AD706902

THE USE OF MICROWAVE OVENS IN THE SPEED FEEDING SYSTEM

— a feasibility study prepared for the U.S. Army Quartermaster Corps, Natick Laboratories — ~~Phase II~~. per Major Snyder as requested

Cryodry Corporation, San Ramon, Calif.

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ILLUSTRATIONS

Contract No. DA19-129-AMC-621(N)

Project No. 1A0-13001-A91A

U.S. Army Quartermaster Corps, Natick Laboratories

Feasibility Study, SPEED Field Feeding System, Microwave Ovens

PHASE II REPORT

I. INTRODUCTION

In this study the contractor has investigated the use of microwave ovens as part of the U.S. Army's SPEED field feeding system. In Phase I, the general feasibility of meeting the cooking and baking requirements of SPEED with microwave technology was confirmed. In Phase II, the contractor has proceeded to develop design characteristics of the ovens and supporting equipment, and to resolve various problem areas uncovered in the first phase of the contract.

II. SUMMARY OF FINDINGS

Guidelines have been established for the design of microwave ovens and supporting equipment for the SPEED bakery and kitchen systems. No critical problems of construction or operation are foreseen which could not be overcome in the normal development of this type of equipment.

Several refinements in the original concepts of SPEED have been made. These include the size and number of ovens, the frequencies desirable for cooking and baking, the utilization of exhaust heat from the electric generating system, the selection of materials for conveyor belts, and the use of high-temperature plastic containers as supplements to the cooking process.

III. DISCUSSION

1.0 Review of SPEED System Requirements

The SPEED feeding system consists of a mobile bakery and a mobile kitchen, each housed in a standard Army pod. The inside dimensions of a pod are 6' - 7" height x 6' - 8" x 11' - 7". The pod can be transported by air, on wheels, or on a standard Army 2-1/2-ton truck.

The bakery is to be capable of producing bread and pastry sufficient for 5,000 men a day. The kitchen is to be capable of cooking three complete meals for 200 men per day.

Each unit is to be self-sufficient, containing its own power-generating equipment, accessories, waste removal system, and storage space.

It is desirable that operating characteristics, maintenance, and replacement parts be similar, and consistent with current military practice.

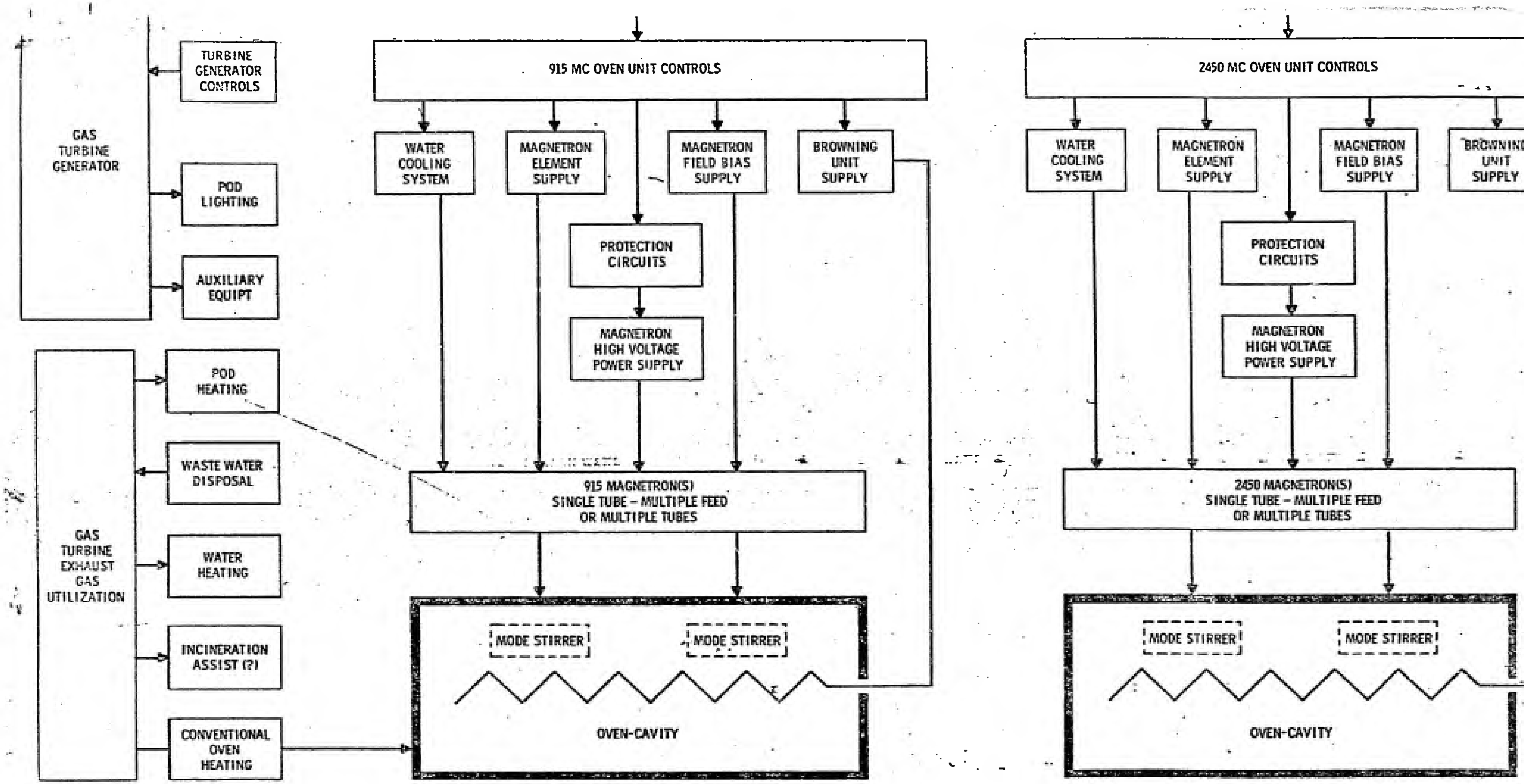
The use of microwave ovens in both the kitchen and bakery units is strongly indicated as the most effective method of achieving the proposed baking and cooking volume within the space limitations of the pod.

2.0 Proposed Microwave Ovens

2.1 Kitchen Unit

2.1.1 Components

The cooking system developed by this study consists of two microwave batch ovens, one operating at 2450 Mc and the other at 915 Mc. One oven at each frequency is recommended to provide greater flexibility and versatility in cooking a great variety of foods. If, after field use, one frequency proves superior to the other for all around use, subsequent units can easily be equipped with two ovens of one frequency.



