TECHNICAL REPORT
67-13-CM

DEVELOPMENT OF A CARBON HEATING UNIT

by

Miles J. McGoff and Walter Milich

MSA Research Corporation
Evans City, Pennsylvania

Contract No. DA-19-129-AMC-105 (N)

July 1966

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

C&OM Division
MR&E 66-3

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Clothing and Organic Materials Division
U.S. ARMY NATICK LABORATORIES
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FOREWORD

In one of the future feeding systems, a heater is required by combat troops to provide boiling water for the reconstitution of precooked, dehydrated Quick-Serve Meals. The heating unit must be lightweight, fast heating, inexpensive, and a one-time-use item.

Studies performed at the U. S. Army Natick Laboratories indicate that carbon fuels show promise as a heat source.

This report on the development of a carbon heating unit was prepared by Mine Safety Appliance Research Corporation, Evans City, Pennsylvania, under U. S. Army Natick Laboratories, Contract No. DA-19-129-AMC-105(N). It covers investigations made between 5 June 1963 and 5 August 1965. The principal MSA Research Corporation engineers working on the project were Miles J. McGoff and Walter Milich. Mr. David J. Kunard assisted with some of the work.

Mr. T. Kapala, of the NLABS Clothing and Organic Materials Division, served as Project Officer for this contract.

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ABSTRACT

Experimental carbon heating units to boil water for reconstituting precooked dehydrated foods were developed at the U. S. Army Natick Laboratories and produced in contractor's pilot plant for field and laboratory study. These were designated as Phase I units. As a result of further experimentation and based on the test findings, the contractor produced an improved unit that was designated as Phase II.

Both units consisted of carbon fuel, igniter, stove support, base reflector, and shield or chimney. The Phase I fuel was a charcoal slab with perforations. The reflector was of rigid aluminum. At an ambient temperature of 68°F, this unit boiled 6 quarts of water in 10 minutes and, at an ambient temperature of 46°F, thawed snow or ice and boiled the resultant water in 22 minutes. In Phase II, several types of fuel were developed, the most promising of which was made from commercially available char fuel briquettes broken into approximately 1-inch pieces. Inexpensive fiberboard and aluminum foil replaced the rigid aluminum as reflector and the stove support was made of 4 simple parts. Under the same ambient conditions, these units brought 6 quarts of water to a boil in 14 minutes and thawed snow or ice and boiled the resultant water in 30 minutes.

Although the Phase II units required slightly more heating time, their cost, estimated at about $1.00 each in quantities of 100,000, was approximately one-fifth that of the Phase I units.

DEVELOPMENT OF A CARBON HEATING UNIT

I. Introduction

Through the years, the U. S. Army has provided the soldier with several types of heating units for preparing his food in the field. Of interest recently has been a heating unit that would boil the six or seven quarts of water, or thaw ice and subsequently boil the water, required to reconstitute dehydrated meal packages. The U. S. Army Natick Laboratories has been investigating the possibility of such a unit that would use charcoal as the potential low-cost fuel.

An experimental unit developed by the NLABS consisted of a perforated fuel cake (1 in. thick, 10-1/4 in. square, with 144 5/8-in. holes), an igniter, a stove support, a base reflector, and a shield for heat conservation. This unit brought 6 quarts (12-1/2 pounds) of water from ice to a boil in 21 minutes at a temperature of 50°F. and in 30 minutes at -40°F. An empty 6-in-1 meal container was used for the water. (A 25-in-1 meal container containing 3 gallons of water could also be used but would require two heating units placed side by side.) The fuel cake weighed 1.8 (± 0.1) pounds, and the complete heater 2.8 pounds packaged in a polyethylene bag.

The schedule of contract drawn up with the MSA Research Corporation (MSARC) stated in Article I, Section A, that using the NLABS unit, "6 quarts of water can be boiled in 8-1/2 minutes at 68°F., and in 30 minutes at -40°F. It requires approximately 50 minutes to thaw snow and ice and boil the subsequent water." The performance specifications for one carbon heating unit were that it a) boil 6 to 7-1/2 quarts of water at low ambient temperatures (below freezing) in less than 15 minutes, and b) thaw snow and ice and boil the resultant water at low ambient temperatures in less than 30 minutes. General requirements were that a) the charcoal burn without smoke or odor, b) the unit be usable in sheltered but ventilated areas, c) procedures be developed and commercial carbonizing equipment used to produce the fuel, d) the efficiency be determined of fuels, such as charcoal that has been commercially produced from select wood precut to the required form, for easy ignition and rapid burning, and e) an expendable stove be developed that is light in weight and easy to assemble. Also required was that the unit have structural integrity and not be damaged or become inoperative after air drop.

It was hoped that MSARC would further develop the fuel and stove and the manufacturing methods so that ease of ignition would be improved, less carbon monoxide produced, the weight and volume of the unit decreased, and the cost reduced. To this end, several types of fuels were investigated, performance trade-offs were studied, and value analyses were conducted. Production was divided into two phases. In Phase I, MSARC was to produce 750 units of the original NLABS design for field tests at Fort Lee (Virginia) and Fort Greely (Alaska). A Phase II production of 500 units was to incorporate design and cost improvements suggested by the data from the Phase I units and by other experimental fuels and stoves from NLABS and MSARC Labs.

Projected requirements for the carbon heating unit are on the order of one million per year. While the production of only 500 would result in a higher unit cost than would mass production, the cost as related to manufacturing methods would be projected on a mass production basis.

II. Phase I Carbon Heating Unit

A. Production

The 750 heating units produced by MSARC during Phase I (Fig.1) followed the experimental design developed at Natick. They included a fuel slab (with igniter strip) encased in a chicken-wire cage and wrapped in foil, a wire-frame stove to hold the fuel and support the water container, a sheet aluminum (15-mil) reflector base that lowered time to boil and served as a leveling support for the stove, and a foil chimney, plus plastic (for water-proofing) and paper wrappings, cardboard carton, and wooden crate. The total weight was 2.8 pounds.

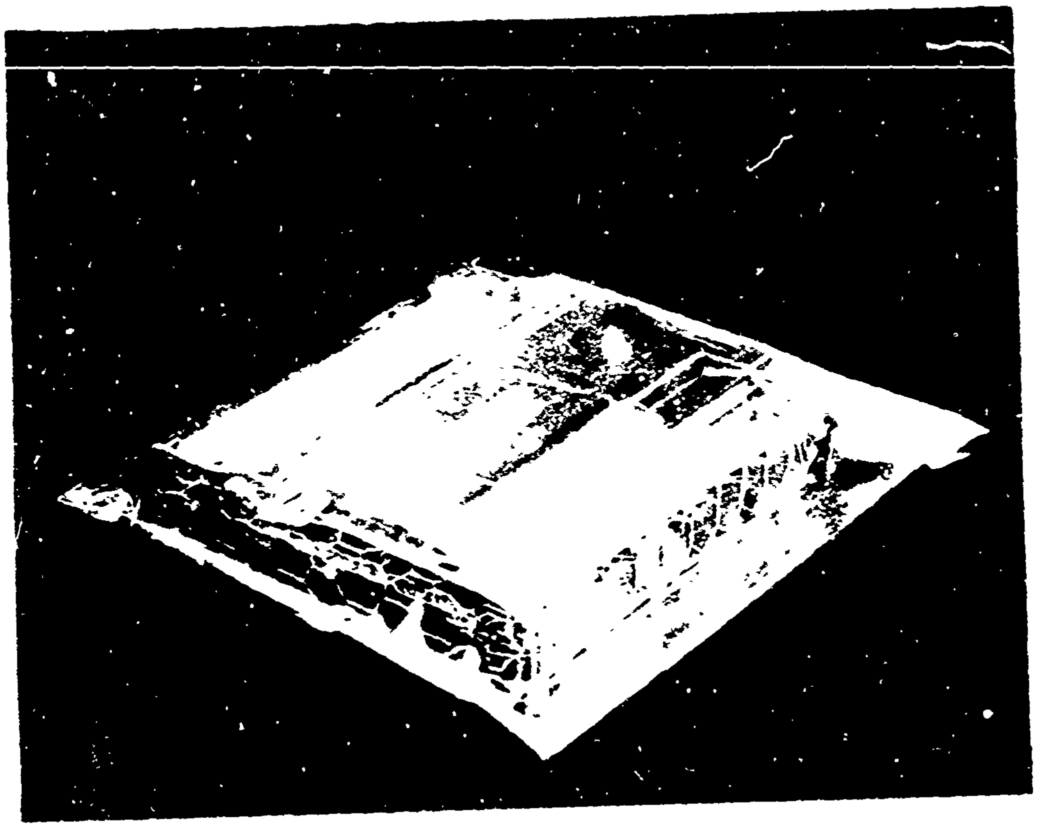
1. Fuel Cakes

The fuel cakes, which were of similar composition and geometry to those developed at Natick, were made up in 25-batch lots. No scale-up problem was encountered. Performance tests, made on one cake from each batch of 25, showed the fuel to be homogeneous. Each 25-batch mix had the following ingredients:

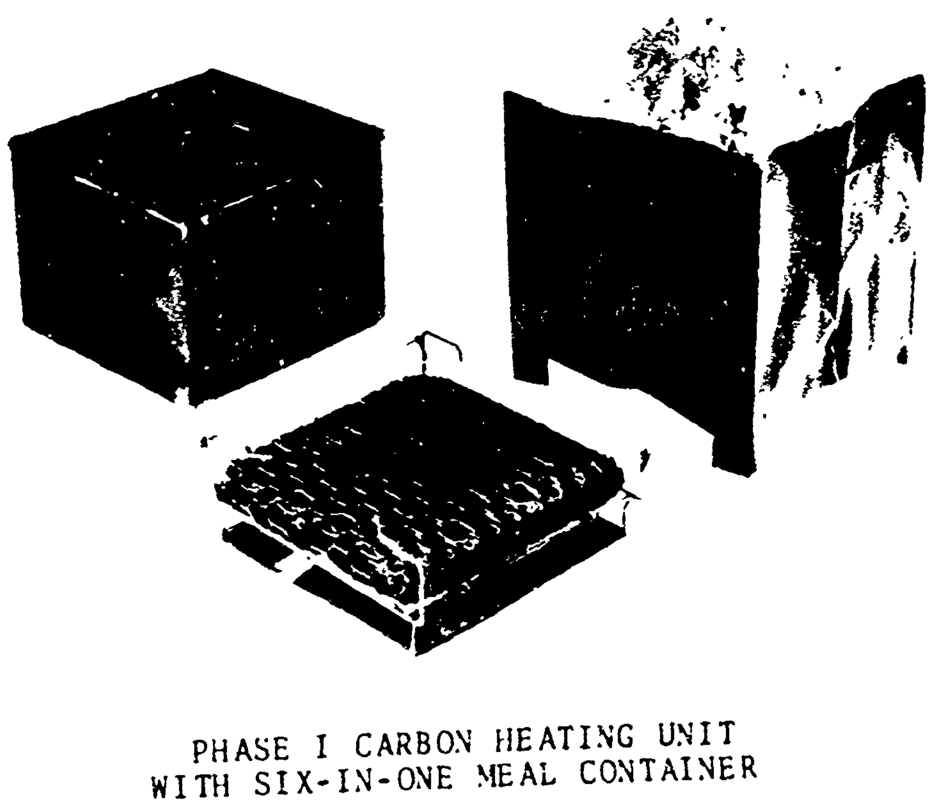
Charcoal, hardwood, 300-mesh air float	35 lb
Iron oxide, Glidden J-110	9 " 6 oz
Sugar	6 " 4 "
Starch, briquetting	3 " 6 "

MSARC found that the best method of forming and perforating the fuel cakes was by pressing and piercing them simultaneously. Extrusion was considered as an alternative method and a sample of the mix was taken to a plastic extrusion firm to ascertain if it was compatible with their equipment, for the charcoal mix is unusual in consistency and behaves somewhat like plastic putty in that it is pliant and spreads out when vibrated. However, the extrusion method was found to be impractical, not only because of the type of mix but, primarily, because of the size of the cake (10-1/4 in x 10-1/4 in x 1 in) and, further, the large capital investment required for the discs and the time-consuming labor required by the technique itself.

Although the MSARC fuel cakes were ostensibly like the experimental ones, NLABS found, upon testing some of those made during the early stage of production, that they required six minutes longer to bring water to a boil. This difference in results was



PHASE I CARBON HEATING UNIT
(Packaged)



PHASE I CARBON HEATING UNIT
WITH SIX-IN-ONE MEAL CONTAINER

attributed to smaller perforations in the fuel cage. The 3/8-inch rubber plugs in the die at NLABS produced 5/8-inch holes while the 3/8-inch steel plugs in the MSARC die produced 3/8-inch holes. MSARC then modified its die so that the subsequent Phase I cakes (including most of those tested in Alaska) were of the larger-hole type and were 144 to a cake.

2. Wire Cage

The pre-cut chicken-wire cage for the fuel cake was formed and stapled by hand. Special care was required to encase the fuel cake and igniter sheet firmly; it was a time-consuming operation.

3. Chimney

The chimney, or convective windshield, without which the unit would not boil water, was made from 1-1/2 mil olive drab (2 coats) Reynolds aluminum foil, 1235-0 temper, similar to Reynolds Experimental Type FX-20308. The tight production schedule necessitated that the chimneys be assembled by hand in an apparatus where the aluminum foil could be unwound, folded, and cut. Although MSARC has folding machines (used in the production of filters) and although machine folding would have lowered labor costs, the foil was too fragile to be handled in this way.

4. Stove, Reflector, and Igniter

While the fuel cakes, wire cage, and chimney were made by MSARC with specially adapted equipment, jigs, and tools, the stove, reflector, and igniter were made commercially according to MSARC specifications. These all proved to be expensive. Little reduction in cost was foreseen as possible, even for larger quantities of the stove and reflector, hence redesign was indicated.

The Delrin igniter was made of virgin material. It was believed that used material would reduce the cost by 60 percent.

B. Production Cost Analysis

The Phase I unit was found to be prohibitively expensive, largely because of the preparation which involved the following time-consuming operations:

a. Hydrolyzing the starch and sugar in a jacketed vessel equipped with an air-actuated stirrer, at 170°F.

b. Mixing the hardwood, 300-mesh, air float charcoal with iron oxide powder; adding the starch-sugar mix; and blending into a homogeneous mass (usually water must be added to give the proper consistency).

c. Removing the mix and placing weighed amounts into a mold that has 144 tapered pins that pierce the cake as it is pressed into shape.

d. Stripping the molds and placing the cakes in drying ovens (a 3-man operation), where they are held at 180°F for several hours.

e. Double-wrapping the dried cakes with pre-cut aluminum foil, with seams alternating to prevent burning during the subsequent carbonization.

f. Carbonizing the cakes in an 800°F oven for 4 hours to reduce the starch and sugar to carbon.

g. Carefully cooling the cakes before unwrapping (charcoal still warm from carbonization will spontaneously ignite).

The steps required by the entire operation are given in Exhibit A. Exhibit B itemizes the cost of the materials, which total $2.33. The total cost of the Phase I unit including labor at $3.00 per hour, was $5.00.

