, be insulated, and be electrically heated. All pipelines should be electrically heated. Controls for the electric heat insulation should be located in the water supply building. The controls should be equipped with a device to indicate when the system is in operation or if failure occurs.

The cost of the new systems can be reduced by elimination of the wanigan-mounted snow melter which is not required to substitute for the subsurface water well. Also, at the water source, the steam generator wanigan and auxiliary electric generator are not required. The standby steam generator should be located in the water supply building. The generator should be equipped with an exhaust heat recovery system to heat the water in the storage tanks. This will reduce the amount of heat discharged into the trench and reduce the settling rate of the snow arches.

To reduce operational costs, water conservation should be practiced. Personnel should be instructed to conserve water. All faucets and showers should be equipped with flow controllers to reduce waste. Liquid waste from the latrines could be treated by aerobic digestion and re-used for flushing toilets.

A water-borne sewage system when used wherever water is plentiful improves living conditions and is a factor contributing to the high morale of the personnel from an aesthetic and sanitary viewpoint.

If the present Camp Century sewage disposal system is used in the future camps, the sewage collection tank should be located inside a heated building. The tank should be equipped with two pumps to insure service if one pump fails. Also, as the sewage is discharged into the same aquifer of the water well the horizontal distance between the well and sewage sump should not be less than 1,000 ft.

IV. CONCLUSIONS

9. Conclusions. It is concluded that:

a. Drinking water can be obtained from glacier subsurface sources more economically and efficiently than from surface snow melting, and the water produced is normally not contaminated and is acceptable without further treatment.

b. Glacier subsurface wells can be used as heat sinks for the dissipation of waste heat of nuclear reactors.

c. Subsurface cavities which are no longer used for obtaining water can be used for the storage of supplies and fuels and for the disposal of waste products including low-activity waste water from nuclear reactors.

d. The equipment installation and operating procedures contained in Appendix B of this report are a simplified design for future glacial water supply systems using subsurface wells.

e. The discharge of sewage into the subsurface of the glacier is an economical and reliable method for the disposal of liquid wastes.

APPENDICES

APPENDIX A

CAMP CENTURY WATER SUPPLY AND SEWAGE SYSTEMS

Purchase specifications and drawings for the water supply and sewage systems installed at Camp Century, Greenland, are as follows:

1. Purchase specification entitled "Water Supply and Waste Disposal Systems for Camp Century," U. S. Army Polar Research and Development Center, Corps of Engineers, Fort Belvoir, Virginia.

2. Purchase specification entitled "Glacier Subsurface Water Supply Equipment," 18 December 1959, supplemental to paragraph "1" above, U. S. Army Polar Research and Development Center, Corps of Engineers, Fort Belvoir, Virginia.

3. Drawings D-11566-1 to 76, inclusive, entitled "Camp Century Water Supply and Sewage Systems," U. S. Army Polar Research and Development Center, Fort Belvoir, Virginia.

APPENDIX B

GLACIER SUBSURFACE WATER WELL-DRILLING, MELTING, AND PUMPING PROCEDURES

I. GLACIER SUBSURFACE WATER WELL-DRILLING PROCEDURE

1. References: The following U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia, drawings titled "Glacier Sub-Surface Water Supply System" are used as references for the water well-drilling procedure.

	Drawing Number	Sub-Title
a.	D13207E9981-2	Water Well Drilling - Equipment Assembly
b.	D13207E9981-4	Water Well-Servicing Unit - Tiedowns
c.	D13207E9981-5	Wooden Skid Platform - Details
d.	D13207E9981-6	Water Well-Servicing Unit - Equipment Assembly & Details
e.	D13207E9981-7	Water Well Servicing - Equipment Assembly & Details
f.	D13207E9981-8	Melting Drill Bit - Equipment Assembly & Details

2. The following procedure presents the principal steps to be followed in drilling a typical glacier subsurface water well.

a. Level an area of trench floor 30 by 14 ft where the well-servicing unit is to be located.

b. Assemble the wooden skid base as indicated in drawing D13207E9981-5.

c. Dig a hole in the trench floor of sufficient size to permit installing the 6-ft-long, 60-in.-diameter ARMCO liner plate circular section. Fasten the ARMCO liner plate section to the wooden skid base as indicated in drawing D13207E9981-5. This will prevent the ARMCO liner from sliding into the well shaft if the shaft becomes enlarged as a result of wall melting.

d. Erect the water well-servicing unit on the wooden skid base as shown in drawings D13207E9981-6 and 7. Fasten the servicing unit to the wooden skid base as shown in drawing D13207E-9981-4. Do not install the servicing unit I-beam cross members as this will interfere with drilling the well shaft.

e. Assemble the dynamometer and the drilling bit as shown in drawings D13207E9981-2 and 8. Connect the steam hose to the drilling bit and to the steam line as shown in drawing D13207E9981-8.

f. Note the dynamometer scale reading while the drilling bit is suspended in air. This is a measure of the weight of the drilling bit.

g. Lower the drilling bit until it touches the snow surface and the weight registered on the dynamometer scale is 50 lb less than when the bit was previously suspended in the air.

h. Start the steam flow into the drilling bit. Notice that as the steam melts the snow under the bit, the dynamometer will once again register original weight.

i. Lower the drilling bit again until the dynamometer scale reads approximately 50 lb less. While the well is being drilled do not let the dynamometer scale read much below the 50-lb difference as this may result in a crooked shaft. Also, drilling through ice lenses causes the rate of penetration into the glacier to decrease markedly, and the bit may be temporarily submerged in water. Do not stop drilling. However, if water continues to form a pond at the bottom of the shaft after 24 hr of steam injection, impervious water-retaining ice has been penetrated.