GAS TURBINE GENERATOR
TURBINE GENERATOR CONTROLS
POD LIGHTING
AUXILIARY EQUIPT
GAS TURBINE EXHAUST GAS UTILIZATION
POD HEATING
WASTE WATER DISPOSAL
WATER HEATING
INCINERATION ASSIST (?)
CONVENTIONAL OVEN HEATING
915 MC OVEN UNIT CONTROLS
WATER COOLING SYSTEM
MAGNETRON ELEMENT SUPPLY
MAGNETRON FIELD BIAS SUPPLY
BROWNING UNIT SUPPLY
PROTECTION CIRCUITS
MAGNETRON HIGH VOLTAGE POWER SUPPLY
915 MAGNETRON(S) SINGLE TUBE – MULTIPLE FEED OR MULTIPLE TUBES
MODE STIRRER
MODE STIRRER
OVEN-CAVITY
2450 MC OVEN UNIT CONTROLS
WATER COOLING SYSTEM
MAGNETRON ELEMENT SUPPLY
MAGNETRON FIELD BIAS SUPPLY
BROWNING UNIT SUPPLY
PROTECTION CIRCUITS
MAGNETRON HIGH VOLTAGE POWER SUPPLY
2450 MAGNETRON(S) SINGLE TUBE – MULTIPLE FEED OR MULTIPLE TUBES
MODE STIRRER
MODE STIRRER
OVEN-CAVITY

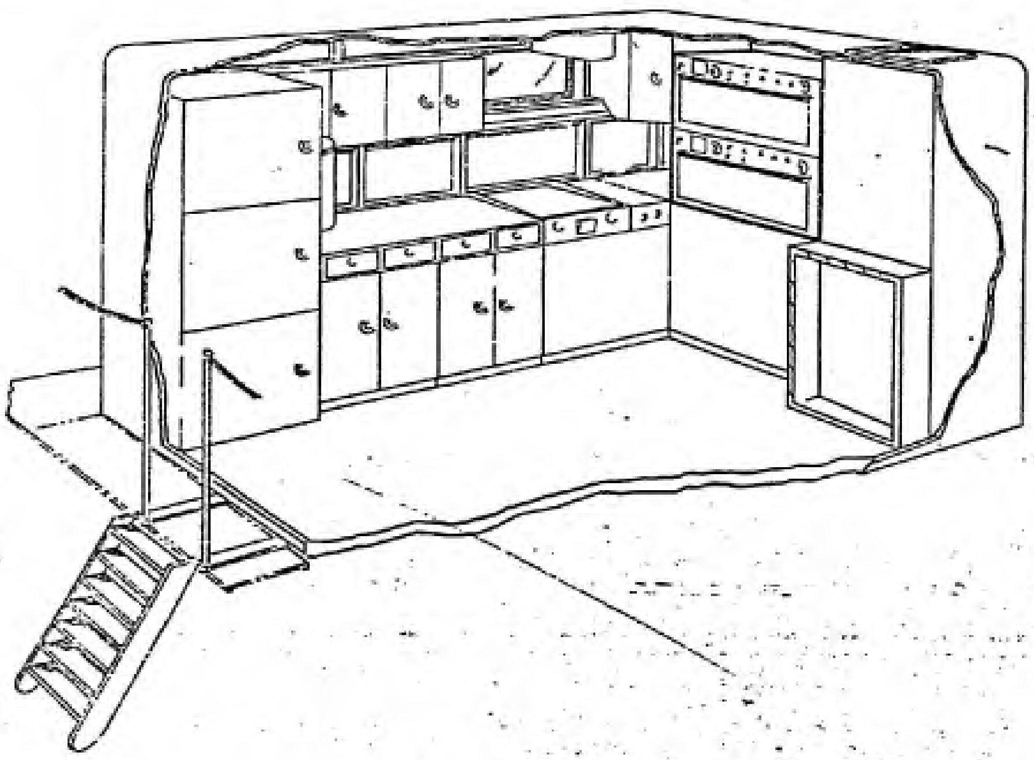
Each oven consists of a microwave power generating system of 6 kw, a conventional oven heating system, an infra-red browning unit, the oven cavity, and a control panel. Electric power is supplied to both ovens by a 50 kw gas-turbine generator. The generator also supplies power for lighting, cooling the pod, and auxiliary electrical devices. An exhaust system for the generator is utilized to supply heat for the pod, to heat water, to dispose of waste water, to provide conventional oven heat, and possibly to assist the incineration system.

2.1.2 Operating Characteristics

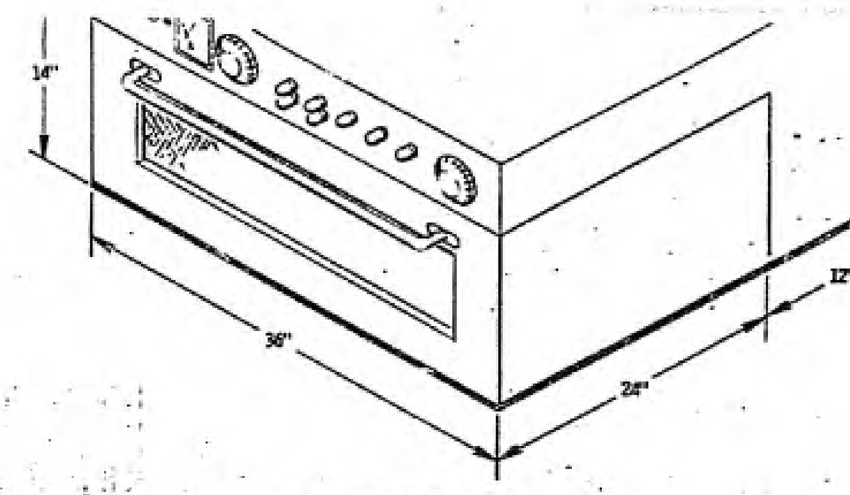
The 915 Mc oven will be used to cook the larger food items requiring deeper heat penetration, such as fibrous vegetables and bulky meats. The 2450 Mc oven will be used primarily for less bulky foods and for heating pre-cooked foods. A conveyor type oven would not be sufficiently superior to batch handling of foods in either case to justify the considerable additional space required.

Together, the two ovens are capable of cooking 80 lbs of raw meat, 50 lbs of fresh vegetables, and 50 lbs of raw potatoes in 60 minutes. Servings would be available within 15 to 30 minutes from the start of the cooking cycle and would be staggered thereafter. High-temperature plastic cooking and serving vessels would be employed for many food items for a more even distribution of heating and for the "holding" time required for full development of food flavor and texture. The plastic is transparent to microwave power permitting cooking in the container and because of their excellent heat-retention, these containers also permit the cooking process to continue when removed from the oven.

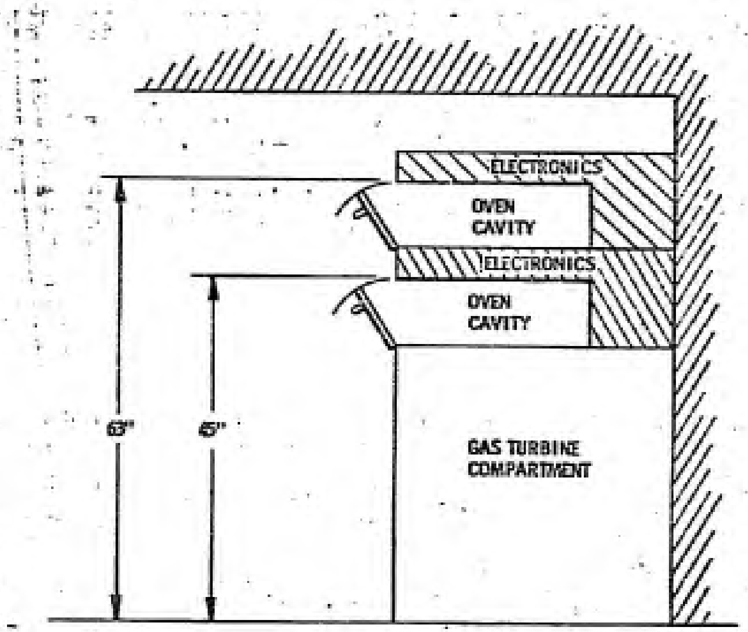
Browning of certain foods would be done by means of infra-red units. Conventional heat supplied by the generator exhaust system would supplement the microwave cooking. This combination has proved to be the most satisfactory for cooking quality in commercially designed units (Page 19).