EXHIBIT A

OPERATION SEQUENCE FOR PHASE I CARBON HEATING UNIT

No.	Operation Description	Each Piece Time - (hr)	Tools
1	Cut wrapping foil	0.0088	Scissors
2	Cut chicken wire and bake	0.0621	Wire shears, oven
3	Cellulose tabs and paint	0.0100	Scissors, spray gun
4	Staple tabs to igniter	0.0078	Table stapling fixtures
5	Fold, cut, form, and staple chimney	0.1050	Cutting table, notching and table stapler
6	Prepare cake materials, mix to proper consistency, weigh out one cake, prepack mold, finish packing mold and assemble, pressing and punching holes into cake; strip; load drying oven (3-man operation)	0.4200	Mixer, press, ovens
7	Unload drying oven and double-wrap cakes with precut foil for charring	0.0870	Bench
8	Unload charring oven, cool cakes, and unwrap	0.0285	Bench
9	Form precut chicken wire and encase cake and igniter within wire; fold wire over cake and assemble; hog-ring enclosed cake to wire stove	0.0665	Bench
10	Assemble contents and pack in plastic bag	0.0385	Bench
11	Heat-seal bag	0.0350	Heat sealer
12	Wrap and pack bags in carton (10/carton)	0.0140	Bench
13	Pack cartons in crate, stencil, and nail (10 cartons/crate)	0.0090	Stencil equipment
	Total	0.8922	

EXHIBIT B

MATERIAL COST OF PHASE I CARBON HEATING UNIT
(on basis of 750 units)

	Item		Unit Cost ($)
1	Fuel		
	Charcoal	0.0650	
	Iron oxide	0.0319	
	Sugar	0.0316	
	Starch, briquetting	0.0135	0.1420
2	Stove		0.7500
3	Base reflector (aluminum)		0.4500
4	Delrin igniter		0.1893
5	Chinmey, aluminum foil		0.2120
6	Plastic bag		0.0467
7	Fuel cage		0.0737
8	Fuel cage rings		0.0300
9	Wrapping foil, aluminum		0.0723
10	Instruction sheet		0.0500
11	Packing paper		0.0340
12	Cardboard cartons		0.0277
13	Wood crate, prorated over 750 units		0.2500
		Total	$2.3277

C. Test Results

1. Cold Weather Performance

Performance tests conducted on 500 Phase I units at -40°F in Alaska were favorable (USATECOM #7-3-0258-02K (Service Test-Alaska), substantiating results that had been obtained in the NLABS Arctic Chambers (Table I). In Natick, the performance of both the 3/8- and 5/8-inch holed fuel cakes of Phase I was compared with that of fuel cakes made at NLABS and of other experimental fuels, one of which was a perforated hardwood slab directly carbonized at 800°F in a commercial retort. The hardwood slab had poor heating performance. Shrinkage and distortion also detracted from the direct carbonization of hardwood board as a fuel.

2. Carbon Monoxide Production

At Fort Lee Virginia the U. S. Army General Equipment Test Activity (GETA) conducted a carbon monoxide concentration study of Phase I units in 5-man Army tents and reported that the units did not produce dangerous levels of CO. However, in tests made by MSARC, where an Army tent was monitored by an MSA Model 300 Carbon Monoxide Lira, CO in excess of 100 ppm was recorded. This level is considered to be harmful. MSARC also measured CO production in a closed (unventilated) 4000-cubic foot chamber, with results as shown in Figure 2. MSA findings corroborate the assumption that ventilation is a factor in CO concentration but that, under proper conditions it should be possible to avoid harmful CO accumulations.

III. Experimental Program

The experimental program was divided into physical and chemical investigations. The physical investigations included the geometry of the fuel cakes as well as of the briquette; also the distance between the fuel and the water container and the fuel and base reflector. The chemical investigations encompassed primarily the fuels and the igniter components of the carbon heating unit and their influence on performance.

A. Physical Investigations with Fuels

1. Fuel Cake of Phase I

Results of combustion and geometry tests are shown in Tables II and III (pp 12.13 and 14), where cake size and composition and hole size and shapes were varied. No improvement was observed when the

TABLE I

Cold Weather Performance at NLABS of Phase I Heaters

Fuel (No.)	Water at Start: State	Water at Start: Temp(°C)	Time from Start (min): To Boil	Time from Start (min): To Stop Boil	Heat Delivery, Btu (per min)**	Heat Delivery, Btu (per lb)***	
MSA-ET*	liquid	+ 3.0	38.0	--	--	--	-18°C,
MSA-ST	solid	-16.7	22.0	38	218	2960	20 mph wind
121A-Br	liquid	+ 0.7	13.0	29	179	1935	
MSA-ET*	solid	-27.0	43.0	--	--	--	-28°C,
MSA-ST	liquid	+ 7.8	12.8	60	145	3025	3-4 mph wind
MSA-ST	solid	-31.1	29.2	65	132	4120	
121A-Br	solid	-30.0	28.5	64	147	3550	
121A-Su	liquid	+ 1.7	26.0	69	73	2633	
MSA-ET*	liquid	+ 5.0	26.5	--	--	--	-40°C,
MSA-ET*	solid	-35.5	41.0	--	--	--	3-4 mph wind
MSA-ST	liquid	+12.5	14.8	63	123	3303	
121A-S1	solid	-38.9	31.5	67	131	2750	
121A-S1	liquid	+ 7.8	13.0	59	165	3170	
MSAR-4	liquid	+ 1.7	36.0	56	69	4460	-40°C,
MSAR-5	liquid	+ 0.0	58.0	80	40	2650	4 mph wind
MSAR-6	liquid	+ 4.4	26.0	70	79	2720	

*Tests conducted at NLABS by GETA (U.S. Army General Equipment Test Activity, Fort Lee, Va.)

Fuel Code:
- MSA-ET = mfd by MSARC 3/8 in. holes also tested by GETA (Eng. Test)
- MSA-ST = mfd by MSARC 5/8 in. holes (Service Test)
- 121A-Br = made at NLABS corrugated oval briquettes with hardwood charcoal and iron oxide
- 121A-Su = made at NLABS an uncarbonized slab
- 121A-S1 = made at NLABS hardwood charcoal and iron oxide slab, carbonized
- MSAR-5 = mfd by MSARC carbonized block of white oak, with holes
- MSAR-4,6 = NLABS slabs carbonized in retorts of Otto Chem. Co. for MSARC

**Btu per minute measured from initial temperature to 71°C.

***Btu per pound measured from initial temperature to end of boil.

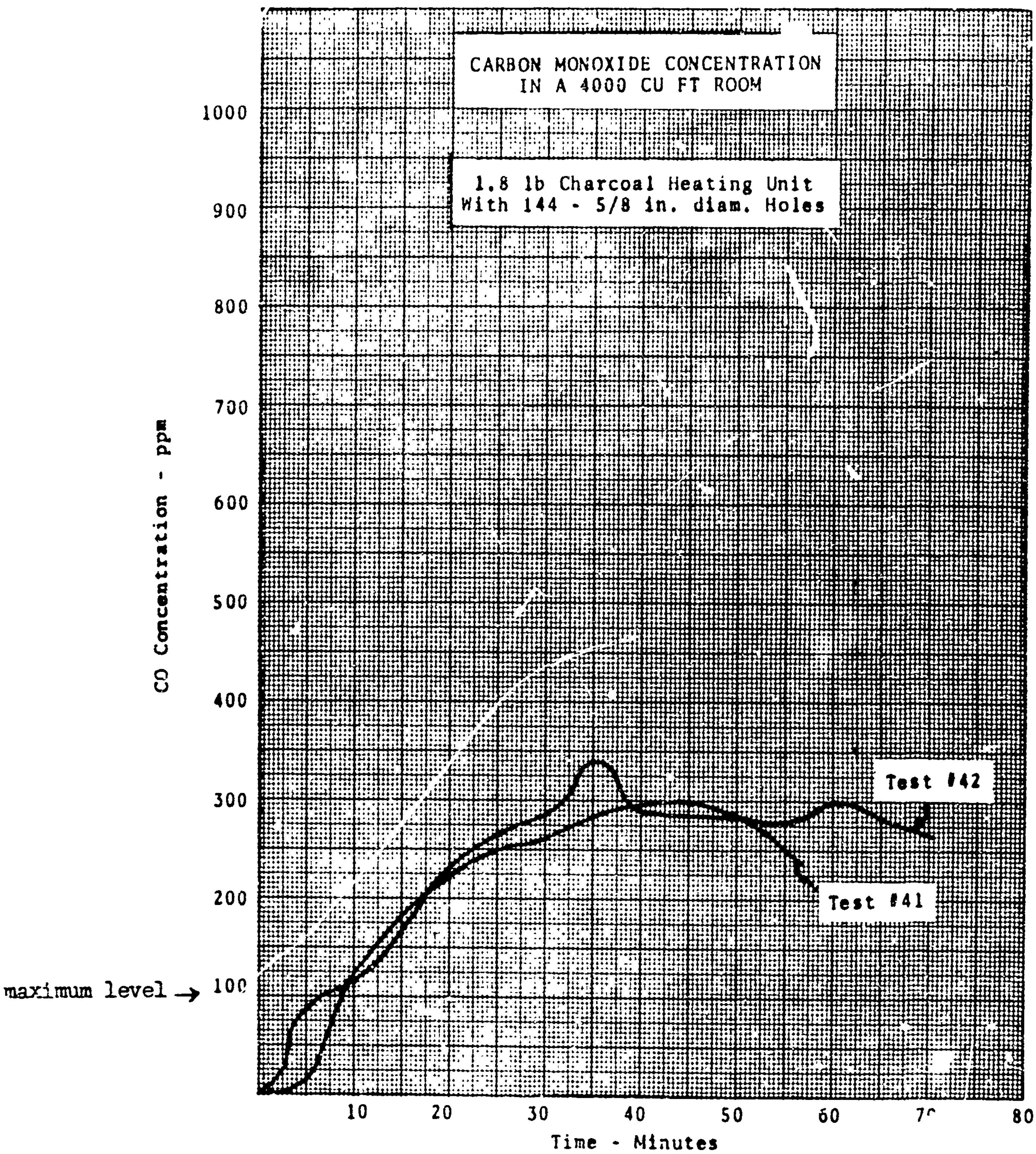


FIG. 2 - CO CONCENTRATION IN CLOSED CHAMBER - PHASE I CARBON HEATING UNIT

TABLE II - COMBUSTION TESTS WITH CHARCOAL FUEL CAKES

Charcoal Fuel Cake

Composition: Charcoal - 64.8%
Starch - 6.2%
Sugar - 11.6%
Iron Oxide - 17.4% (Glidden J-110)

Igniter: Delrin Sheet, 10 mil thick (except No. 14 & 16, which were Celcon)

Tests Conducted with Water Container and Heat Shield

Test No.	Fuel Cake Description	Weight (gms)	Temp (°F) Ambient	Temp (°F) Water	Wind Velocity (MPH)	Time to Boil min-sec	Total Time (min)	Water Evap. lb-oz	Therm.* Eff. (%)	Remarks
1	144-3/8 in. dia. holes	810	69	74	2-5	14-33	-	8-13	46	Glidden A-130 iron powder in fuel.
2	144-3/8 in. dia. holes	783	69	72	Slight	18- 0	-	6 -8	38	Glidden A-130 iron powder.
3	144-3/8 in. dia. holes	724	75	74	0-5	16-45	89	6 -0	40	Used 15 lb water, A-130 iron in fuel.
4	144-3/8 in. dia. holes	796	77	82	5-10	14- 0	81	7 - 9	41	Used 15 lb water, A-130 iron in fuel.
5	144-3/8 in. dia. holes	-	67	69	3-5	15-15	-	-	-	Fuel cake the type sent to Ft. Lee. This fuel and subsequent fuel cakes prepared with iron oxide (Glidden J-110).
6	144-3/8 in. dia. holes	893	60	42	0	19-55	85	5 - 8	38	Smoked considerably.
7	144-3/8 in. dia. holes	-	72	72						Test made in combustion chamber, data collected on CO vs time.
8a	144-3/8 in. dia. holes	-	72	72	-	13-30	-	-	-	Test conducted to compare MSAR fuel cake with QMC fuel. Fuel cake 8b prepared with sponge iron, 8c with internal igniter (nitrates) and smoked.
8b	144-3/8 in. dia. holes(NLABS)	-	72	76	-	10-30	-	-	-	
8c	Perforated 10 in. sq. cake (NLABS)	-	72	68	-	50- 0	-	-	-	
9a	144-3/8 in. dia. holes	843	74	71	3-5	16- 0	-	-	-	Repeat of run 8. Again showed that larger holes in QMC fuel cake 9b, was more rapid in bringing water to a boil. Fuel cake 9b contained Glidden J-110 iron oxide, 9c internal igniter.
9b	144-3/8 in. dia. holes(NLABS)	-	74	68	-	11-30	-	-	-	
9c	Perforated 10 in. sq. cake (NLABS)	-	74	78	-	19-20	-	-	-	
10a	144-3/8 in. dia. holes	-	74	79	-	11-50	54	-	-	Study effect of larger taper hole. Definite help to have igniter tabs to start off.
10b	144-3/8 in. dia. holes	-	74	68	-	17-45	67	-	-	
11a	144-3/8 in. dia. holes	817	76	68	0-2	13-15	65	-	-	Appears taper hold is helpful, nitrocellulose tabs used with Delrin igniter to this test.
11b	144-5/8 in. to 3/8 in. dia. holes	821	76	71	0-2	11-25	65	-	-	
12a	144-3/8 in. dia. holes	923	82	74	10-20	21- 0	82	-	-	Delrin tabs used hereafter on Igniter sheet. Comparison run to check taper.
12b	144-5/8 in. dia. holes to 3/8 in. dia. holes	880	82	74	10-20	17-35	77	-	-	
13a	144-3/8 in. dia. holes	833	69	68	0-10	16-55	-	-	-	Deepen grooves.
13b	144-3/8 in. dia. holes	846	69	69	0-10	19-20	-	-	-	Filed surface and holes.
13c	144-3/8 in. dia. holes	865	69	68	0-10	16-45	-	-	-	As is.
13d	144-3/8 in. dia. holes	888	69	68	0-10	20-20	-	-	-	Filed surface - holes. (13a,b,c,d) Run to check effect of roughing surfaces. Not much help. Hole size more critical.
14	144-3/8 in. dia. holes	827	90	70	0-5	16-15	-	-	-	Extra thick (0.025 in) Celcon sheet. Some flame and smoke. Odor does not seem as bad as Delrin.

*See Appendix B for sample calculation

TABLE II - COMBUSTION TESTS WITH CHARCOAL FUEL CAKES (Contd)

Test No.	Fuel Cake Description	Weight (gms)	Temp (°F) Ambient	Temp (°F) Water	Wind Velocity (MPH)	Time to Boil min-sec	Total Time (min)	Water Evap. lb-oz	Therm. Eff. (%)	Remarks
15	144-3/8 in. dia. holes	650	78	65	0	10-30	-	-	-	Tested in comb. chamber.
16	144-3/8 in. dia. holes	695	78	70	0	10-30	-	-	-	Celcon igniter. 0.010" thick. Test in combustion chamber. Strong odor.
17	144-5/8 to 1/2 in. taper dia. holes	775	72	68	3-5	1?-50	65	-	-	To check tapered holes.
18	144-1/2 in. dia. holes	745	72	68	3-5	12-50	53	-	-	Check 1/2 in. dia. hole vs previous 3/8" holes.
19	144-1/2 in. dia. holes (Repeat of 18)	745	58	66	0-5	12-30	-	-	-	
20	144-5/8 in. x 1/2 in. taper	762	58	67	0-5	10-45	-	-	-	Larger dia. holes are beneficial.
21a	144-5/8 in. x 1/2 in. taper	792	71	70	0	10-25	5?	-	-	The 5/8 in. dia. holes look best thus
21b	144-5/8 in. x 1/2 in. taper	765	71	68	0	10-50	49	-	-	far.
22a	144-5/8 in. x 1/2 in. taper	818	77	74	2-5	12-45	55	-	-	Check std. heat prod. batch and check cake
22b	144-5/8 in. x 1/2 in. taper	707	77	75	2-5	12-?	55	-	-	weight vs time to boil.
23	144-5/8 in. x 1/2 in. taper	-	64	68	0-10	1?-15	52	-	-	Flaming all way to boiling time. Box coated with white residue. Did not appear to improve boiling time.
24a	144-5/8 in. x 1/2 in. taper (lighter cake)	762	83	70	0-2	11-15	51	-	-	Appears that heavier cake is slower in boiling. (higher density)
24b	144-5/8 in. x 1/2 in. taper (heavier cake)	823	83	21	0-2	16-30	62	-	-	does burn longer.
25a	144-5/8 in. x 1/2 in. taper	712	52	68	0-2	10-15	55	-	-	Weight difference may
25b	144-5/8 in. x 1/2 in. taper (cracked or broken cake)	763	52	65	0-2	12- 0	55	-	-	mask cracked vs whole cake.
26a	144-5/8 in. x 1/2 in. taper (mold clean at start)	780	83	73	5-8	13- 0	54	-	-	Looks like dirty mold does not allow full penetration of pins
26b	144-5/8 in. x 1/2 in. taper (mold dirty at end)	770	83	68	5-8	14-10	55	-	-	through cake.
27a	144-5/8 in. dia. holes	779	45	68	0	9-50	52	-	-	Check production cake. Both cracked slightly.
27b	144-5/8 in. dia. holes	774	45	64	0	11-15	53	-	-	Took Delrin 2-1/2 min. to burn completely. Test 27a from heat 15, test 27b heat 16.
28a	144-5/8 in. dia. holes	?18	52	63	0-5	12-10	62	-	-	Tests measure time to melt ice and boil,
28b	144-5/8 in. dia. holes	816	52	-109 (ice)	0-5	28-30	65	-	-	compared to water. Ambient air at 52°F. Ice subcooled in cold box. Cakes from Heat 17, Type sent Ft. Greely, Alaska.
29a	144-5/8 in. dia. holes	816	50	-109 (ice)	2-5	20-55	-	-	-	Fuel cakes in test 29a and 29b from Heat 18. 29c fuel cake from
29b	144-5/8 in. dia. holes	813	50	68	2-5	12- 7	55	-	-	Heat 8. Tests compared two heats; no apprec-
29c	144-5/8 in. to 1/2 in. dia.	800	50	67	2-5	11- 0	50	-	-	iable difference; and variation in time to boil water as opposed to ice.