II. GLACIER SUBSURFACE WATER WELL-MELTING AND PUMPING PROCEDURES

1. References: The following U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia, drawings titled "Glacier Sub-Surface Water Supply System" are to be used as references for water well-melting and pumping procedures.

	Drawing Number	Sub-Title
a.	D13207E9981-3	Water Well-Melting and Pumping Equipment Assembly
b.	D13207E9981-9	Water Well-Servicing Unit - Details

c.	D13207E9981-10	Water Well - Waterline Equipment Assembly and Details
d.	D13207E9981-11	Water Well - Steam Line Equipment Assembly and Details

2. The following procedure gives the principal steps to be followed in the installation and operation of the melting and pumping equipment of a typical glacier subsurface water well.

a. Remove the drilling equipment after drilling has been completed and sufficient water has formed a pond in the cavity. Remove the dynamometer and the pulley, and install a wire rope on the outside of the well-servicing unit over the pulley. Suspend the swivel marked for steam service from the center wire rope socket and the swivel marked for water service from the left wire rope socket.

b. Proceed to assemble the steam line as shown on drawing D13207E9981-3 and 11. Connect one length of the steam pipe to the swivel. With a winch raise the pipe until the steam nozzle can be connected to the lower end. Connect the steam nozzle, also install the level switch and cable as shown in the drawing. Lower the pipe until the steam nozzle is below the ARMCO liner plate. Install the well-servicing unit I-beam cross members and spiders (drawing D13207E9981-9). To install additional lengths of pipe, lower the pipe until the swivel pipe coupling is 6 in. above the I-beam cross members. Install the spider bushing and the slip. Release the load from the wire rope and remove the swivel. Connect another length of pipe to the swivel and connect the pipe to one supported by slips. Continue to add the pipe, the insulation, and the electric cable (as shown on the drawing) until the steam line reaches the water surface. Connect the level switch cable to the corresponding panel outlet. Continue to lower the steam line until the red light goes off and the green light comes on. Connect the steam hose to the swivel and the steam line and proceed to inject the steam into the well.

c. Proceed to assemble the waterline as indicated in drawing D13207E9981-3 and 10. Connect a 10-ft length of pipe to the water pump and connect the pipe to the swivel. Install the level switch, the level switch cable, and the pump cable as shown in the drawing. To add extra lengths of pipe follow the procedure outlined in paragraph "b." Continue to add pipe and electric cables until the waterline reaches the water surface. Connect the level switch cable to the corresponding panel outlet. Continue to lower the pipe until the red light goes "off" and green light comes "on." Connect the pump electric cable to the corresponding panel outlet and connect the hose to the camp's waterline. The system then is ready for pumping.

d. Inject steam into the cavity for approximately 10 days (240 hr) in order to form a 50- to 60-ft-diameter cavity prior to pumping water for consumption. During this 10-day period, water in the well can be used as feed water for the steam generator. After the 10-day period, well water can be used for camp consumption.

e. Lower the pipes sufficiently for the green light to come "on" and no more if the red indicating light of either pipe string comes "on" while pumping.

f. Add additional pipe, electric cable, insulation, and the like, when required.

g. Install a spare pump before removal of the damaged one in the event of a pump failure.

h. Raise the pump completely out of the water to permit drainage if the steam supply to the well is interrupted and observations reveal that freezing in the well will occur. When steam is available again, before lowering the pump and even if there is no apparent freezing of the water, introduce steam into the well for at least 1 hr. If freezing has occurred, introduce steam into the well until all the surface ice is melted before lowering the pump. When the ice has melted, lower the pump into the water. If possible, do not start pumping immediately. If pumping of water is required, check the pump's operation by using the following procedure: Observe closely the panel ammeter when the pump is started. If starting amperage does not drop to normal running amperage within a reasonable length of time, and if after this time has elapsed the magnetic starter fails to break the circuit, shut off the pump immediately. The above normal running amperage indicates that either the impellers are frozen to the volute or the motor's rotor is locked. With the continuation of steam injection wait 1 hr and check the pump's operation once more. If the pump still fails to operate properly, install a spare pump before the damaged one is removed.

i. Disconnect the hose and drain after pumping water to the camp's storage tank. Also, after the steam supply is shut off disconnect the hose and drain.

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