Pictorial View



Detail of Oven



Cross-Sectional View of Ovens

Figure 2. Kitchen Unit
General Mechanical and Structural Design

The problem of obtaining even distribution of microwave power in the ovens is to be overcome by the use of "mode stirrers" in each cavity, which produce a continually shifting microwave field within the oven.

2.1.3 Development Requirements

Consultation with microwave-oven manufacturers has indicated that the design and production of the 6 kw ovens referred to above would be feasible with present technology. If an accelerated program were required, presently available microwave ovens could be employed in multiples sufficient to provide the oven capacity and cooking time specified by SPEED, but with severe space limitations in the pod.

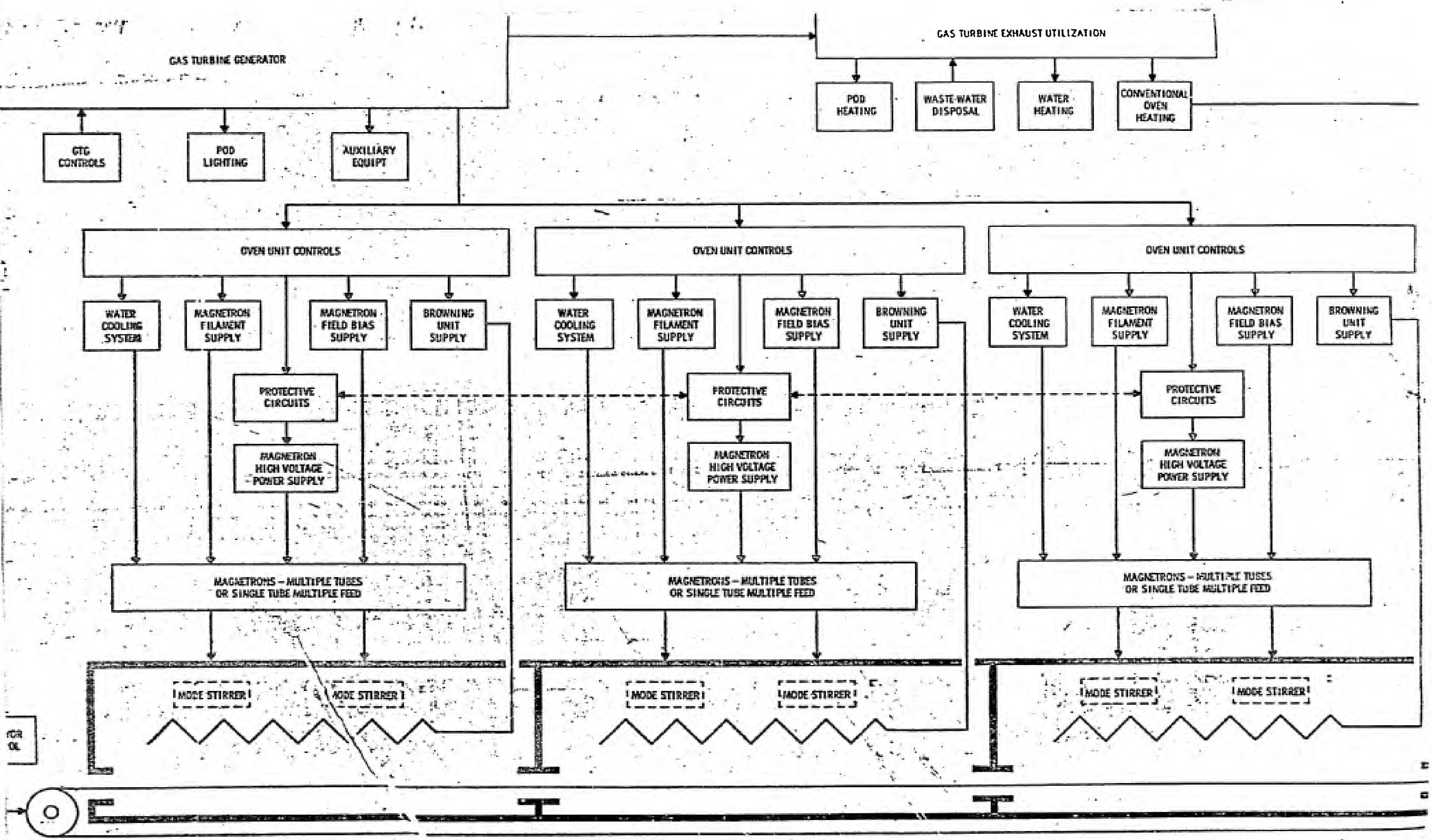
A design aspect which is best left to the final supplier is the choice of using a single magnetron tube with multiple cavity feed, or multiple tubes, for each of the two 6 kw ovens.

There is also an option of developing a high frequency direct-drive turbine generator instead of utilizing conventional reduction-gear types. A direct-drive generator would be more suitable for SPEED's power requirements because of its simplicity and relative economy. (For supplier interest, Page 21).

2.2 Bakery Units

2.2.1 Components

The baking system developed by this study consists of two similar, independent pods, each containing a microwave conveyor-type oven operating at 2450 Mc. The oven proper, which is six ft in length, is made up of three identical oven cavities. Each cavity has a separate microwave power source of 4 kw, consisting of a control unit, individual electrical circuits, and either a single magnetron tube with multiple feeds to the cavity, or multiple tubes. Infra-red browning units are incorporated in each cavity.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MODE STIRRER

A gas-turbine generator identical to that used in the mobile kitchen supplies power for the microwave system, lighting for the pod, and electrical power to operate auxiliary equipment.

The ovens are fed by automatic mixer-extruders, and an automatic cutting device at the delivery end separates the bakery products into loaves or cakes.

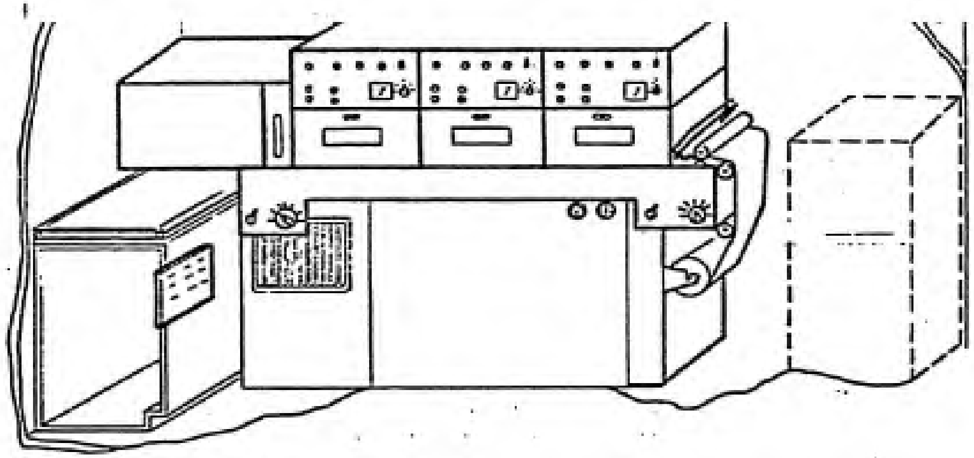
A chamber at the delivery end of the ovens absorbs any microwave energy which may escape from the cavity. A material similar to "Echo-Sorb" is used to absorb the microwave leakage, convert it into heat, and dissipate the heat by air-cooling.