TABLE III - COMBUSTION TESTS BASED ON GEOMETRY OF CHARCOAL FUEL CAKES

Charcoal Fuel Cakes

Size: 10-1/4 in. x 10-1/14 in.
Composition: Charcoal - 64.8%
Starch - 6.2%
Sugar - 11.6%
Iron Oxide - 17.4% (Glidden J-110)
Igniter: Delrin Sheet, 10 mil thick
Tests Conducted with 6-1/2 qts Water and Heat Shield

Test No.	Fuel Cake Description	Ratio Surface to Volume (1/ft)	Weight (of Cake) (gms)	Temp °F Ambient	Temp °F Water	Wind Velocity (MPH)	Time to Boil (min-sec)	Total Time (min)	Water Evap. (lb-oz)	Thermal Eff. (%)	Remarks
38a	169-1/2 in. square holes - cake 1-1/4 in. thick	96	957	53	61	0	11-30	57	9 - 2	40.8	Some of the charcoal fell off in chunks.
38b	121-7/16 in. hex shape holes - cake 1-1/4 in. thick	147	825	53	62	0	11-30	57	7 - 4	39.2	Test was production fuel cake of type supplied in Phase 1 and was conducted as basis of comparison, all tests made this way.
38c	144-5/8 in. dia. holes - cake 1 in. thick (Std. production cake)	87	790	53	64	0	11-30	57	7 - 0	39.8	
39a	144-5/8 in. square holes - cake 1-1/8 in. - 1-1/4 in. thick	122	955	46	58	0-20	12-30	61	8 - 2	37.7	Standard production type cake, ran for comparison.
39b	100-7/16 in. hex holes - cake 1-1/8 in. - 1-1/4 in. thick	102	930	46	58	0-20	12-30	63	7 - 1	34.3	Standard production type cake, ran for comparison.
39c	144-5/8 in. dia. holes (Std. production cake)	87	807	46	64	0-20	11- 0	55	6 - 8	36.7	Stand. production type cake, ran for comparison.
40a	169-1/2 in. dia. holes - cake 1-1/4 in. thick	75	963	40	58	0-20	15- 0	62	7 -11	34.8	
40b	144-5/8 in. dia. holes. Pivoted stove used. Cake not encased in chicken wire.	87	801	40	60	0-20	13- 0	50	4 - 7	29.2	Rack flattened out and food container dropped down in 25 min.
40c	144-5/8 in. dia. holes (Std. production cake)	87	812	40	65	0-20	16-30	62	5 -14	33.8	Standard type production fuel cake and stove.
43a	5/8 in. OD x 1-3/4 in. long extrusions encased in 10-1/4 in. x 10-1/4 in. x 1 in. basket made 5/16 in. square mesh screen	79	800	35	58	0-15	19-30	70	5 -13	34.4	
43b	144-5/8 in. dia. holes, cake sprayed with Plastic-Kote	87	844	35	60.8	0-15	15- 0	58	7 - 3	38.1	
43c	144-5/8 in. dia. holes (Std. production cake)	87	804	35	58	0-15	12-30	54	6 -10	37.9	

number or the size of the holes was changed from the 144 5/8-inch holes of the Phase I reduction. No advantage was obtained by changing the shape of the hole from round to hexagonal or square. In conducting this investigation, the performance of the fuel cakes prepared at the NLABS was also studied. These were of the same Phase I configuration.

The feasibility of directly manufacturing the cake from a solid slab of wood was investigated. Hardwood slabs, approximately the same size as the 10-in-square fuel cake could be processed directly. In the carbonizing of the hardwood block, the high temperatures required caused shrinkage and distortion. The block was relatively fragile and performed poorly.

Manufacturing techniques studied in the experimental program were considered in view of the application to commercial apparatus. The carbonizing of the hardwood boards was done at a commercial carbonizing facility, - the Otto Chemical Company in Kane, Pennsylvania. The performance of a carbonized hardwood block is given in Table I (see No. MSAR-5).

2. Briquettes of Phase II

Briquettes were extensively investigated because of their inherently low cost. Peach pits, which were also considered as a source of fuel, did not prove efficient in their combustion properties.

Information about the production of charcoal is proprietary to the charcoal manufacturers. Consequently, little could be learned from them. One low-cost charcoal obtained from the Quaker Oats Company is unique because the briquettes are made by extrusion and the source of the raw material is the char remaining after the manufacture of furfural from corn cobs.

Table IV shows performance results obtained with briquette fuels including peach pits. The effect of sponge iron oxide in the blend is shown by comparing Tests 60 and 61. Calculations based on CO and CO_2 measurements show that sponge iron oxide reduced CO output by approximately one-half in the hardwood charcoal briquettes. Therefore, the addition of sponge iron oxide is worthwhile with hardwood; however, it does add to the cost. The processing of briquettes with sponge iron oxide by extrusion was discussed with the Quaker Oats Company. In their judgment, extrusion would be difficult and development work would be necessary. However, experiments conducted by NLABS indicated that no reduction of CO output occurred when sponge iron oxide was added to the Quaker Oats material. This is also shown by comparing tests 55, 56, and 77 with test 70 (See Table VI p23).

TABLE IV - BRIQUETTE FUEL TESTS - PHASE II

Fuel Tray - 10 in. square
Igniter - Delrin Sheet

Tests conducted with 6 qts. water and 12 in. chimney

Test No.	Fuel Type	Weight (gms)	Amb. Air Temp. (°F)	Max. CO (ppm)	Avg. CO (ppm)	Avg. CO_2 (%)	Total* CO (cu ft)	Ratio* (cu ft CO/lb C)	Burning* Rate (lb C/min)	Time to Burn (min.)	Time to Boil (min)	Thermal* Eff. (%)
55	Briquettes, 56°F, Quaker Oats Company 7/8-in. thick with 3/4-in. hole.	7.2	56	2000	698	0.36	9.20	5.81	0.0171	95	17	38
56	Same as above.	678	48	2000	1280	0.36	15.90	10.60	0.0205	85	16	28
77	Briquettes, Quaker Oats Company, cut 1/2-in. thick with 1/2-in. hole.	400	40	1980	1020	0.29	9.25	10.50	0.0136	65	24	34
78	Briquettes**, MSAR 2 in. donuts, 7/8-in. thick with 3/4-in. hole.	571	40	720	340	0.41	3.10	3.10	0.0228	55	13-1/2	41
49b	Peach Pits	680	20	--	--	--	--	--	--	--	50	--
60	Briquettes,** MSAR 2 in. donuts, 7/8-in. thick with 5/8-in. hole.	518	48	720	356	0.42	2.42	2.60	0.0164	60	1[illegible]-1/2	38
61	Briquettes, MSAR*** 2 in. donuts, 7/8-in. thick with 5/8-in. hole.	343	50	1600	750	0.42	3.35	5.40	0.0108	60	14	43
43a	Charcoal** extrusions 5/8 in. OD x 1-3/4 in. long.	800	35	--	--	--	--	--	0.0110	54	19-1/2	34

*See Appendix B for sample calculation.
**Composition same as fuel cakes.
***Composition same as fuel cakes except no iron oxide.

3. Briquette Extrusion

The process of extruding charcoal was investigated with configurations as shown in Figure 3. Briquettes were extruded from a mold through a die by means of a hydraulic press. These briquettes were prepared from 300-mesh air float charcoal and briquetting starch mixture. These briquettes were successfully ignited to boil water in about 17 minutes. The briquettes, about 2 inches in size, had a central 5/8-inch hole. One form was shaped similarly to a Maltese Cross, another was round, like a doughnut. The performance of these briquettes was comparable with those of the Quaker Oats Company. The extrusion of a perforated cake one quarter the size of that supplied in Phase I was also attempted. Difficulties were encountered in that water squeezed from the mold, the charcoal mix compacted, and pressure to move the mix became excessively high. The extruding pointed out that a carefully prepared mixture is necessary. An extrusion process would require special control in the manufacturing process.

The extrusion process is unique because of the gear-shaped style of briquettes manufactured. The gears (2 in. in diameter and with a central 1/4-in. hole) provide numerous kindling edges for ignition, consequently, good starting characteristics are obtained with this type of briquette. These briquettes are sold commercially with hickory as an additive. The hickory is undesirable for this application because of its smoke and odor-producing properties. In the course of this work, the Quaker Oats Company was cooperative in providing briquettes without hickory, with 5/8-inch holes, and in several thicknesses.

Pure Oil Company also provided briquettes for this experimental program. These were rounded, impregnated with an oil base to give self-igniting characteristics, and were packaged in a Mylar bag. The odor from these briquettes was quite objectionable and, therefore, they were unacceptable for this application.

The Quaker Oats Company briquettes were subjected to extensive testing. The optimum arrangement was obtained by crushing them into granules approximately one-quarter the original size (about No. 2 mesh). Table V lists the results of the fuel evaluation tests with gear-shaped briquettes, both crushed and uncrushed. These briquettes were packaged in a fuel tray approximately 10 inches by 10 inches and 1-1/2 inches high. Ignition was further improved by placing several pieces of the fuel underneath the igniter sheet. This arrangement was ultimately used in the Phase II carbon heating unit that was delivered to the Natick Laboratories.

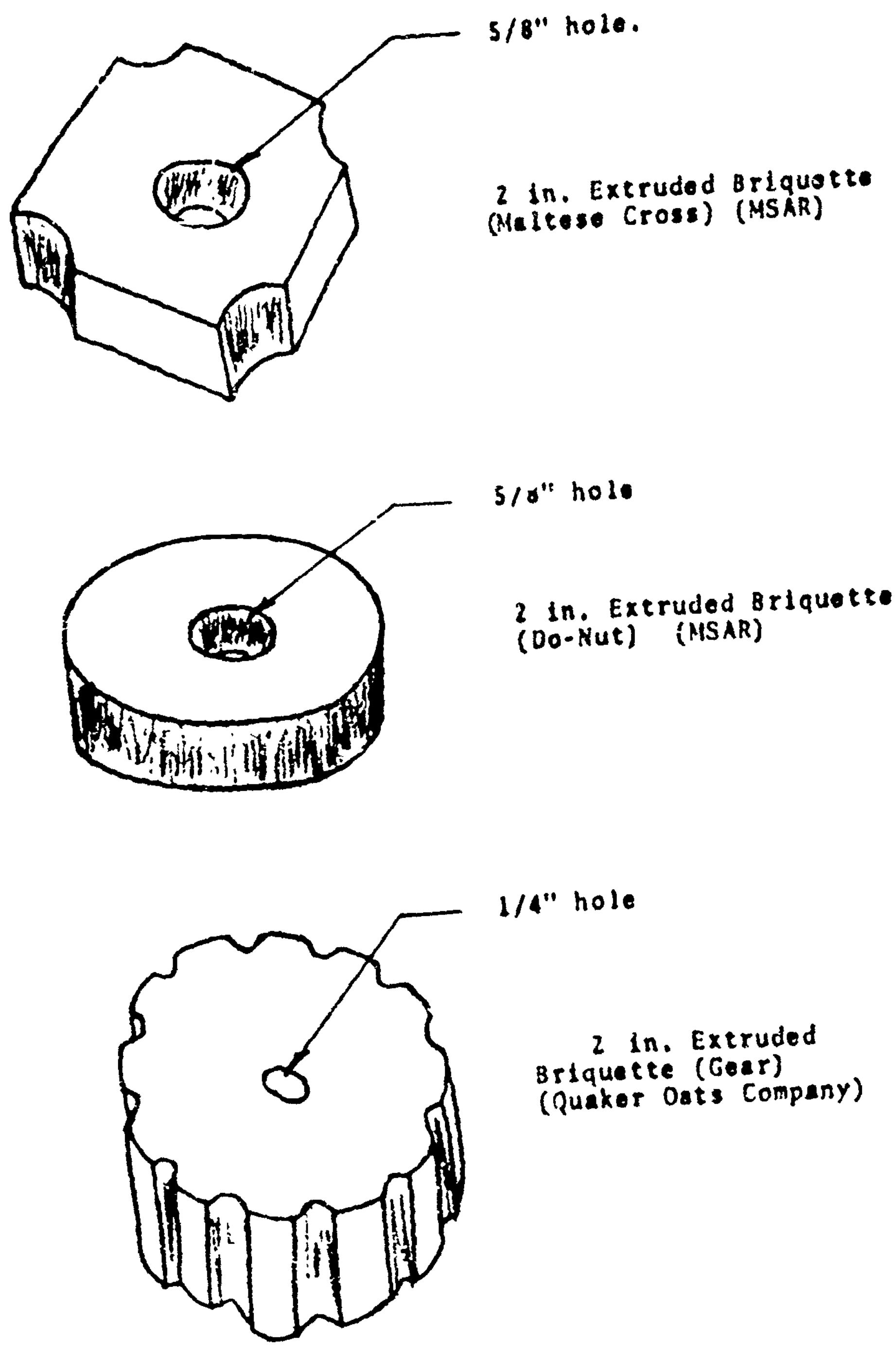


FIG. 3 - EXTRUDED CHARCOAL BRIQUETTES

TABLE V - RESULTS OF FUEL EVALUATION TESTS - PHASE II - ON GEAR-SHAPED BRIQUETTES

(12 in. high chimney, aluminum foil reflector, 10 in. x 10 in. fuel tray
Delrin igniter, MSAR in-house 4-point stove)

Tests conducted with 6 qts. water or ice

Test Set	Briquettes: Nominal Thickness (in.) 5/8	7/8	1-1/4	Packaging in Trays: Uniform	Scattered	Other	Processing: Carb.	Non-Carb.	Amb. Temp. (°F)	Fuel Cage Wire Mesh Size No.	Time to Boil (min): Ice	Water	Remarks
1	x			x				x	50	1	-	16	Satisfactory structural design
			x					x	50	1	-	23-1/4	
2				x				x	40	1	42	-	Satisfactory
				x				x	40	2	45	-	structural design
				x				x	40	3	43	-	3-mesh fuel cage difficult to light
3	x			x				x	22	1	-	18	
	x					Broken*		x	22	2	-	14	Satisfactory
	x				x			x	22	2	-	16 1/4	
4	x			x				x	48	[illegible]	44	-	
			x	x			x		28	2	41-1/2	-	"
	x			x			x		28	2	41-1/2	-	
5		x		x			x		8	2	48	-	"
	x					on end			8	2***	49	-	
6	x				x		x		20	2	37	-	
	x					Broken**	x		20	2	28	-	Stove collapsed.
	x			x			x		20	2	47	-	
7	x					Broken**	x		14	2	25-3/4	-	Stoves and alum-
	x					Broken*	x		14	2	22	-	inum foil were
	x					Broken**		x	14	2	28	-	satisfactory.
8	x					Broken*		x	50	2	23	-	--
	x					Broken*		x	50	2	28	-	Unit cold soaked at 60°F. Stove collapsed.
9	x					Broken*		x	20	2	22-1/2	-	--
	x					Broken*		x	20	2	24	-	Unit cold soaked.
10	x					Broken*	•		35	2	22	-	Units cold soaked
	x					Broken*		x	35	2	22	-	at -60°F.

* - broken in quarters
** - broken in halves
*** - 8 in. x 8 in. tray

B. Chemical Investigations With Fuels

Chemical means of improving combustion efficiency were investigated with carbon fuels and with the igniter. Combustion improvements that were possible, however, were found to be impractical from the standpoint of cost, odor, and manufacturing methods.

Both the fuel cakes of Phase I and the briquettes used in Phase II were investigated. The CO output from the Quaker Oats Briquettes was higher than from the fuel cakes.