2.2.2 Operating Characteristics

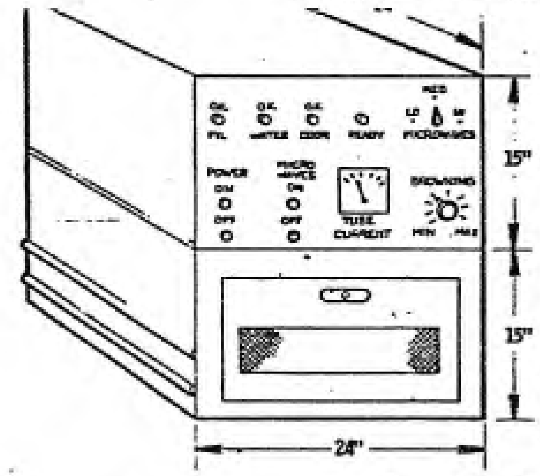
The only difference between the two bakery pods is that one is used for continuous bread baking and the other for baking cakes and other individual pastries. Because of their mechanical and electrical similarity, parts can be interchanged or either pod can be quickly substituted for the other for maximum field versatility.

The bread-baking oven, with a total power level of 12 kw, is capable of supplying 150 lbs of bread per hour. Military instant bread mix is extruded continuously 18 inches wide and 1/2 inch thick onto a conveyor belt, and passes through the oven in 7.2 minutes. Porous paper fed onto the conveyor belt supports the dough and at the same time allows the bread to "breathe," thus preventing sweating on the bottom of the loaves. The operator may control the baking time, especially at the start and finish of a run when over-baking can occur, by varying the speed of the conveyor.

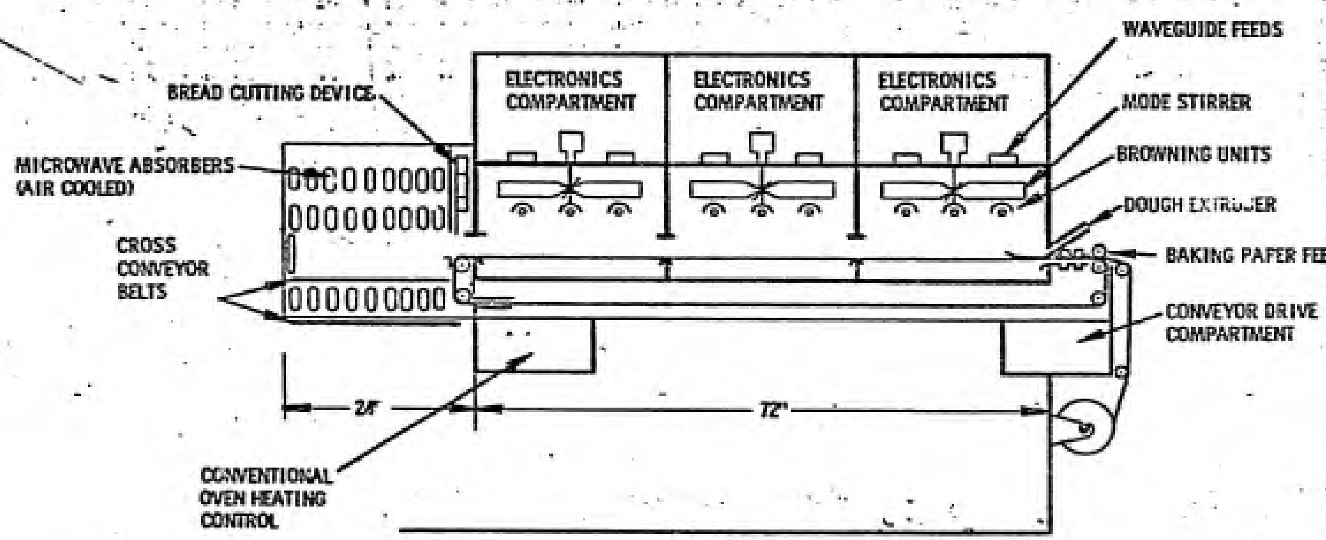
The pastry oven is capable of supplying 50 lbs of cakes or other low-density pastry items per hour. Tests have shown that oven "dwell" times of 4 or 5 minutes are satisfactory for this type of baking. Pie crusts and thin cookies, however, do not bake with entire satisfaction at either 915 or 2450 Mc.



Pictorial View



Detail of Oven Sections



Cross-Sectional View of Oven

Both the bread and the pastry ovens use conventional heat as well as microwave energy to disipate the moisture and obtain the best results for flavor and texture. Infra-red units brown the bread and pastry during the baking cycle.

Doors at the exposed side of each oven cavity permit routine inspection and cleaning of the conveyor. A positive automatic interlock system shuts off all three microwave circuits when any door is opened.

2.2.3 Development Requirements

The bakery ovens required to meet SPEED production rates are somewhat larger than originally envisioned, but are easily compatible with existing pod dimensions. Although no commercially available ovens meet the specifications proposed herein, several manufacturers appear to be interested in development of microwave units of this concept.

Difficulties of belt design and of absorption of microwave energy from the delivery end of the ovens have been largely overcome. Silicone-rubber-coated glass cloth belts have been successfully tested for stability and release characteristics in temperatures well above 400°F, which exceeds maximum operating temperatures for the bakery.

3.0 Conclusion

This study has uncovered significant areas of practical and theoretical benefit in the development of the SPEED mobile kitchen and bakery. The confidence of the Army Quartermaster Corps in the adaptability of microwave technology to its field requirements has been amply justified. It appears that the microwave requirements are well within the "state of the art" and that only a modest development effort will be required by a supplier. Several major vendors have expressed interest in the equipment.

IV. DESIGN AND DEVELOPMENT DATA

This section is intended to supply data supporting the findings of the study, specifically covering the subjects referred to in the Statement of Work, Phase II.

1.0 General Structural and Mechanical Design

1.1 Structural Materials for Kitchen and Bakery Ovens

All metal equipment subject to cleaning procedures must be stainless steel. Where different metals are required for microwave purposes, a microwave window should be utilized, which will seal the non-stainless area from cleaning solutions and moisture.

Standard design techniques utilized on food handling equipment will be applied to the ovens. In particular:

1. All welds will be continuous and polished.
2. No re-entrant area will be utilized.
3. All surfaces will be accessible for wiping with a wet rag.
4. Minimum disassembly should be required for cleaning purposes.

Structural dielectric materials can be utilized in the high field area, and these materials should conform to the description given for food containers (See Page 28).

All parts of the oven (including the electrical components and assemblies) must be designed for the transport conditions expected in the vans. If special mounting clamps and other hardware are required, they must be easily removable in a few moments, without use of special tools (wing nuts, for example).