1. Fuel Cakes of Phase I

The fuel cakes, of the configuration used in Phase I, were prepared with the chemical agents dried, charred, and ignited. The cakes were tested in a combustion cell (Fig. 4) and monitored for CO. The CO concentration in the flue was plotted against time (Fig. 5). The iron oxide was shown to be the most effective agent for lowering the CO level and manganese powder was the next most effective. A fuel cake prepared with no additives (No. 71) evolved more CO per pound of carbon than did any of the other specially treated cakes (approximately seven times that evolved by a cake with iron oxide). These data are given in Table VI. Since CO is evolved, the use of any additive may not be warranted for this application.

The fuel cakes discussed above were prepared with air-float type charcoal. A very interesting phenomenon resulted from the cake in which potassium permanganate was added (No. 82). This cake possessed spontaneous ignition properties, hence theoretically would not require an igniter sheet or matches. All charcoal spontaneously ignites after carbonizing when subjected to the proper conditions. The addition of potassium permanganate extends the spontaneous ignition properties. This blend possessed self-ignition properties even after 48 hours, which is the cooling time required by ICC before shipment.

In general, the combustion of charcoal fuel cakes blended with additives was more rapid.

1. The more porous the fuel cake, the more rapid was combustion. In some cases, as little as 7-1/4 minutes was required to bring 6 quarts of water to a boil. This was thought to be primarily due to increased porosity of the cake rather than to the additive.
2. Perforated fuel cakes burn more rapidly than the briquettes. Evidently the holes permit more air flow than is possible with briquettes.

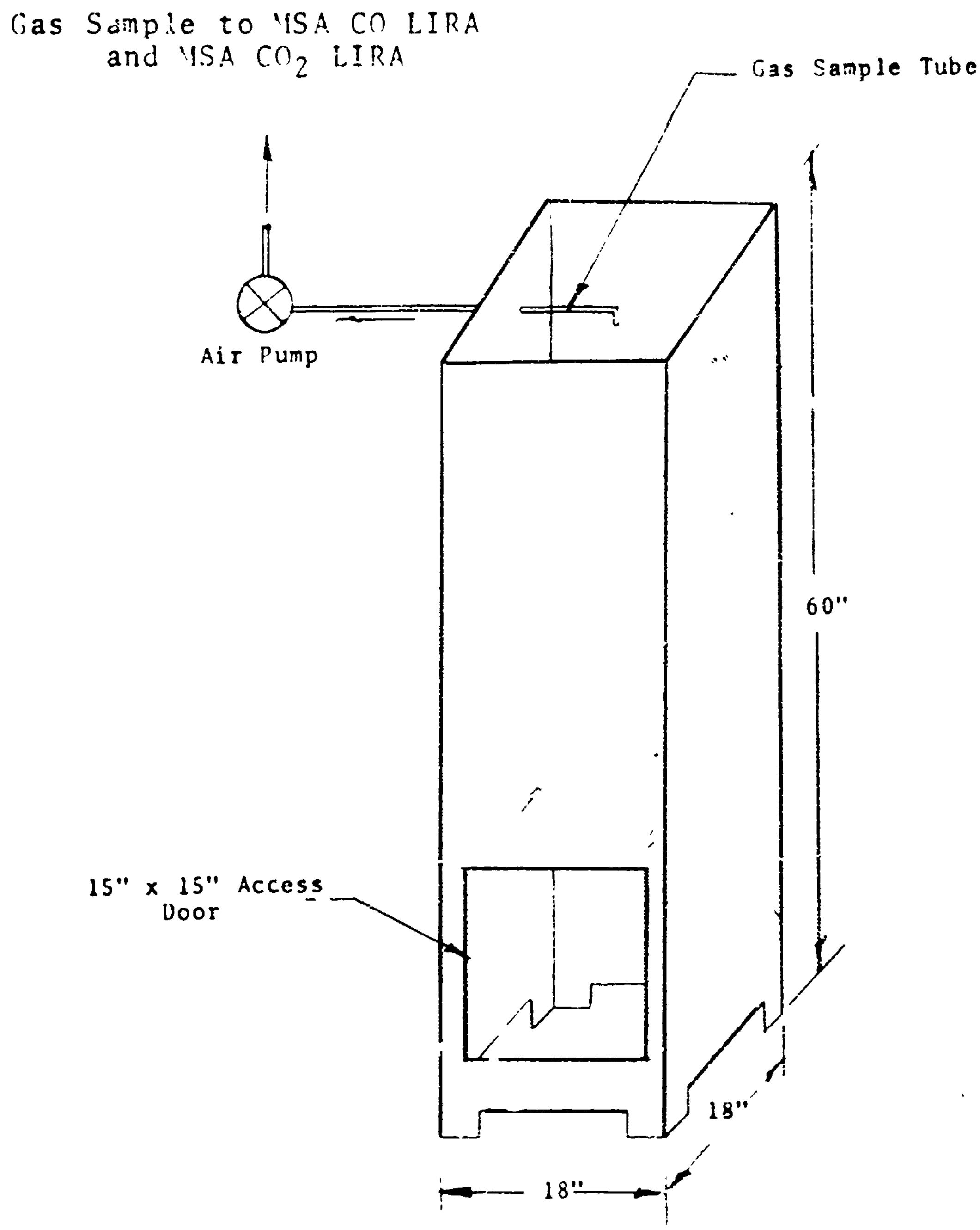


FIG. 4 - COMBUSTION CELL TO MONITOR FLUE GAS FROM CARBON HEATING UNIT

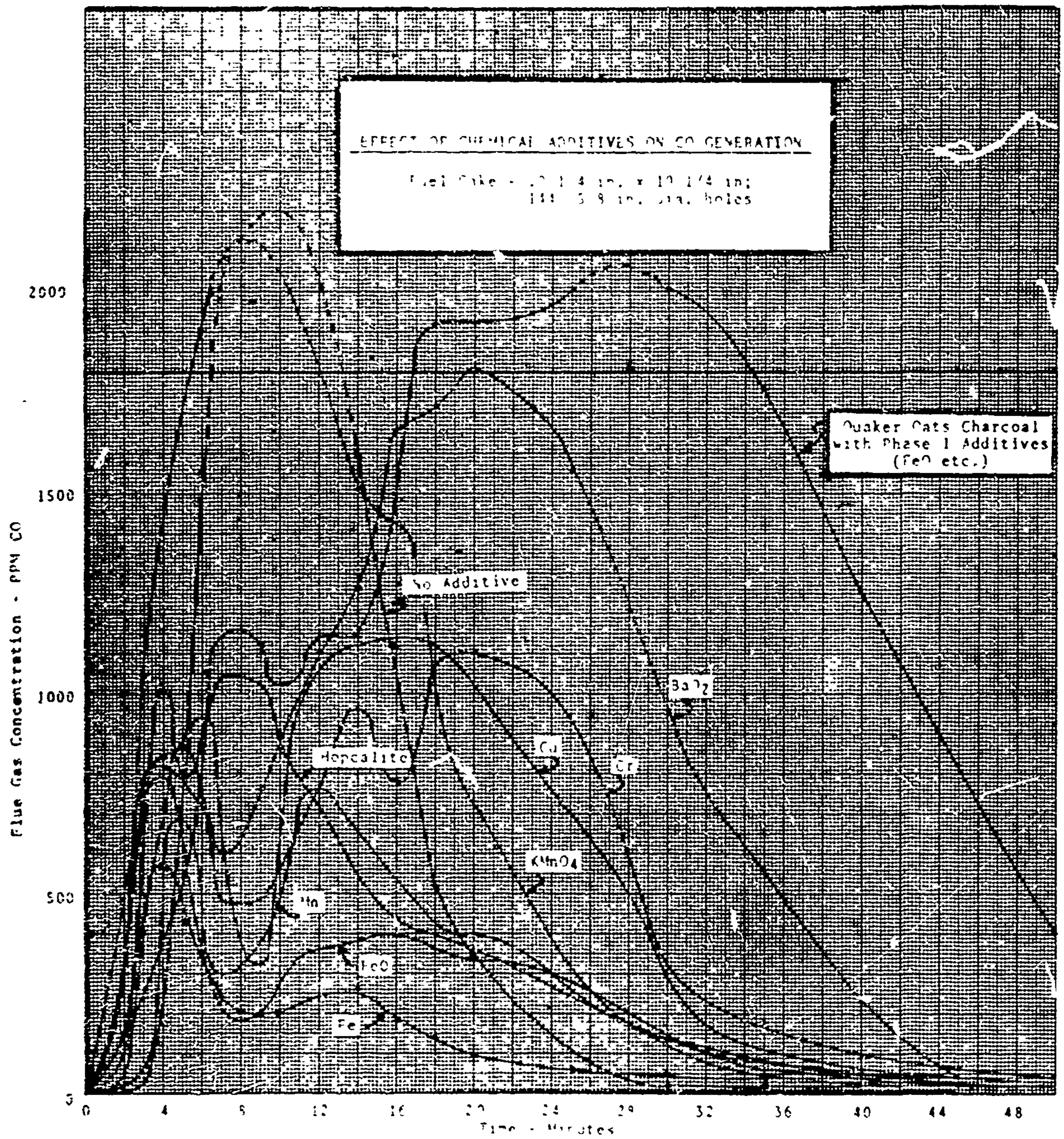


FIG 5 - CARBON MONOXIDE GENERATED FROM COMBUSTION OF CHARCOAL FUEL

TABLE VI - CHEMICAL ADDITIVE TESTS

Test No.	Additive	Cake Wt. (g)	Max. CO (ppm)	Avg. CO (ppm)	Avg. CO_2 (%)	Time to Burn (min)	Thermal* Eff.	Total* CO (cu ft)	Ratio* (cu ft CO/lb C)	Burning* Rate lb C/min)	Time to Boil (min)	Comments
62	Mn	405	840	432	0.542	48	38.8	2.27	2.6	0.0186	9-1/2	Little smoke or odor.
63	Mn	363	760	437	0.407	38	36.6	2.57	3.2	0.0186	9-3/4	Little smoke or odor.
64	FeO	491	790	326	0.522	43	35.5	2.03	1.9	0.0252	10	Little smoke or odor.
65	Hopcalite	241	1040	550	0.460	43	38.4	1.90	3.6	0.0128	12	Weak cake - little smoke or odor.
66	Cu	328	1140	603	0.395	48	36.6	3.30	4.6	0.0151	12	Little smoke or odor.
67	Cr	371	1100	555	0.417	48	37.0	3.26	4.0	0.0176	12	Little smoke or odor.
68	BaO_2	357	1810	895	0.444	43	38.8	4.75	6.0	0.0183	11	Little smoke or odor.
69	$NaHCO_3$	292	2000	918	0.471	48	40.5	3.75	5.9	0.0134	10	Little smoke or odor.
70	FeO**	724	2000	987	0.243	63	24.2	19.4	12.1	0.0253	12-1/2	More smoke and odor than with air float.
71	None***	467	2000	1060	0.21	33	43.4	15.1	14.7	0.0313	8	Little smoke or odor.
72	Wheelerite	484	1700	727	0.50	50	--	--	--	--	7-1/4	Ammonia fumes.
73	$Pb(C_2H_3O_2)_2$	477	2000	1070	0.47	43	57.0	5.0	7.0	0.0168	7-1/2	Noticeable odor.
82	$KMnO_4$	146	2000	1195	0.48	50	--	--	--	--	9	Some odor - this blend spontaneously ignited.

* See Appendix B for sample calculation.
** Quaker Oats briquettes were crushed and made into a cake with FeO.
*** Air float charcoal (300 mesh) mixed with starch and sugar but no FeO.

2. Briquettes

An attempt was made to impregnate the commercial briquettes with additives. They were soaked with a solution of sodium chlorate (an oxidizing agent) with the hope of accelerating combustion, but this was unsuccessful primarily because of the quantity of smoke evolved during burning.

The briquettes received from Pure Oil Company were treated with a naphtha-base compound. These briquettes also evolved substantial amounts of smoke hence were considered unsuitable.

Grinding the briquettes into smaller particles proved to be the most effective method of improving their combustion characteristics.

C. Igniter

The characteristics sought in an igniter were low cost and a non-luminous flame. Both Delrin and Celcon, which are similar, possess non-luminous flames and both effectively ignite charcoal.

A series of igniters screened in an evaluation test showed Delrin (No. 4) and Celcon (No. 1) to be the most desirable from the standpoint of performance (Table VII) although both emitted a formaldehyde-like odor. Although complete elimination of odor could be obtained with heat paper, the paper is undesirable because of its cost and high flame level. Plastic type igniters other than Delrin and Celcon generally have slow, sooty, combustion properties, hence were not acceptable.

Oxidizing solutions (chlorates and nitrates) applied to absorbent papers were unsuccessful because all produced excessive smoke.

Results of tests of various igniters used with charcoal fuel cakes are given in Table VIII. The igniter selected was the 10-mil Delrin sheet to which two 3/8 by 4-inch tabs of nitrocellulose were stapled for quick ignition. (Delrin tabs stapled to the igniter Delrin sheet were less effective than nitrocellulose tabs.) An all-nitrocellulose igniter was unacceptable because of its luminosity (Table VII) and high flame level. However, nitrocellulose tabs were more effective than the Delrin to start ignition, especially at sub-freezing temperatures.

Delrin is a commercial item that can be bought conveniently. The Delrin sheets supplied with the first unit were expensive (approximately $0.10 each for virgin Delrin made into flawless film).

TABLE VII - SCREEN TESTS TO EVALUATE CHARACTERISTICS OF IGNITERS

Sample Size: Tabs, 1/2 in. Wide x 4 in. Long

Test No.	Material	Specimen Size	Ambient Temp. (°F)	Flame Characteristics	Smoke	Odor	Remarks
1	Celcon	TAB	70	Non-luminous	-	Yes	Looked similar to Delrin. Some dripping.
2	Nitrocellulose	TAB	70	Yellow - large flame	Yes (sooty)	Yes	
3a	Nitrocellulose (flame retardent)	TAB-0.010 in.	70	Rather luminous	-	Some	All three thicknesses ignited.
3b	Nitrocellulose (flame retardent)	TAB-0.015 in.	70	Rather luminous	-	Some	" " " "
3c	Nitrocellulose (flame retardent)	TAB-0.020 in.	70	Rather luminous	-	Some	" " " "
4	Delrin	TAB	-20	Non-luminous	-	-	Screened samples of both painted and unpainted tabs.
	Nitrocellulose	TAB	-20	Luminous	-	-	All ignited.
5	Polyethylene bag	TAB	70	Luminous	Yes (sooty)	Yes	Rather hard to ignite, quick burning.
6	Bagee (Saran)	TAB	70	Luminous	Yes	Yes	Hard to ignite - but burned fast when it did.
7	Wax Paper	TAB	70	Luminous	Yes	Yes paraffin	Burned fast.
8	Nylon	TAB	70	Non-luminous	Yes	Yes	Self extinguishing.
9	Polycarbonate	TAB	70	Luminous	Yes (sooty)	Yes	Very sooty.
10	Acetate	TAB	70	-	Yes (Heavy)	Yes	Self extinguishing.
11	Polyethylene	TAB	70	Luminous	Heavy	Yes	Lot of flame. Burned fast.
12	Polypropylene	TAB	70	Not too luminous	Heavy, sooty	Yes objectionable	Heavy smoke, sooty flame, high.
13	PVC	TAB	70	Yellow	Sooty, very	Yes objectionable	Self extinguishing, hard to ignite.
14	Cellulose acetate	TAB	70	Yellow, very low	Sooty, heavy	Yes objectionable	Very sooty, luminous, high dripping.
15	Vinyl	TAB	70	Very hard to ignite	Dirty	-	--
16	Flexible vinyl	TAB	70	Very luminous - yellow	Heavy Soot - Dirty	Yes	Tended to extinguish.
17	Plexiglass G	TAB	70	Very slow burning - yellow flame	Rather Clean	Rather Clean	No noticeable drip.
18	Catalyst heat paper	TAB	70	Very luminous - bright flame	None	None	Ran with 144 holes in paper - worked well.
19	Catalyst heat paper slow boron type	TAB	70	Very luminous - bright flame	None	None	" " " " "
20	Lustran I - 461 Monsanto ABS polymer	TAB-0.015 in.	70	Yellow flame	Very sooty		Not promising.