Considerable moisture will be removed from the baking products and will necessitate a heating and exhaust system to remove the moist air. The outside of the oven should have a heat insulating covering.

The apertures through the bakery oven will be 3 x 20 inches providing clearance for a bread product nominally 1.5 to 2.5 x 18 inches at exit. The dough to be baked will be extruded onto the belt directly into the cavity. The input cavity will then need only a minimum size slit to permit passage of the belt. A recessed chamber with absorbing material will be incorporated if injecting dough into the high field region causes too rapid or undesirable rising of the dough.

Infra red browning unit will be positioned in the oven chamber. Each oven will have its own browning unit for flexibility and interchangeability.

1.2 Conveyors

Silicone-rubber-coated fibreglas has been determined to be the most suitable belt material to meet the requirements of product release, localized high temperatures and reliable tracking. Belt joint design at 2450 Mc will require greater care than at 915 Mc. An endless belt presents serious structural problems, but may also be explored. It is also feasible to consider a "throw-away" type belt of coated paper or plastic. In this case the cost, storage, and disposal problems must be evaluated.

For conveyor equipment, self-cleaning pulleys are recommended. A crowned pulley should be utilized for coated glass types. Intermediate supports (of dielectric material if in microwave field) must be included to reduce the tension on the pulleys from product loading. A spring-loaded idler pulley is recommended. The pulley mechanism (in particular the drive system and bearings) must be outside of the high power microwave field to reduce potential sparking and corona effects.

The conveyor speed must be adjustable. A continuously variable dc motor is ideal for this purpose, and many types of variable dc motor controls are readily available.

An exploration of materials to meet the requirements of the proposed ovens led to the selection of silicone-rubber-coated fibreglas. Concepts which were tested or investigated include:

1. Glass-filled polyester slats with hinges, openings, and a sealing mechanism.
2. Extruded panels of polypropylene and polyethylene, with a solid hinge.
3. Mylar belts, either in pure form or with reinforcing bands of Mylar strips or glass tapes.
4. Non-belt mechanisms capable of providing continuous motion through the oven.

After investigating the above concepts with various manufacturers, it was determined that each presented fabricating difficulties. The possibility of using silicone-rubber-coated fabrics for the conveyor belt was suggested by the excellent low dielectric loss and food-resistant characteristics of silicone rubber. A number of manufacturers were approached and the fabricating feasibility of this type of belt was confirmed. At the same time, teflon coatings were investigated but were found to be inferior to silicone rubber in bonding to glass cloth.

Silicone rubber belts were fabricated by bonding the silicone rubber to glass cloths in a drying tower following a dipping procedure. An excellent bond was obtained by coating individual strands.

It was found that cracking was minimized by the elastromeric qualities of the coating. The glass can withstand temperatures up to 1100°F before complete loss of strength, although the increasing dielectric loss tangent of certain glasses necessitates a careful selection of glass types which do not exhibit this tendency to a pronounced degree. In tests, the contractor showed that life of the pure rubber is reduced to 80% at 700°F, and some toughening and cracking may occur after continuous operation at 600°, but performance at 400° is excellent. At least one grade of silicone rubber has already been accepted by the Food Drug Administration for use with foods.

The silicone-rubber belt was also found to allow perforation (with edges of openings recoated) without affecting the life or functioning of the belt.

In investigation of release and cleaning characteristics, the contractor found potential difficulty only with oil pick-up (5% by weight after 24 hours immersion). Migration of oil to the cloth, however, can be prevented by pre-treatment of the glass fabric.

1.3 Determination of Oven Size, Kitchen

The maximum microwave cooking requirements were stated as 50 lb potatoes, 50 lb vegetables, and 80 lb meat per meal.

Total square inch shelf space requirements for above load:

Item	
Potatoes (50 lb)	7.5 sq ft
Vegetables (50 lb)	10.5 sq ft
Meat (80 lb)	3 sq ft
	21 sq ft

Total power requirements for above load:

Item	
Potatoes (50 lb)	2.5 kwh
Vegetables (50 lb)	3.1 kwh
Meat (80 lb)	6.4 kwh
	12.0 kwh

Thus to cook all the above in one hour we would need 21 sq ft of shelf space and 12.0 kw of microwave power.

General Requirements

Microwave Power	Time	Shelf Space	Average No. Loads
12 kw	1 hr	21 sq ft	1
12 kw	1 hr	10.5 sq ft	2
12 kw	1 hr	7 sq ft	3
6 kw	2 hr	7 sq ft	3

If oven shelf dimensions total 12 sq ft (or 2 ovens of 6 sq ft each), each oven would have to deliver 6 kw of microwave power to cook in 1 hour. The available pan space in each oven will be about 5.0 sq ft.

Item	Loads	Lbs/Load	Oven Time	Time/Load
Potatoes	2	25	25 minutes	12 minutes
Vegetables	2	25	30 minutes	15 minutes
Meat	2	40	60 minutes	30 minutes

1.4 Determination of Oven Size, Bakery

Under the conditions set forth in this proposal, the major factors of heat required to bake a pound of bread dough by microwave heating are:

(a) Heat absorbed by dough.

(b) Latent heat of evaporization.

The first factor (a) may be separated into the following:

1. Specific heat of dough between 70-212°F.
2. Heat of gelatinization of starch.
3. Heat of coagulation of gluten.
4. Heat of fusion of fat.

From theoretical calculations (a) may be summarized as:

1. Dough ingredients

43% water	0.43 x 1	=	0.43 BTU
2.6% fat	0.026 x 0.5	=	0.013 BTU
6.5% protein	0.065 x 0.25	=	0.016 BTU
36.2% starch	0.362 x 0.25	=	0.091 BTU
10.7% other	0.107 x 0.25	=	0.027 BTU
			0.577 BTU

giving an approximate specific heat of 0.577 BTU per lb per °F.

2. $0.362 \text{ lb} \times 28.1 \text{ BTU}/_{\text{glucose units}} \times \frac{454}{178} \text{ glucose units}/_{\text{lb}} =$

26 BTU/lb dough

3. $0.065 \times 30 \times \frac{454}{178} = 5 \text{ BTU}/_{\text{lb dough}}$

4. $0.026 \times 45 \times \frac{454}{252} = 2.1 \text{ BTU}/_{\text{lb dough}}$

From these four (a) factors:

	1. 1 x 0.577 x (212-70)	=	82.5
	2. 1 x 26	=	26
	3. 1 x 5	=	5
	4. 1 x 2.1	=	2.1
	Heat absorbed by dough	=	95.6 BTU/lb dough
(b)	Latent heat loss by evap 0.1 x 970	=	97.0 BTU/lb dough
	Total microwave energy required	=	192.6 BTU/lb dough

$$\frac{192.6}{3413} = 0.0565 \text{ kwh/lb bread dough}$$

Based on 70% efficiency, 0.08 kwh/lb bread dough is required. At 150 lb dough per hour, a 12 kw oven is required.

The following data for bread baking is of interest:

Baking Reaction	Temperature °F
Gas expansion	Room - 212
Starch gelatinization	140 - 212
Gluten coagulation	170 - 250
Carmelization	375 - 425

The surface temperature should not be allowed to go above 425-450°F as at 475-500°F, the melanoidin substances that form part of the brown crust become black and bitter.

During baking of bread by hot air ovens, the internal portion never gets above 212°F, thus caramels and melanoidins never form internally. However, in microwave baking, internal moisture can be translocated, giving internal areas a chance to increase in temperature, thus producing burnt areas within the loaf. Care must be taken that the oven load and oven time for the power level being used is maintained.

References: Matz, S. A., Bakery Technology and Engineering
Avi Publishing Co. 1960

Copson, D. A., Microwave Heating
Avi Publishing Co. 1962

Scott-Blair, G. W., Foodstuffs: Their Plasticity, Fluidity, and Consistency
Interscience Pub. 1953

Matz, S. A., Miller, J., and Davis, J.
Modern Baking Concepts for Troop Feeding:
Development of the Instant Bread Mix.
Food Technology 12, 625 (1958)

1.5 Availability of Kitchen and Bakery Microwave Units

The batch and conveyor ovens proposed in this study must be specifically developed for the SPEED system. Various microwave-oven manufacturers, however, have produced ovens similar in concept to these units and have expressed interest in further developmental work toward the optimum design.

The following excerpts from reports on contacts with prospective manufacturers indicate supplier interest in oven and generator development.

CALL REPORT

TO: Mr. Richard Prucha, General Electric Company
FROM: Don Service, Cryodry Corporation

"G.E.'s present design philosophy for domestic microwave ovens is that microwaves alone cannot do a complete job. They are therefore producing a unit which combines conventional hot air cooking, broiler browning, and microwave power. This unit is incorporated in the General Electric Americana Range. The oven cavity dimensions in the range are 21 x 18 x 15 inches. The microwave portion of the unit operates at 915 Mcs with a cavity power level of 500-600 watts of microwave power. Food to be cooked is placed on a rotating table about 2 inches above the floor of the oven; this rotating table is a metal reflector. G.E. has developed a special low voltage magnetron Model Z5458 for use in this range. This magnetron will operate with an anode voltage of 600 volts. When the oven is operated from 240 volts ac using a full wave bridge they are able to run the magnetron without using a high voltage transformer, thus saving on cost and weight. The Model number for this oven is JE 895 YI. This is the only domestic oven G.E. has available and at the present time it is being test marketed only.

"The G.E. Commercial Equipment Department located in Chicago Heights, Illinois (Mr. M. Rice, Manager) builds microwave ovens for institutional and commercial applications. Originally this group manufactured a 2450 Mc oven which utilized a Litton tube and electronic components. Prucha said they are now phasing out the 2450 Mc oven and will adopt 915 Mc units. This unit will be the same unit which is used in the domestic range but operated at 700-750 volts with a microwave output of 1-1.2 kw.

"I briefly outlined to Prucha the Quartermaster Kitchen oven requirements for 6 kilowatts of microwave power in approximately 6 cubic foot oven space, and asked if he felt this was feasible or if G.E. contemplated ovens of this size. Prucha indicated that they had been working on cavities using multiple magnetron feed. He said that they envisioned a single cavity with several magnetrons feeding the cavity. The reason for this approach was their feeling that multiple source cavities were the best way to achieve more uniform fields. He said that they had experimentally shown they could overcome the problems of coupling several magnetrons into a single cavity. He seemed certain that if approached by the Quartermaster Corps for a high power large cavity oven that G.E. would be interested in developing this device. The magnetron and power supply work would be done at Louisville and the cavity design work would be done at Schenectady by the general engineering group, probably under the direction of Dr. Peters."

CALL REPORT

TO: Mr. Sten Perrson, Raytheon Range Division
FROM: Don Service, Cryodry Corporation

"My purpose in contacting Raytheon was to discuss high-power batch-type ovens for use in the Kitchen unit of the proposed SPEED feeding system. Mr. Perrson had the following comments on the Quartermaster Corps' proposal and requirements:

a) The upper limit of what is available at the present time is about 2.5 kw for batch-type small ovens.

b) Perrson is dubious about using more than 2 magnetrons in a single cavity. (From another source I later learned that Raytheon had built a custom unit using 4 magnetrons for a total of 3.2 kw of power in a single cavity. Perrson was apparently not aware of this unit.)

c) Raytheon would probably be interested in developing a 6 kw unit for the SPEED project. It could not be determined whether the Radar Range Division or the Industrial Microwave Division of Raytheon would undertake this development."

MEMO

TO: Mr. Jim Stannard, Cryodry Corporation
FROM: J. P. Pierce, Jr., Application Engineer, Solar

"We are following the Natick Laboratories portable army field kitchen project with great interest. As you mentioned, the prospect of using high speed alternators run at our turbine shaft speed, does seem to have several advantages over a more conventional system. If most of the power is for the microwave ovens and can be used at the high frequencies generated without further treatment, then the small amount needed for other uses can be supplied through a small static frequency changer. Solar would be most interested in working further on this concept in conjunction with an electrical manufacturer capable of producing the necessary high speed equipment."

1.6 Specifications for Electric Generators

1.6.1 Scope

This specification covers the requirement of a 50 kw, 120/208 volt, 400 cps 3 phase gas turbine generator set.

1.6.2 Proposed Application

The gas turbine generator set shall be used as the source of electrical power for both the SPEED kitchen unit and the SPEED bakery unit. There will also be limited utilization of the rejected or waste heat.

1.6.3 Electrical Requirements

The electrical power produced by the gas turbine generator set will be used to operate microwave cooking ovens and their related electronic and electro-mechanical components, small motor operated kitchen appliances, small resistance heater appliances and lighting. The aggregate connected load of these appliances will not exceed 50 kw at 0.8 power factor. The generated voltage shall be 120/208 volts ± 5% and the generated frequency shall be 400 cps ± 2%.

1.6.4 Optional Electrical Requirements

Serious consideration will be given to proposals offering high frequency power generation resulting from the use of a direct driven alternator. The 5% voltage variation and 2% frequency variation would still be applicable. Direct utilization of the high frequency power would be feasible in the electronic, resistance and lighting loads, while rectification for dc operation of the small motor and relay loads would be proposed.

1.6.5 Additional Electrical Requirements

The gas turbine generator set shall be equipped with an electrical starting system which shall operate on a 24 volt storage battery. In addition provision shall be made, either through rectification of the generated power or through an auxiliary dc generator, for recharging the starting batteries and providing excitation, ignition and control power as required.

The starting batteries will be supplied by others, however, the proper battery or batteries shall be specified by the gas turbine generator set supplier. The batteries shall be sized to permit a successful start after three abortive start attempts, and the recharging rate shall permit restarting with a normal duty cycle of only one hour run per start. The starting battery ambient temperature range will be +32°F to +120°F.

The normal starting and stopping of the gas turbine generator set shall be accomplished remotely from inside the kitchen. The operator's controls shall be similar to those specified by various manufacturers of turbine driven generators, such as Solar, Garrett, and Century. A circuit-breaker-type load center which shall control power to the various electrical circuits of the kitchen is to be furnished.

1.6.6 General Requirements

The gas turbine generator set shall be essentially a skid mounted unit, without enclosure. The basic unit shall include the turbine engine and accessories including starter; lube and fuel oil pumps, filters and piping; gear reduction unit, generator, dc generator if required, running hour meter, and electrical connections for generated power and necessary controls; and intake and exhaust mufflers.