TABLE VIII - IGNITION TESTS WITH CHARCOAL FUEL CAKES

Charcoal Fuel Cakes Description

Geometry: 10 1/4 in. x 10 1/4 in. x 1 in; 144 5/8 in. dia. Holes

Composition: Charcoal - 64.8%
Starch - 6.2%
Sugar - 11.6%
Iron Oxide - 17.4%

Tests Conducted With 6 1/2 qts Water and Heat Shield

Test No.	Igniter Identification	Weight of Cake (gms)	Temp (°F) Ambient	Temp (°F) Water	Wind Velocity (MPH)	Time to Boil (min-sec)	Total Time (min)	Water Evap. (lb-oz)	Therm. Eff. (%)	Remarks
31	Fuel cake encased in 3-mil polyethylene bag	763	58	68	0-3	12 45	56	7-5	42.3	Tightly sealed cake in present shipping plastic bag slow to start. [illegible] 8 min for bag to burn out. Heated fast after bag was ignited.
32	Catalyst Research Corp. heat paper, Type P/N 401811	782	83	66	0-5	27 0	65	-		Fuel was slow to burn even though heat paper burned in 1 sec. The solid sheet of residue from paper blocked cake holes, which probably cut down rate.
33a	Delrin Sheet, 10-mil thick	781	82	64	0-2	11 45	57	7-7	42.1	
33b	Nitrocellulose, flame retardant, 10-mil thick	762	82	66	0-2	Did not ignite cake. Failure				Smoked and flamed badly for 35 sec. No ignition.
33c	Nitrocellulose flame retardant, 20-mil thick	783	82	56		Did not ignite cake. Failure				Smoked and flamed badly for 35 sec. No ignition.
34a	Catalyst Heat paper, Type P/N 401811, perforated with 144 1/2-in. dia. holes	763	80	70	0-5	10 15	55	8-0	45.1	Burned igniter in less than 1 sec. Perforated.
35b	Delrin sheet, 10-mil thick perforated with 144 1/2-in. dia. holes	785	80	71	0-5	10 20	52	7-8	41.8	Not as much smoke or drippings. Looks as though optimum efficiency from ignition, thermally. Appears only improvement is from toxic, odors, etc.
35c	Delrin sheet, 10-mil thick no holes	792	80	68	0-5	11 0	53	7-14	43.4	
36	Glass filter, 15-mil thick, perforated with 144 1/2-in. dia. holes. Paper treated with 90 gms Fe powder (Type Edison An-3), 10 gms $NaClO_3$, 40 cc H_2O and dried. Fuel cake was painted with mixture made of 71% Fe and 29% water.		82	66	0-5	24 0	85	-	-	Reason for slow boiling time was that the solution that the cake was painted with caused a shielded cake surface, thus keeping the air away from the cake. This slowed the combustion.
37a	Glass filter, 15-mil thick, perforated with 144 1/2-in. dia. holes. Paper treated with 90 gms Fe powder (Type An-3) 10 gms $NaClO_3$, 40 cc H_2O and dried.	782	54	64	0-2	31 0	77	-	-	Smoked at start only.
37b	Heat paper perforated with 140 1/2 in. dia. holes.	812	54	64	0-2	10 30	56	-	-	Bright glow from heat paper.

The manufacturers claimed that reworked scrap could lower the cost, possibly to $0.05 each. Advances in manufacturing could result in extruding Delrin sheets directly, which would also lower the cost.

D. Stove Support

The Phase I stove is expensive to manufacture. A lower cost and more compact stove was developed for Phase II. The positioning of the fuel relative to the base and to the bottom of the water container to be heated are important considerations in the design of these stoves. Tests were conducted to determine the optimum positioning of the fuel and the clearances of the stove. Figure 6 shows the effect of distance on boiling water with charcoal fuel cakes. This plot shows that the optimum distance between the base reflector and the under surface of the fuel is approximately 1 inch. This plot also shows that the optimum distance between the top surface of the fuel and bottom surface of the water container is approximately 2-1/2 to 3 inches. These values were used in evaluating stove concepts.

The fan-style stove depicted in Figure 7 was adopted for use in Phase II units. This stove also proved to be the lowest in cost on the basis of estimates from manufacturers. The stove consists of four members held together by a clip. Figure 8 shows details of the stove member. The segments of the stove were made from No. 9 gage steel wire. The fan is folded for packing and is unfolded for use. The middle rod supports the fuel tray. Clearance from the bottom of the stove is 2-1/8 inches. The overall height of the stove is approximately 5 inches.

Figure 9 shows other stove concepts. The fan-style stove appears at the top of the figure. The original model (top left) had three members. Hotter burning fuels develop higher temperatures, thus, the greater strength and stability of a four-member stove was required. The higher temperatures also made it necessary to increase the distance between the base reflector and the bottom of the fuel (from 1 inch to 2-1/8 inches) to prevent the softening and bending of the stove wire.

E. Chimney

To lower its cost and yet provide the functions intended, several changes in its design were considered.

If the height of the chimney was reduced from 12 to 8 inches, effective heating could be achieved at less cost.

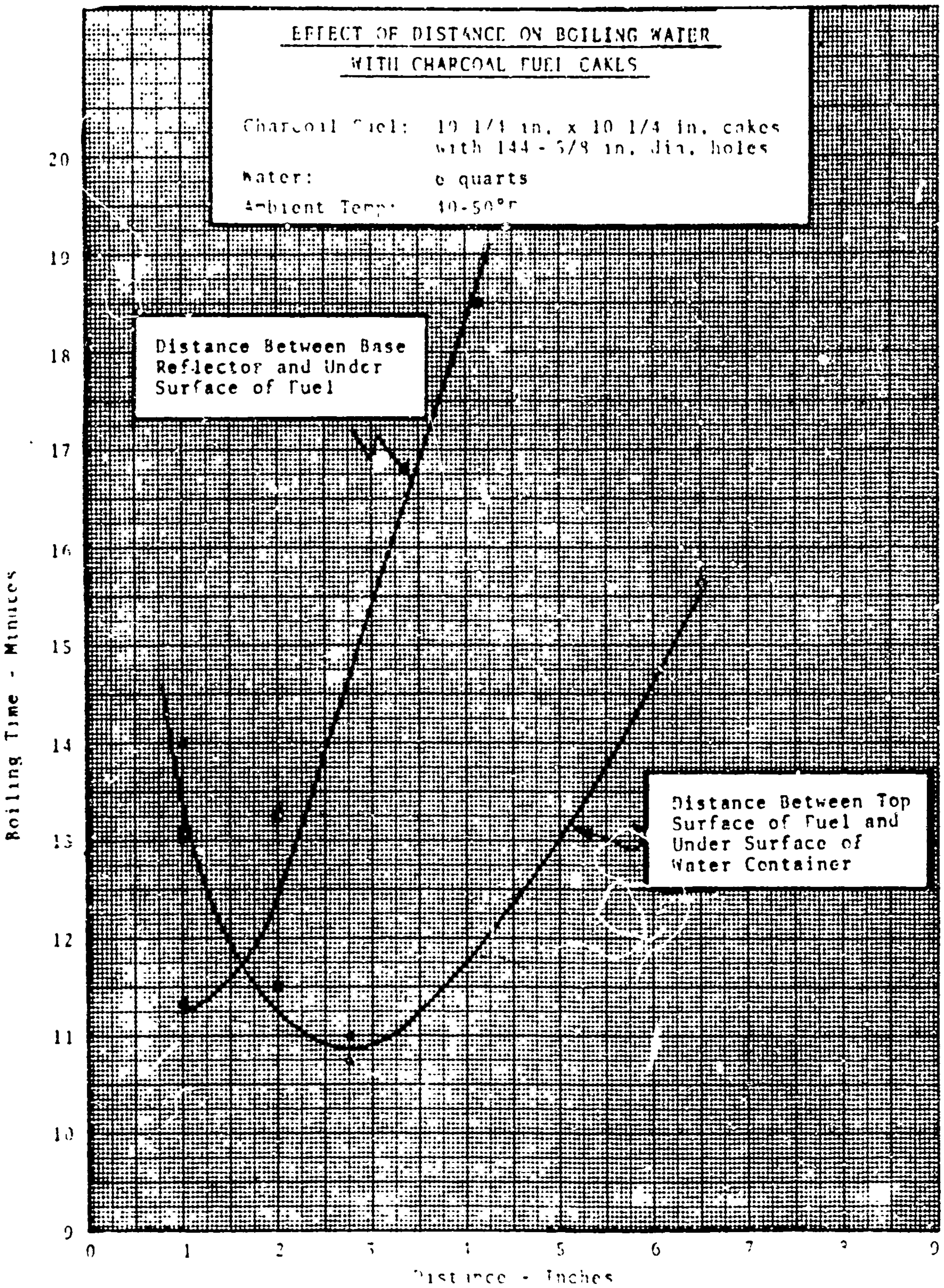


FIG. 6 - DIMENSIONAL FACTORS IN THE DESIGN OF THE STOVE

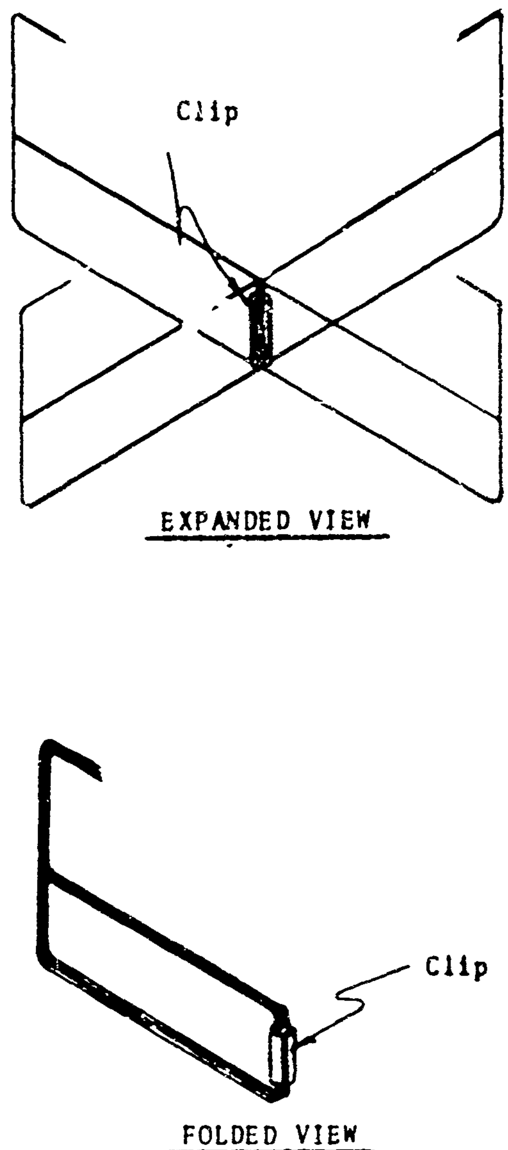


FIG. 7 - FAN-STYLE STOVE SUPPORT FOR PHASE II
CARBON HEATING UNIT

Notes

1. No. 9 Gage Wire (0.148")
2. Material - C 1008/1010 steel wire
3. Plain Finish

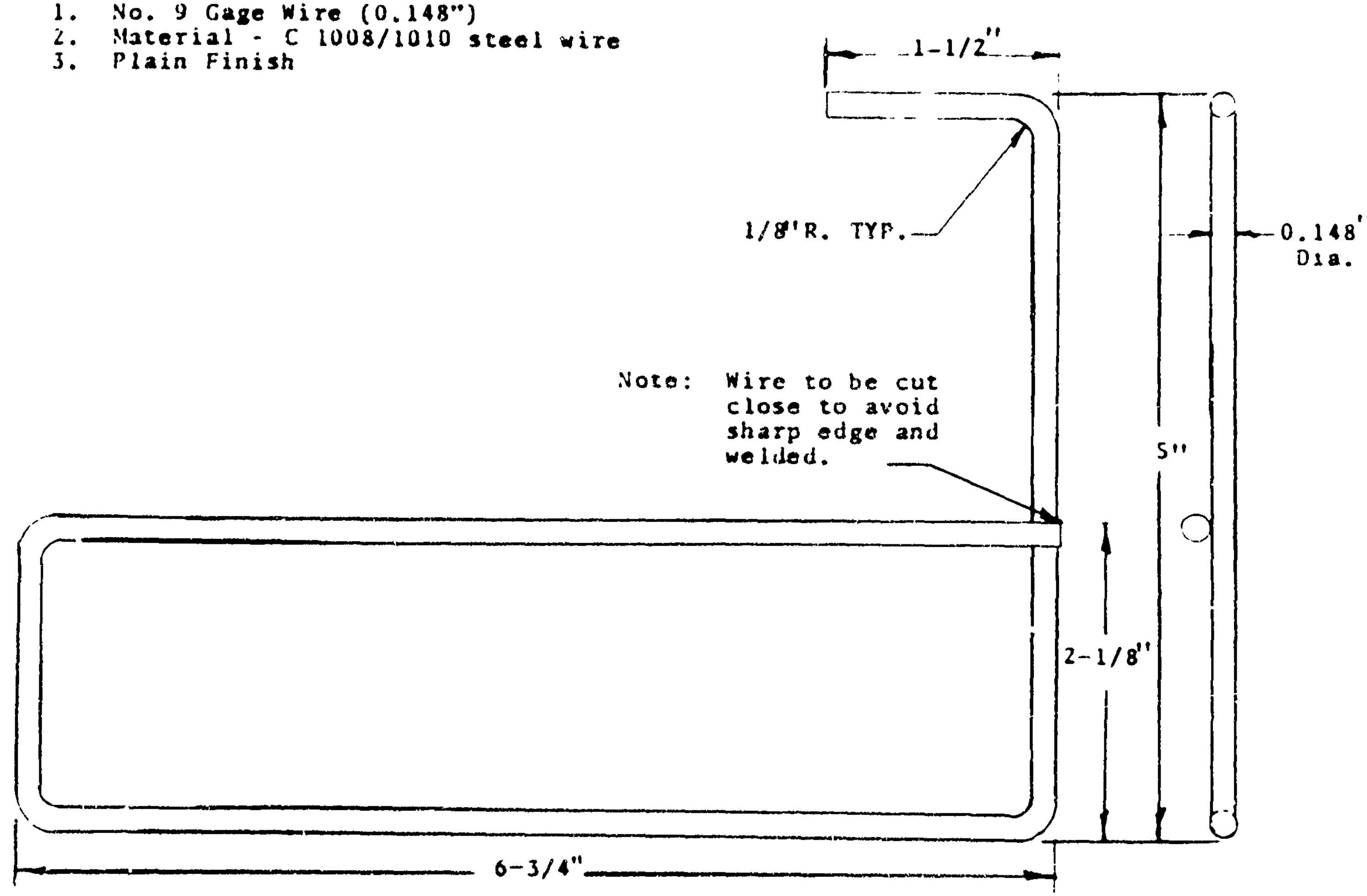


FIG. 8 - DIMENSIONAL DETAIL OF PHASE II CARBON HEATING UNIT STOVE SUPPORT

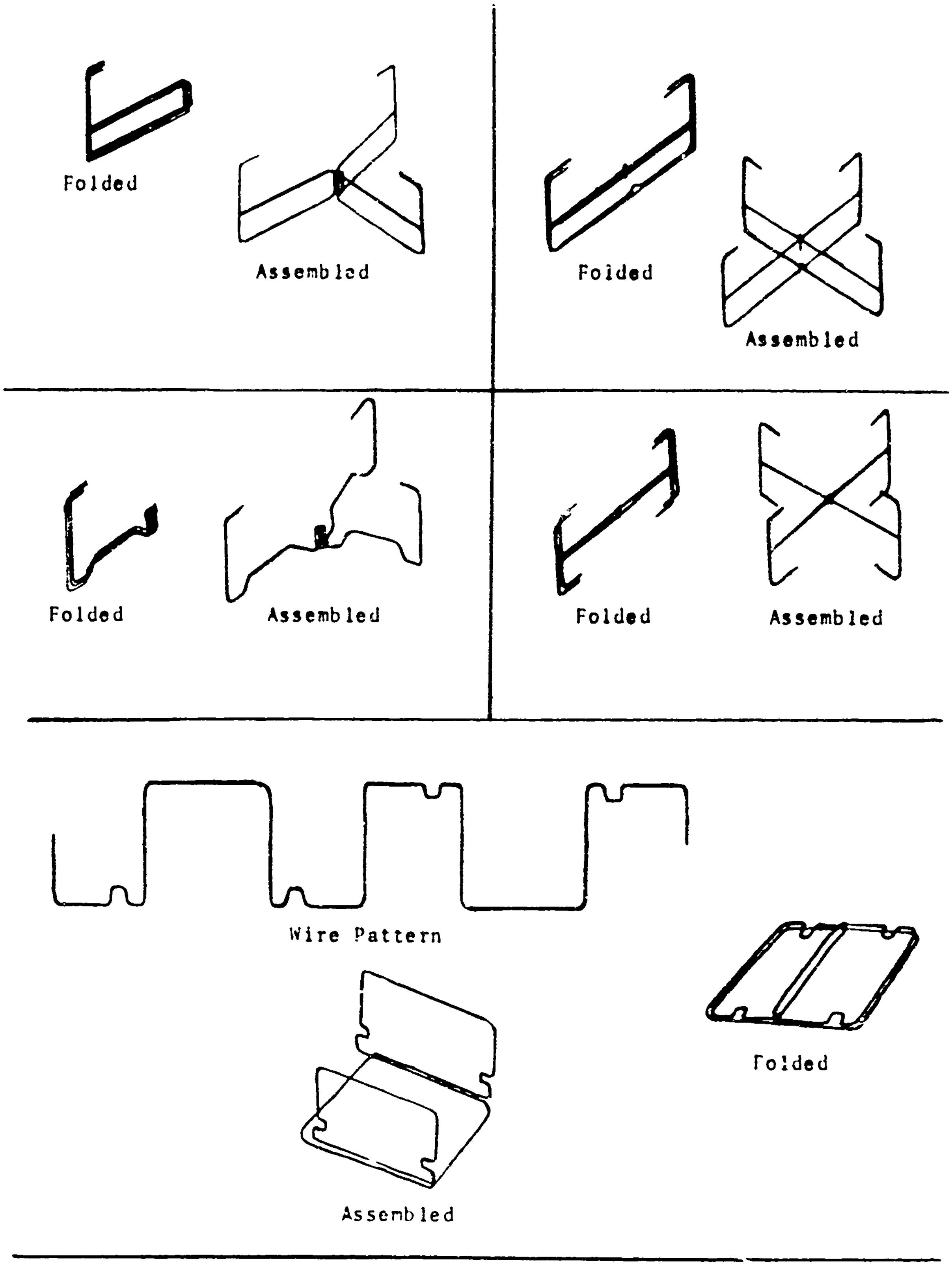


FIG. 9 - SOME STOVE CONCEPTS EVALUATED FOR THE PHASE II CARBON HEATING UNITS

Tests showed that a chimney is essential; it is impossible to bring water to a boil without one. A chimney was fabricated from 1-1/2 mil aluminum foil having two layers of non-reflective olive drab coating. At 8 inches, the water level in the container was at the same elevation as the foil. This heat was adequate to bring water to a boil at ambient conditions without any changes in the former times noted. However, at sub-freezing temperatures, the reduced height required a much longer time to bring water to a boil, therefore the height was retained at 12 inches.

Tests were also made to determine the influence of the reflective surface. When the painted surface was placed inside and the reflective surface outside, no difference in boiling time was noted. This led to the conclusion that the chimney is more of a convective than a radiation shield. The elimination of one layer of coating permitted some reduction in the cost.

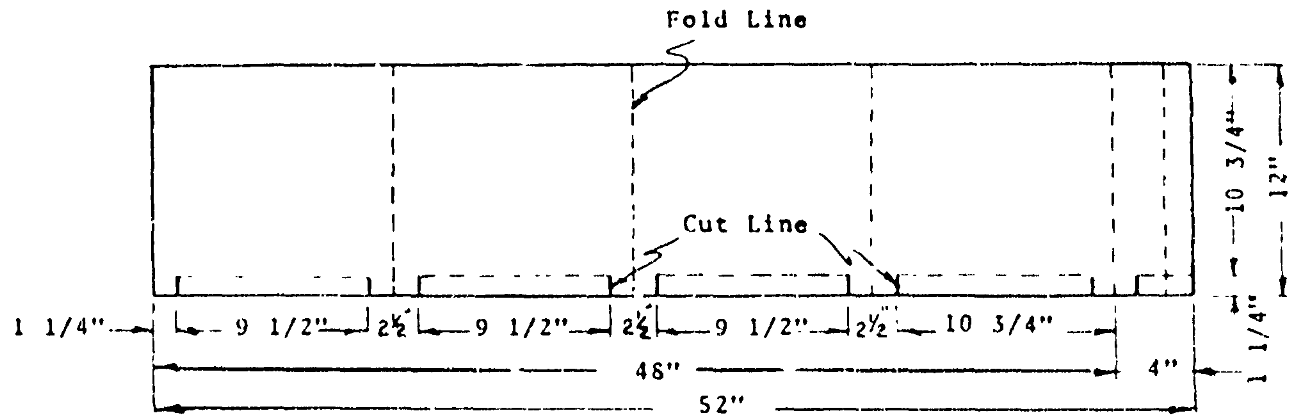
The strength, heat resistance, and cost of substitute materials for aluminum foil were considered. Chimneys were made from glass paper, but glass paper is more expensive and is subject to tearing. Asbestos paper behaved similarly; therefore, both were considered less desirable than aluminum foil.

The chimney design selected for the carbon heating units is shown in Figure 10. This figure shows the layout of the template from which the chimney is fabricated.

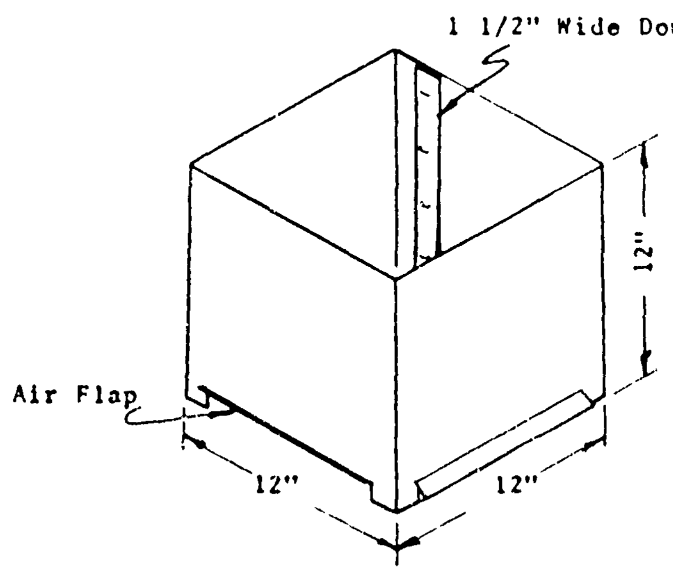
F. Base Reflector

The base reflector used in Phase I provided support as well as a reflective surface. The reflective surface is important since it reduces boiling time. Tests run without a base reflector required approximately 1-1/2 minutes longer to bring water to the boil. Thus, the reflective surface was considered functional and was retained.

The objection to the Phase I base reflector, which was made of 15-mil aluminum sheet, was its high cost. A 12-inch square of ordinary household aluminum foil provides the same reflective surface, so it was used as the base reflector in the Phase II units. However, aluminum foil provides no support, other means must be provided to support the overall unit. The fiberboard used to package the food containers can serve this purpose. Tests showed that, although fiberboard will char during the ignition and combustion of the heating unit, it does not proceed to the point that rigidity is lost.



CHIMNEY TEMPLATE



Material: Reynolds Aluminum Foil 1235-0 temper, 1 1/2 mil thick dry annealed, single olive drab coat on mat side.

FIG. 10 - CHIMNEY DESIGN

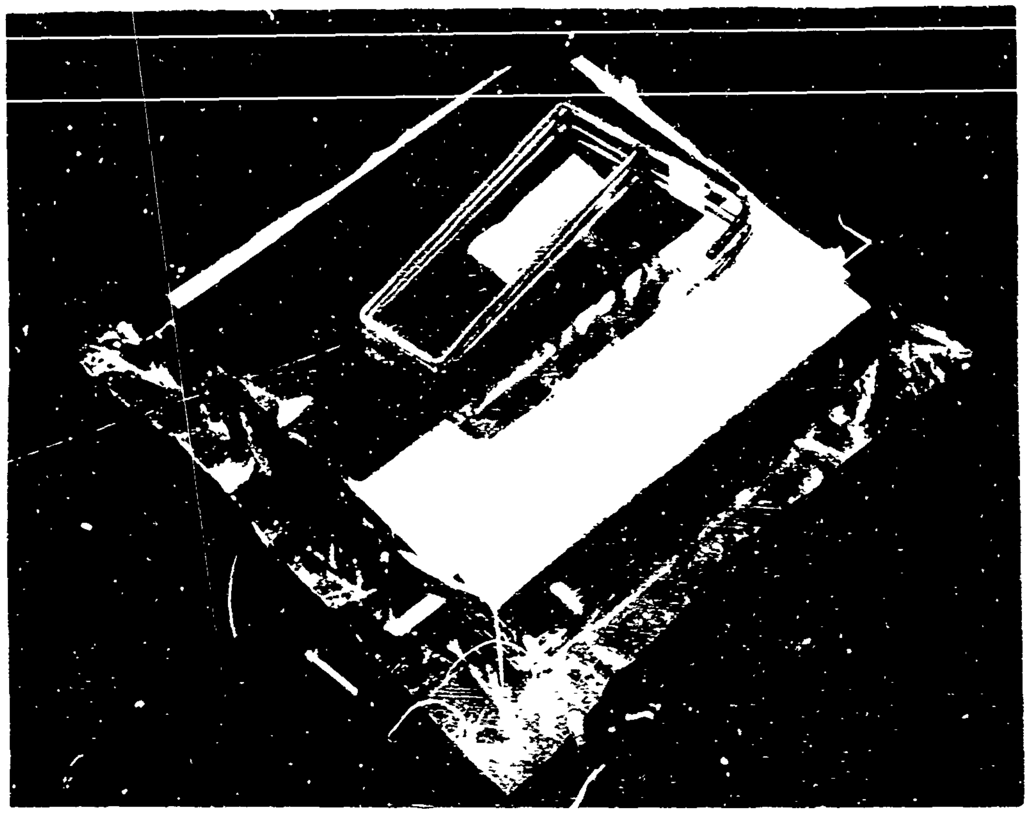
IV. Phase II Carbon Heating Unit

A. Production

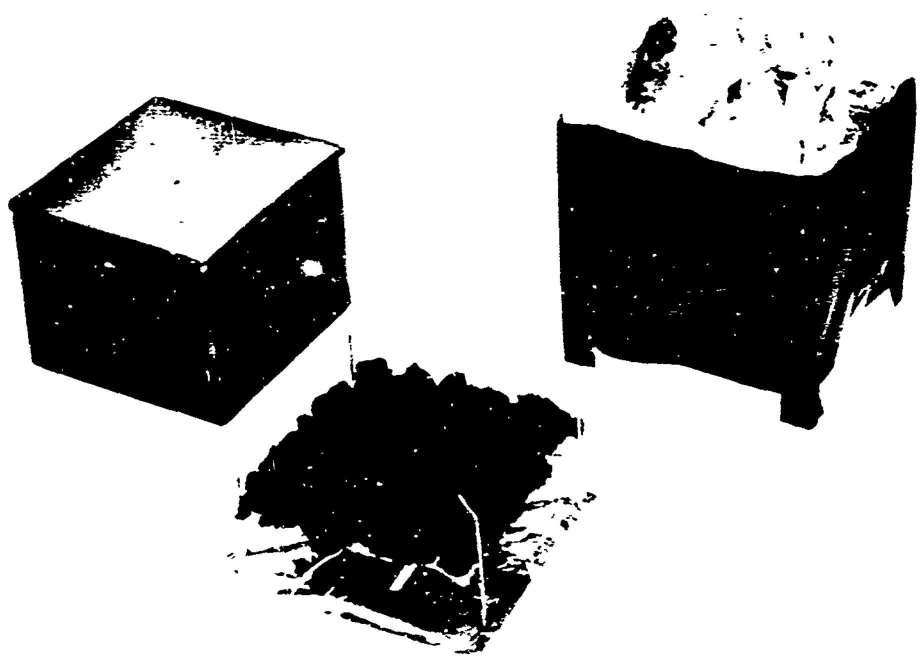
The production requirement of Phase II called for 500 carbon heating units designed to feature improved performance and reduced production time over the earlier models. Commercially available, low-cost gear-shaped charcoal briquettes were substituted for the fuel slab of Phase I. A new stove of more compact design was developed. Changes were made in the basket and base reflector. Maximum fuel efficiency was gained through the optimum geometrical spacing of the fuel and water container. The packaged components of the Phase II unit is shown in Figure 11.

The use of commercially obtainable gear-shaped charcoal briquettes eliminated the need for blending, pressing, drying, carbonizing, wrapping in foil, and unwrapping. To improve the comparatively poor combustion efficiency of the 2 by 7/8-inch briquette, No. 2 mesh (1/2-inch) granules were formed by crushing and screening. This was the only change made. Although smoke and odor were more pronounced with this fuel than with the fuel slab (some smoke was also caused by the coated aluminum shield), this was not thought to be serious since the units are to be used in ventilated areas. Approximately 15 percent of the charcoal was lost as fines in the crushing process. A motorized Champion No. 25 ice crusher and a Sweco Model H-2D separator (18-inch screens) are shown in Figure 12, together with the original briquettes and resultant granules. The ice crusher prongs were more effective in breaking the briquettes than reciprocating jaw-type crushers, for the latter lead to high loss from fines. This equipment processed the granules at the rate of 1 pound per minute, conservatively. In large-scale production, larger crushers and separators could be used.

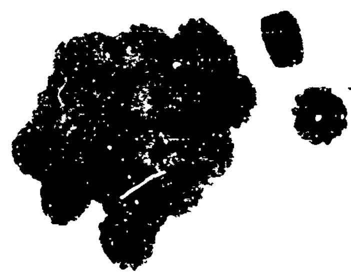
A 10-inch-square by 1-1/2-inch-high steel basket of No. 2 mesh, welded No. 19 wire (standard hardware cloth) was formed from 13-inch squares of mesh (cut from wide rolls) notched at the corners. (The wire can be fabricated into 13-inch rolls.) The baskets were formed by hand with a jurying arbor press to which a block was attached and which was operated by an air cylinder. The block drove the precut wire into a mold, where it was formed to shape and could be removed as a basket. For large-scale production, a die and pneumatic press could be used. The baskets were designed to hold 1.8 ($\pm$ 0.1) pounds of charcoal granules. First, several granules were placed in the basket (Figure 13), then the Delrin igniter sheet was inserted (its slight elevation due to the granules was found to improve the ignition). The basket was then filled with the rest of



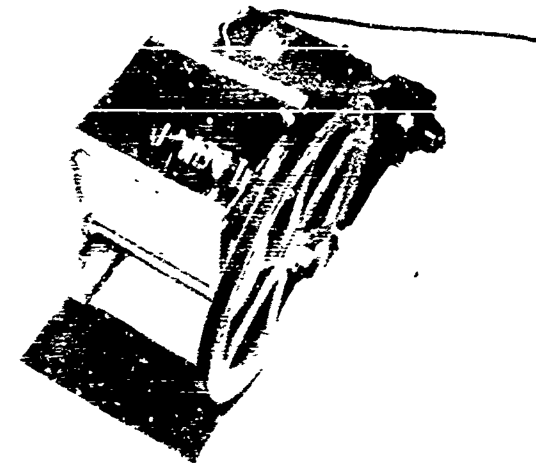
PHASE II CARBON HEATING UNIT
(Packaged)