The unit and components shall, where applicable, meet or exceed all approproate military specifications. Furthermore, wherever economically feasible all components shall be interchangeable with other existing gas turbine units now in stock of the U.S. Army or other branches of the Department of Defense.

1.6.7 Fuel

The unit shall function satisfactorily throughout its operating range with fuel conforming to Specification MIL-J-5624, grade JP-4. The operating limits of the unit shall not be exceeded when fuel having any of the variations in characteristics permitted by Specification MIL-J-5624 grade JP-4 is used. In emergencies, the unit shall also function with aviation, combat and ordinary gasoline, kerosene, JP-1, JP-5 and diesel fuel. To meet this requirement, external control adjustments shall be permitted.

1.6.8 Ratings

The performance ratings of the unit shall be based upon using fuel conforming to Specification MIL-J-5624 (JP-4). The 50 kw output rating of the unit shall be based upon continuous operation with an ambient temperature of +120°F, and 1000 foot elevation.

1.6.9 Altitude and Temperature Limits for Starting and Operation

The unit shall function satisfactorily throughout its operating range, including starting with ambient temperature of -30°F to +130°F at sea level and from -30°F to +95°F at 7000 foot elevation.

1.6.10 Emergency Controls

The unit and its associated control panels and relaying equipment shall incorporate automatic shut-down equipment which will shut the unit down in the event of low oil pressure, over-speed or excessive exhaust temperature. Visual indication of operation of shutdown controls shall be provided. (If feasible, "first-out" indication would be preferred.)

1.6.11 Mounting

The gas turbine generator set will be mounted by others in a draw-out cabinet. Provisions shall be made in skid for bolting skid to draw-out rails and an easily operated coupling shall be provided between the vertical exhaust stack and the muffler. Provisions shall also be made to incorporate an electrical interlock in the engine control circuit to prevent engine operation in the drawn out position. Fuel and drain connections shall be equipped with Quick-Connect Double-End Shut-Off fittings to permit hose connections to tanks.

1.6.12 Exhaust Manifold

The heat of the exhaust stack is to be utilized for several purposes, and the manifold may be designed accordingly. First, for conventional oven heat, air will be drawn across a fluted exhaust jacket, then mixed by thermostatic control with cold air for the proper temperature. Second, water will be heated in a small heat exchanger unit mounted on the stack. Third, waste water can be drawn up and evaporated out the stack by a venturi jet. Fourth, heat for the pod can be obtained by means of a fan drawing air through a vent and around the stack. Fifth, if necessary the direct exhaust can be utilized to assist the operation of the incinerator.

1.7 Incinerator Design

Normal incinerating temperatures of about 2000°F preclude the possibility of performing this function merely by the use of exhaust heat from the generator, which is 900°F. Discussion with the Contracting Officer has indicated that an incinerator manufacturer has been located to provide an oil-fired unit capable of handling the anticipated refuse load. It was suggested that turbine exhaust gas at 800 - 900 °F could supplement the oil burners.

It is possible to pipe direct turbine exhaust gas to the incinerator unit. However, the problems of routing and insulating a 800° duct to the incinerator

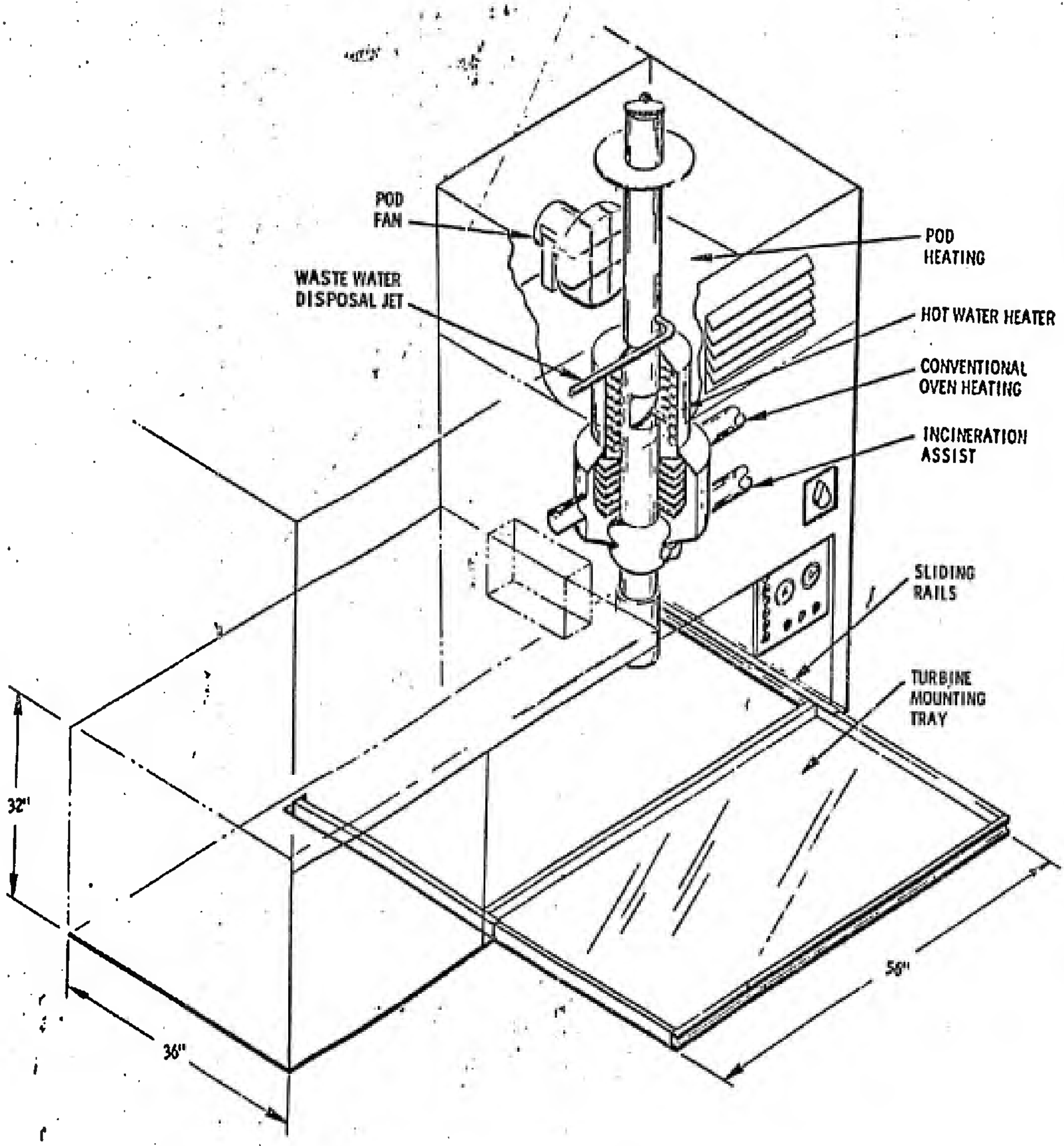


Figure 5. Turbine Generator and Exhaust Utilization General Mechanical and Structural Design

may offset the gain in fuel oil economy. Locating the incinerator adjacent to the turbine exhaust could reduce this ducting problem.