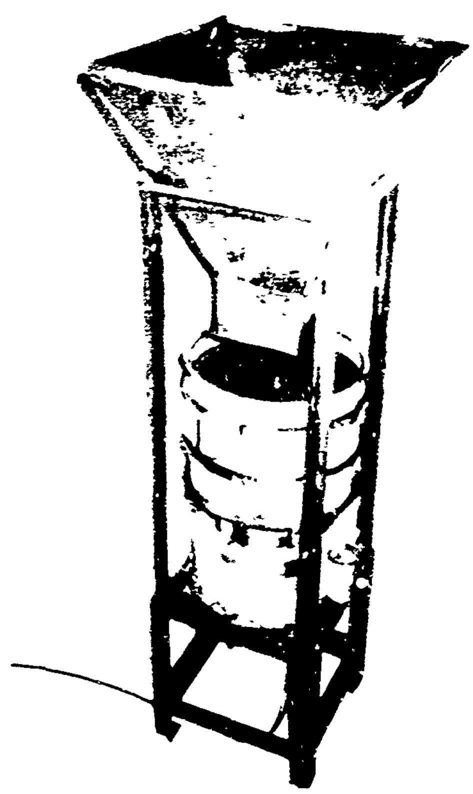
PHASE II CARBON HEATING UNIT
WITH SIX-IN-ONE MEAL CONTAINER



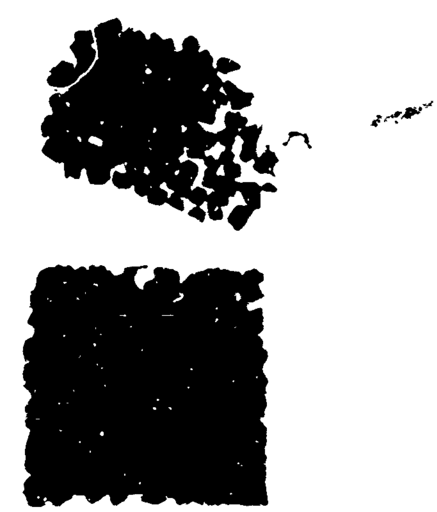
CHARCOAL BRIQUETTES



CRUSHER



SEPARATOR



FUEL GRANULES

FIG. 12 - PROCESS EQUIPMENT TO REDUCE CHARCOAL BRIQUETTES TO GRANULES

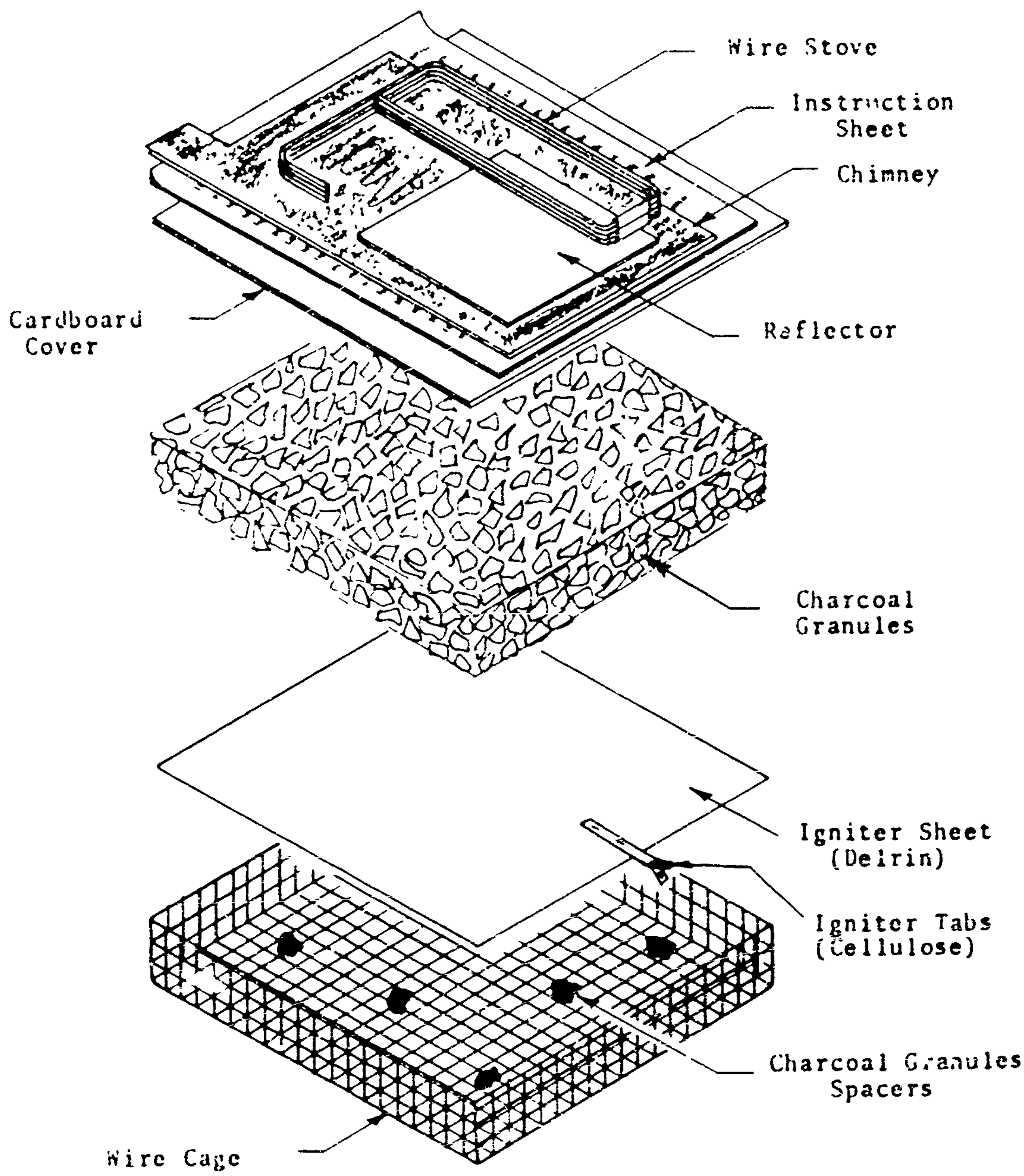


FIG. 13 - PHASE II CARBON HEATING UNIT PACKAGING ASSEMBLY

the granules by means of a volumetrically calibrated scoop. In large-scale production, the basket could be filled directly through a chute extending from the separator (see Flow Chart, Figure 14). A cardboard cover was added to hold the granules within the basket.

For the base reflector, household-type aluminum foil replaced the aluminum sheet. The foil, cut 12 inches square, was folded to a 6-inch square for packaging. It was less expensive and less bulky than the aluminum but not as structurally rigid as a base support. It was decided to use the cardboard cover with foil on top as the base.

The man-hours estimated to complete a Phase II unit was 0.3671 hour ($1, at $3 per hour) and the cost of the materials was estimated to be 55 cents, or a total cost of $1.55 per unit. Exhibits C and D give the breakdown of operations and materials costs on the basis of 100,000 or more units.

B. Results and Discussion

The packaging of the components is simple, but the production of the unit is less routine. A single shop would be unlikely to have the production diversity required. It would probably be best to subcontract the individual components. For instance, while the processing of charcoal briquettes could well be done by MSARC, the special tooling and equipment required for the stove could best be provided by a specialty wire manufacturer. However, basket forming and chimney production are not attractive to industry, hence the methods as described above, and using a paper-folding machine with adaptations, would probably prove to be the best solution. The cost of the chimney now remains the highest of any of the single-labor items involved. Its design cannot be simplified without sacrificing structural integrity, which is not feasible, and the thin aluminum foil requires careful manual handling and assembly.

V. Summary and Conclusions

The carbon heating units supplied for Phase I boiled six quarts of water in 10 minutes at an ambient air temperature of 68°F; six quarts of water as ice were thawed and brought to a boil in 21 minutes at a temperature of 50°F and in 30 minutes at -40°F. This high combustion efficiency of the charcoal fuel was obtained by special and relatively expensive processing. The units had to be used in a ventilated tent to prevent carbon monoxide buildup.

In Phase II, high combustion efficiency with lower CO output was sought at decreased cost. Charcoal formulations and fuel supply

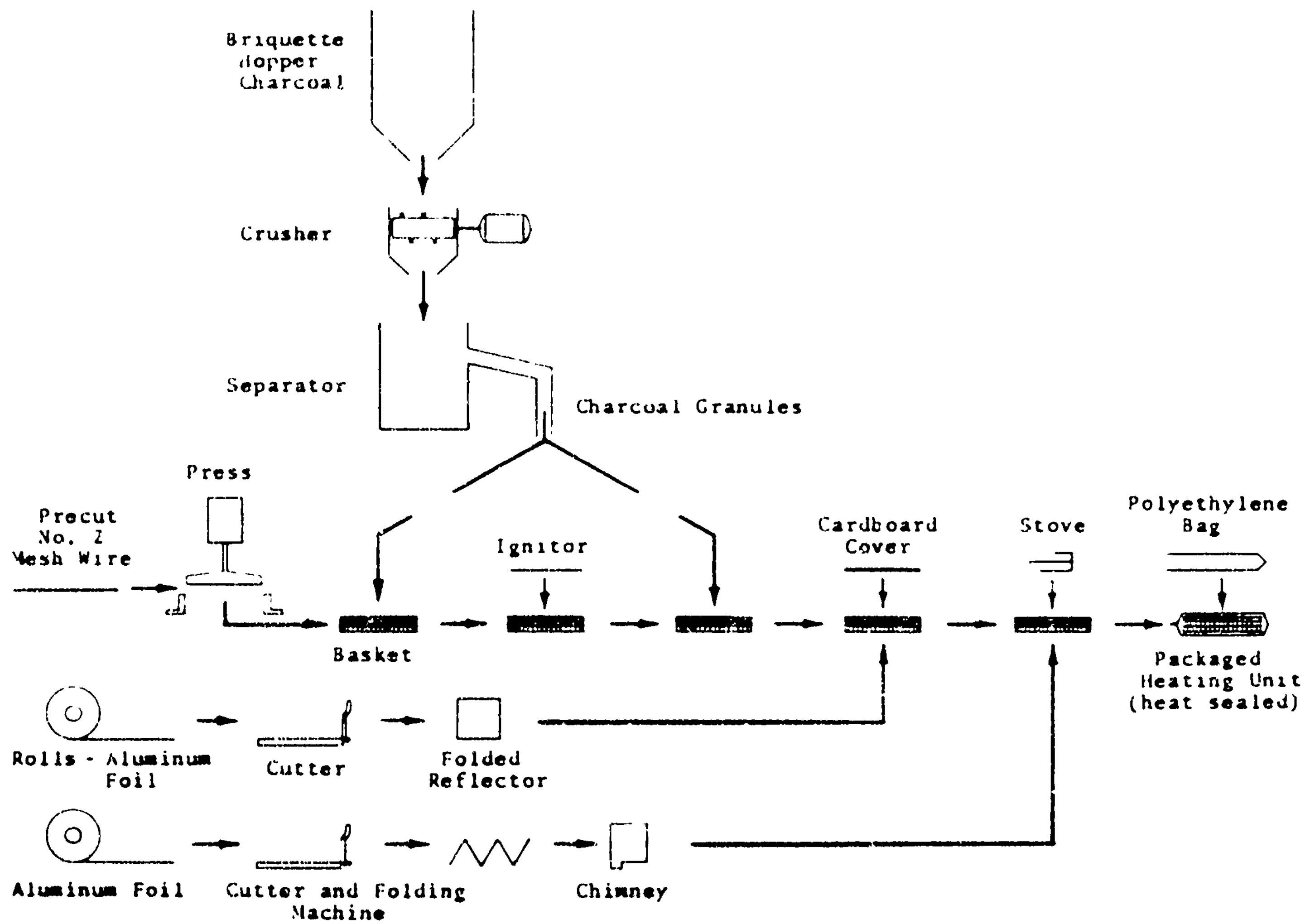


FIG. 14 - PROCESS FLOW SHEET FOR CARBON HEATING UNIT PRODUCTION

EXHIBIT C

OPERATION SEQUENCE FOR PHASE II
CARBON HEATING UNIT

No.	Operation Description	Each Piece Time (hr) Actual*	Projected**	Tools
1	Crush charcoal briquettes and screen	0.0167	0.0080	Crusher, separator
2	Cut wire and form basket	0.1000	0.0200	Shears, Arbor press
3	Precut cellulose tabs and paint, two	0.0100	0.0050	Paper cut-term spray gun
4	Staple tabs to igniter (Delrin)	0.0089	0.0039	Stapler
5	Place igniter sheet into basket and fill 1.8 lb ± 0.1 lb fuel granules	0.0200	0.0015	Hopper
6	Fold, cut form and staple chimney	0.1050	0.0500	Shears, table staplet
7	Cut and fold base reflector	0.0100	0.0075	Shears
8	Assemble contents and pack in plastic bag	0.0385	0.0300	Bench
9	Heat-seal bag	0.0350	0.0300	Heat sealer
10	Wrap and pack bags in carton (10/carton)	0.0140	0.0140	Bench
11	Crate, stencil ship	0.0090	--	Bench
	Total (hr)	0.3671	0.1699	

*For 500 units delivered in Phase II.
**On basis of 100 000 or more

EXHIBIT D

PROJECTED MATERIAL COST ESTIMATE FOR PHASE II
CARBON HEATING UNIT

(on basis of 100,000 or more)

	Item	Unit Cost ($)
1	Fuel, 1.8 lb @ $0.05/lb, Quaker Oats Co., Chicago, Illinois	0.0900
2	Stove, Anchor Wire Specialty, Homestead, Pennsylvania	0.1669
3	Wire basket, Wickwire Bros., Inc., Cortland, New York	0.0945
4	Delrin igniter, Danielson Mfg. Co., Danielson, Connecticut	0.0462
5	Chimney (3-1/2 lb, Olive Drab color) Reynolds Metals Co.	0.0965
6	Base reflector, aluminum foil, Bennett Paper Co., Pittsburgh, Pa.	0.0014
7	Cardboard cover, Keystone Box Company, Pittsburgh, Pennsylvania	0.0100
8	Polyethylene bag, Ken Covers, Lower Burrell, Pennsylvania	0.0221
9	Instruction sheet	0.0005
10	Cardboard carton (pro-rated for 10 units per box) Keystone Box Company, Pittsburgh, Pennsylvania	0.0262
	Total	$0.5543

Note: Figure 12 illustrates individual components arrangement of the Phase II Carbon Heating Unit.

geometries were studied and value analyses performed. To lower the CO output, the air-float charcoal was treated and blended with oxidizing agents. The most effective of these was iron powder and iron oxide, with manganese powder the next best. The special blending increased the cost and did not appear to completely eliminate the CO, which continued to be produced in concentrations that would be dangerous in an unventilated 5-man Army tent.

Heating efficiency was found to be strongly influenced by the geometry of the fuel and its position in the unit. The 5/8-inch hole size was found to be the optimum; a reduction of hole size to 3/8-inch increased boiling time by six minutes. Gear-shaped charcoal briquettes were tested but a layer of these was not as effective as the Phase I fuel unit. A higher surface-to-volume ratio was achieved with the briquettes by crushing them to nominal 1/2-inch granules. A separation of 1-5/8 inches between the top surface of the fuel and the bottom of the water container, and of 2-1/8 inches between the base reflector and the bottom surface of the fuel, was found to produce optimum heating efficiency.

Consideration of the type of charcoal (commercially available briquettes) required and of its design features led to the conclusion that the Phase II unit is more adaptable to bulk manufacture would substantially reduce the cost. In mass production, the cost of material was $0.55 and the cost of the labor was $1.00 (0.367 man-hours/unit at $3.00/hour), or a total of $1.55. The projected cost of the labor was $0.51 (0.17 man-hours/unit at $3.00/hour), which would total $1.06. This is approximately one-fifth the cost of the Phase I unit. This lower cost is achieved at some sacrifice in performance, but six quarts of water can still be boiled in 15 minutes (as against 10) at 68°F and six quarts of ice in approximately 30 minutes (as against 21 at 50°F) at 46°F ambient. (See Section B under the discussion of the Experimental Program.)

APPENDIX A

INSTRUCTIONS FOR ASSEMBLY AND USE OF
EXPENDABLE CHARCOAL HEATER

WARNING: DO NOT BURN IN A TENT OR NON-VENTILATED AREA. DO NOT HAVE FACE, BODY, OR CLOTHING OVER STOVE WHILE BURNING FUEL. IN STRONG WIND, EXERCISE CARE TO PREVENT WINDSHIELD AND FOIL BASE FROM BEING BLOWN AWAY

Parts of Heater: (see attached figure)

1. Aluminum foil base (Figure 1).

2. Grate containing igniter sheet with colored igniter strips and fuel (Figure 1).

3. Folding four-leg stove frame to support water container and fuel grate (Figure 1).

4. Aluminum foil windshield with OD coating on outside (Figure 2). (Water container, lid and fiberboard box are a part of the meal package, Figure 1).

Assembly of Heater for Six-In-One Meal:

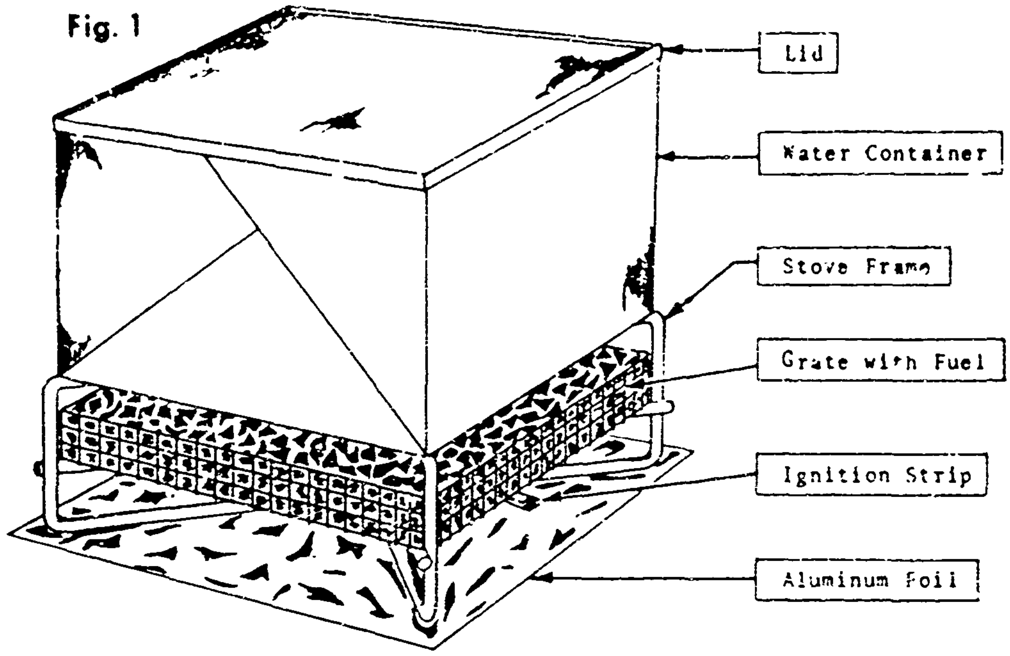
1. Unfold and place aluminum foil base on level ground cleared of burnable materials. Select a protected location, making use of a hillside, tree, vehicle, or other object as a wind screen. On ice, snow, or mud, place the foil base on the flattened fiberboard box from the meal package.

2. Unfold stove legs so they are equidistant from each other and place upright with cross-pieces down and prongs up (Figure 1).

3. Remove fiberboard cover from top of fuel grate. Slide fuel grate onto center of stove, spreading stove legs apart as necessary. A stove leg should be placed at each corner of grate.

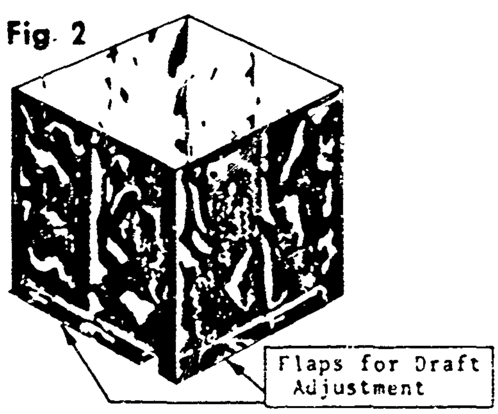
EXPENDABLE CHARCOAL HEATER COMPONENTS

Fig. 1



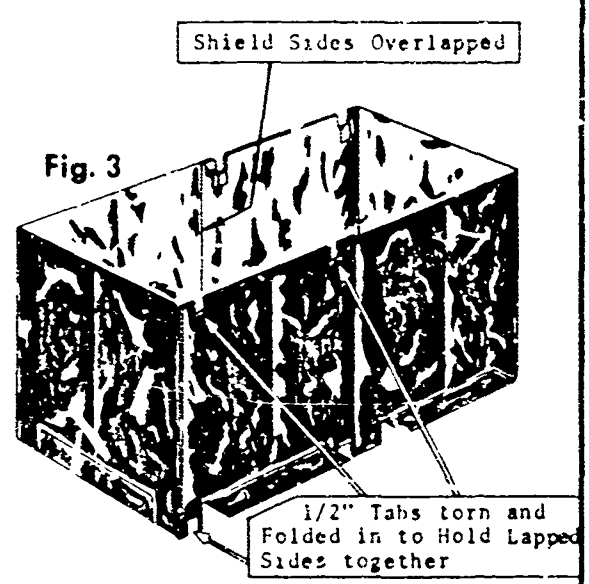
STOVE WITH 6-IN-1 WATER CONTAINER

Fig. 2



WINDSHIELD

Fig. 3



WINDSHIELD ARRANGEMENT FOR 25-IN-1 WATER CONTAINER

4. Place Stove with grate on foil base so that the colored igniter strip faces into any wind.

5. Place aluminum container of the six-in-one meal with the required amount of water on the supports of the stove. Fit cover tightly. If necessary, place stones on cover to hold in place.

6. For best performance, unfold windshield and adjust flaps (Figure 2) according to wind conditions:

   Little or no wind, leave open (folded up) all flaps.

   Moderate wind, leave open the two flaps on opposite sides of shield.

   High winds, have flap on o e side open. Avoid exposing shiny surface of flaps.

7. Place windshield around water container and stove with draft openings next to ground and with the flap open on side of igniter strips.

8. Ignite charcoal by holding one, two, or three matches lighted at once under the exposed colored igniter strip. In high winds, shield the stove until the fuel is glowing.

Assembly of Heater for Twenty-Five-In-One Meal:

1. Use four heaters.

2. Assemble four heaters as for the six-in-one meal, using two heaters placed side by side for each of the two sections (top and bottom of meal container). Be sure the colored igniter strip of each heater faces into the wind. If fiberboard base is required, tear meal package carton into two pieces and use one as a base under the foil reflector for each two stoves.

3. Place one-half of the total required water into each of the two sections of the container. Place each section over two heaters.

4. Cover each section of the container with the coated aluminum foil which is included in the twenty-five-in-one meal package. Place foil with coated side up and press edges down around container. This cover is required to reduce heat losses.

5. To make a large shield (Figure 3) for each pair of stoves:

   a. Unfold two windshields and remove staples or cut the shield down the fold at the stapled corner.

   b. Combine the shields by overlapping the ends of one shield with the ends of the other shield for 12 inches (one full side) (Figure 3).

   c. Fasten the overlapping portions of the shield together at top and bottom by tearing two 1/2-inch wide 1/2-inch long tabs and folding tabs in (Figure 3).

6. Adjust flaps so that at least two flaps next to each other are open under high wind conditions and four or more flaps are opened under less severe wind conditions (See step 4 of instruction for six-in-one meal).

7. Place windshield around the large water container and the two stoves with the draft openings next to the ground and the two flaps opened on the side of the igniter strips.

8. Ignite fuel in each stove according to step 6 of instructions for the six-in-one meal.

4. Place Stove with grate on foil base so that the colored igniter strip faces into any wind.

5. Place aluminum container of the six-in-one meal with the required amount of water on the supports of the stove. Fit cover tightly. If necessary, place stones on cover to hold in place.

6. For best performance, unfold windshield and adjust flaps (Figure 2) according to wind conditions:

   Little or no wind, leave open (folded up) all flaps.

   Moderate wind, leave open the two flaps or opposite sides of shield.

   High winds, have flap on one side open. Avoid exposing shiny surface of flaps.

7. Place windshield around water container and stove with draft openings next to ground and with the flap open on side of igniter strips.

8. Ignite charcoal by holding one, two, or three matches lighted at once under the exposed colored igniter strip. In high winds, shield the stove until the fuel is glowing.

Assembly of Heater for Twenty-Five-In-One Meal:

1. Use four heaters.

2. Assemble four heaters as for the six-in-one meal, using two heaters placed side by side for each of the two sections (top and bottom of meal container). Be sure the colored igniter strip of each heater faces into the wind. If fiberboard base is required, tear meal package carton into two pieces and use one as a base under the foil reflector for each two stoves.

3. Place one-half of the total required water into each of the two sections of the container. Place each section over two heaters.

4. Cover each section of the container with the coated aluminum foil which is included in the twenty-five-in-one meal package. Place foil with coated side up and press edges down around container. This cover is required to reduce heat losses.

5. To make a large shield (Figure 3) for each pair of stoves:

    a. Unfold two windshields and remove staples or cut the shield down the fold at the stapled corner.

    b. Combine the shields by overlapping the ends of one shield with the ends of the other shield for 12 inches (one full side) (Figure 3).

    c. Fasten the overlapping portions of the shield together at top and bottom by tearing two 1/2-inch wide 1/2-inch long tabs and folding tabs in (Figure 3).

6. Adjust flaps so that at least two flaps next to each other are open under high wind conditions and four or more flaps are opened under less severe wind conditions (See step 4 of instruction for six-in-one meal).

7. Place windshield around the large water container and the two stoves with the draft openings next to the ground and the two flaps opened on the side of the igniter strips.

8. Ignite fuel in each stove according to step 6 of instructions for the six-in-one meal.

APPENDIX B

SAMPLE CALCULATIONS

1. Theoretical heat available per pound of carbon, $q_{theor.}$

$C + O_2 \quad CO_2 \qquad H = -94.05$ Kcal/mol

$12 + 32 \quad 44$ g/mol

$$\frac{94.05 \text{ Kcal}}{\text{mol}} \times \frac{1000 \text{ cal}}{\text{Kcal}} \times \frac{\text{mol}}{44 \text{ g}} \times \frac{\text{BTU}}{252 \text{ cal}} \times \frac{454 \text{ g}}{\text{lb}} =$$

3850 Btu/lb CO_2

$$q_{theor.} = \frac{3850 \text{ BTU}}{\text{lb } CO_2} \times \frac{44 \text{ lb } CO_2}{12 \text{ lb C}} = 14{,}100 \text{ Btu/lb carbon}$$

Allowances for inerts in charcoal = 11

Heat available in charcoal = q = 12,500 Btu/lb charcoal

2. Thermal efficiency, Test 71 data

(a) Cake weight, w = 467 g or 1.028 lb

(b) Available heat

$q_{avail} = wq = 1.028\ (12{,}500) = 12{,}900$ Btu

(c) Heat absorbed, q_{abs}.

Sensible heat by water = $w_{H_2O}\ c_p\ dt$ =

12.5 (1) (212-52) = 2000 Btu

Latent heat = water evaporated x heat

vaporization = 2-5/8 (970) = 2600 Btu

Total, q_{abs}. 4600 Btu

Thermal efficiency = $\frac{q_{abs.}}{q_{avail.}}$ x 100 = $\frac{4600}{12{,}900}$ x

100 = 43

3. Calculation for CO_2 production, Test 71 data

(a) $C + O_2 \quad CO_2$

12 44

$$\frac{44 \text{ g mol x } 467 \text{ g}}{\text{mol x } 12 \text{ g}} = 1660.51 \text{ g } CO_2$$

(b) $$\frac{22.4 \text{ l} \quad \text{mol x } 1660.15 \text{ g}}{\text{mol x } 44 \text{ g}} = 845.165 \text{ liters of } CO_2$$

(c) 845.165 l x 0.03532 cu ft/l = 29.85 cu ft CO_2

OR

(a) $C + O_2 \quad CO_2$

12 44

$$\frac{44 \text{ g} \quad \text{mol x } 467 \quad \text{g} \quad \text{lb}}{\text{mol x } 12 \text{ g} \quad 454 \text{ g}} = 3.66 \text{ lb } CO_2$$

(b) $$\frac{22.4 \text{ b} \quad \text{cu ft x } 454 \text{ g}}{\text{g mol x } 28.32} = 359 \text{ cu ft/mol lb}$$

(c) $$\frac{3.66 \text{ lb x mol} \quad \text{x} \quad 359 \text{ cu ft}}{44 \text{ lb}} = 29.9 \text{ cu ft } CO_2$$

(d) Volume of air, average CO_2 readings (LIRA) =

0.21 by volume.

Volume air = $\frac{29.9 \text{ cu ft } CO_2}{0.0021}$ = 14,250 cu ft

(e) Volume of CO, average CO readings (LIRA) - 1060 ppm

$$14{,}250 \times 1060 \times 10^{-6} = 15.1 \text{ cu ft CO}$$

4. Ratio of cu ft of CO per lb carbon

$$\frac{15.1 \text{ cu ft CC}}{1.025 \text{ lb}} = 15.7 \quad \frac{\text{cu ft CO}}{\text{lb carbon}}$$

5. Combustion

Combustion time

Weight of Charcoal - 1.028 lb.

$$\text{rate} = 1.028/33 = 0.0313 \quad \frac{\text{lb carbon}}{\text{minute}}$$

APPENDIX C

PROCUREMENT SPECIFICATIONS FOR THE CARBON HEATING UNIT

Component	Specifications
1. Fuel	Briquettes, 2-inch diameter x 7/8-inch thick without hickory additive. Briquettes to be crushed to No. 2 mesh granules (1/2-inch particle size). Approximately 1.8 ± .1 pound charcoal per unit. Supplier: Quaker Oats Company Chicago, Illinois Price - $0.05/pound
2. Stove support	Wire members, four required per stove. Members to be held together with steel clip. No. 9 gage C1008/1010 grade plain finish steel wire. Steel clip, 26 gage commercial quality C.R. steel, C1010 grade steel; temper, half hard; finish No. 1 dull; edge, slit edge. Supplier: Anchor Wire Specialty Co. 543 Dixon Street P.O. Box 290 Homestead, Pa. Price - $0.1669/M (on basis of 100,000 stoves)
3. Chimney	Roll, Reynolds Al foil, 1235-0 temper 1-1/2 mil thick dry annealed, single olive drab coat on mat side (3-1/2 pound per ream, 6500 sq in per 1 pound). Approximately 10 chimneys per pound. Supplier: Reynolds Metals Co. Price - $0.969/pound

Component	Specifications
4. Fuel cage	No. 2 mesh, 19 gage plain steel welded wire cloth, 26-inch or 39-inch wide rolls 100-200 feet long. Supplier: Wickwire Brothers, Inc. Cortland, New York 13046 Price - $9.55/100 sq ft (on basis of 1,250,000 cages or 1,465,000 sq ft).
5. Igniter	Sheet, 10-1/4 inch x 10-1/4 inch (± 1/16) x 0.010 (± 0.002) inch thick. Danco Acetal Strip (Delrin). Scrap delrin as raw material. Supplier: Danielson Manufacturing Co. Danielson, Connecticut Price - $0.0586 each (on basis of 1,000,000 sheets) $0.0637 each (on basis of 500,000 sheets).
6. Reflector	Roll, aluminum foil, Reynolds household type; 12 in. wide x 0.001 gage. Supplier: Bennett Paper Co. 918 Reckenbach Street Pittsburgh, Pa. 15212 Price - $23.89 per 25 lb roll (1770 reflectors at $0.00135 each).
7. Cardboard cover	Sheet, 10-1/4 inch x 10-1/4 inch pad, 125-pound cardboard. Supplier: Keystone Box Co. Pittsburgh, Pa. Price - $0.01 each (on basis of 1000).
8. Plastic bag	Polyethylene, 15 inch x 15 inch x 3 mil thick. Supplier: Ken Covers Lower Burrell, Pa. 15069 Price - $22.00/M less 2% (on basis of 100,000 and over).

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Security Classification

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4 DESCRIPTIVE NOTES (Type of report and inclusive dates)
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13 ABSTRACT

Experimental carbon heating units to boil water for reconstituting precooked dehydrated foods were developed at the U. S. Army Natick Laboratories and produced in contractor's pilot plant for field and laboratory study. These were designated as Phase I units. As a result of further experimentation, and based on the test findings, the contractor produced an improved unit that was designated as Phase II.

Both units consisted of carbon fuel, igniter, stove support, base reflector, and shield or chimney. The Phase I fuel was a charcoal slab with perforations. The reflector was of rigid aluminum. At an ambient temperature of 68°F, this unit boiled 6 quarts of water in 10 minutes and, at an ambient temperature of 46°F, thawed snow or ice and boiled the resultant water in 22 minutes. In Phase II, several types of fuel were developed, the most promising of which was made from commercially available char fuel briquettes broken into approximately 1-inch pieces. Inexpensive fiberboard and aluminum foil replaced the rigid aluminum as reflector and the stove support was made of 4 simple parts. Under the same ambient conditions, these units brought 6 quarts of water to a boil in 14 minutes and thawed snow or ice and boiled the resultant water in 30 minutes.

Although the Phase II units required slightly more heating time, their cost, estimated at about $1.00 each in quantities of 100,000, was approximately one-fifth that of the Phase I units.

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