1.8 Heat Load in Pod

The calculated heat load for the mobile bakery is as follows:

	Latent	Sensible	Total
Bread cooling	1,455	11,250	12,705
Oven leakage	-	1,080	1,080
Lighting	-	10,236	10,236
Electronic gear	-	10,236	10,236
Turbine heat	-	3,700	3,700
2 people working	900	420	1,320
Heat leak into pod* (110°F ambient)	-	6,510	6,510
Totals	2,355	43,432	45,787

*The heat leak into the pod is based on a reasonably well insulated pod wall and roof with a K valve of about 0.5 BTU/hr/ft^2/°F. Similar treatment has been visualized between the gas turbine enclosures and the working space. Only 3 kw of heat dissipation has been considered for the electronic equipment on the assumption that the bulk of that heat will be exhausted to the outside.

This heat load is approximately equal to 3.5 tons of refrigeration. However, assuming that much of this heat could be dissipated to exhaust air, the air conditioning load can be cut markedly. For example, assume 50% of the above load could be driven off as exhaust, the cooling requirement for 20 changes per hour outside air at 6350 BTU/hr or slightly more than 1/2 ton.

The bakery unit appears to have about the same heat load as the SPEED kitchen and the concept of adequate ventilation seems to be equally valid.

1.9 Baking and Roasting Containers

Containers for use in the microwave oven at temperatures of 400°F and above must be constructed entirely from non-conductive materials. Although many of the thermoplastic compounds (such as polyethylene, polypropylene, etc.) are excellent from a microwave standpoint, the maximum operating temperature for most is 250°F. For this reason the selection is limited almost entirely to thermosetting plastics. From our experience to date we would recommend the following materials, listed generally in order of their acceptability for low dielectric heating characteristics in a microwave field:

A. Silicone resin (Dow-Corning 302 or 304)

B. Polyimides

C. Diallyl Isopthalate or Diallyl Pthalate

D. Epoxies

All of the above should be utilized with some type of reinforcing compound, and most are available with various lengths and styles of glass fibers. When molded from glass reinforced material, parts will exhibit flexural moduli of $1x10^6$ psi and tensile strengths of 10,000 psi at 400°F. These characteristics will allow containers to be made with extremely thin wall sections and low overall weight.

For cooking many foods we visualize a molded plastic container and fitted lid with smooth walls and a foamed core similar to existing containers for keeping foods hot. These containers would be of appropriate size for fitting the ovens and serving. Cooking, holding and serving would be done in the same container.

2.0 Evaluation of Electrical Requirements

2.1 Total Power Estimate

Kitchen Unit

6 kw 915 Mc Oven	12 kw
6 kw 2450 Mc Oven	12 kw
Browning Units	10 kw
Pod Lighting	1 kw
Pod Auxiliaries	5 kw
Kitchen Total Required	40 kw

Bakery Unit

12 kw 2450 Mc Oven	24 kw
Browning Units	12 kw
Conveyors	1 kw
Pod Lighting	1 kw
Pod Auxiliaries	5 kw
Baking Total Required	43 kw

The total required power for both the kitchen and baking units is well below the 50 kw Turbine Generator capacity. This would permit the incorporation of refrigerator type air conditioning if desirable.

2.2 Microwave Power Modules and Cavities

The final design of the microwave cavity and the choice of a magnetron tube are very closely related for technical reasons. We recommend that a single supplier be responsible for both the cavity design and tube selection.

At present there are two design alternatives: Use a single high power magnetron for each kitchen oven (6 kw) and bakery section (4 kw) or use two, or possibly four lower power magnetrons for each oven or section.

The cavity design should incorporate multiple microwave feed points. If a single tube per cavity is used, its output can be split before coupling to the oven cavity. If multiple tubes are used on each cavity attention must be devoted to eliminating magnetron interaction which tends to produce unstable operation. The suggested cavity sizes in this report are based on a power level of about 1 kw per cubic foot which is common practice in small commercial ovens.

The electronic components for control, protection and production of the magnetron high voltage are thoroughly known to the microwave industry. Simple modular packages can be easily designed, and will be very similar to those presently used on commercial batch type microwave ovens.

2.3 Direct Drive Turbine Generator

In the event that a direct drive turbine generator is available, some changes will be necessary in the design of the electrical equipment. The direct drive generator is expected to produce power at 3200 cycles/sec. All pod electrical equipment suppliers should be informed of this change. The majority of electrical components (lights, hv transformers, and browning units) can be readily adapted to high frequency power. For those items which cannot be easily adapted (ac motors and relays), we suggest converting to dc power and rectifying a few kilowatts of the generator output.

3.0 Evaluation of Baking and Cooking Capabilities

3.1 Bread Baking

Requirements:

Bake and top brown 150 lb of bread dough per hour

Maximum length of oven - 6 feet

Extruded dough sheet to be 18 inches wide by 1/2 inch high

Calculated Data:

Dough sheet 18 inches wide by 1/2 inch high ≅ 3 lb per foot

Inlet dough feed rate ≅ 2.5 lb per minute

Belt speed ≅ 0.833 ft per minute

For a six foot long oven:
Oven dwell time = 7.2 minutes

0.0565 kwh of absorbed energy per lb of dough is needed. Based on 70% efficiency of microwave power 0.08 kwh is needed. Thus for 150 lb of dough per hour we need 12 kw of microwave power. Based on this data the following experiments were performed:

Types of Bread: Military instant bread mix which utilized glucono-delta-lactone as the leavening agent.

Size of Mix: 908 grams of mix blended with 475 grams of water.

Other general information: It was suggested that the bread would be extruded in a continuous loaf onto a paper covered belt which would pass through the oven.

Results: Tests with a non-porous glazed surface paper did not permit loss of moisture thru the bottom of the loaf, thus giving a too moist (soggy) bottom layer.

Utilizing hot air in the oven with the non-porous paper did not alleviate the soggy bottom.

A porous paper, even without the use of hot air, produced a loaf with proper moisture distribution throughout. However, a flow of hot air throughout the oven would prove advantageous as an 8 to 10 percent weight loss (of moisture) takes place during baking and this moisture should not be allowed to condense in the oven.

It was found that this instant bread mix could be satisfactorily baked in a minimum time of three minutes exposure to microwave energy. Less time can not be used because cooking is a time-temperature relationship and, in this type oven (atmospheric pressure), increased energy input would seriously dehydrate the loaf. It can be considered that the cooking time, of three minutes exposure to sufficient microwave energy plus the time during cooling is necessary for starch gelatinization and other changes necessary to go from raw dough to a cooked bread. However, at less than optimum power levels, increased exposure time can produce a satisfactory loaf of bread.

Bread was satisfactorily baked in the 915 Mc conveyorized research machine as follows:

Bread dough weighing 1383 grams was spread out on porous paper to a size of 29 x 9-1/2 x 1/2 inches and subjected to microwave energy for three minutes with the generator dials set at 7.8 kv and .85 amps. The finished loaf was 29 x 9-1/2 x 2-1/2 inches and weighed 1276 grams after cooling to room temperature. This was a five-fold increase in volume and an 8% weight loss. The amount of power absorbed in this test cannot be accurately calculated. However using 70% as the efficiency of conversion to microwave power, this gives 4.64 kw microwave. This power applied for 3 minutes to 3.05 lbs of bread dough gives 0.076 kwh per lb of bread dough. From theoretical calculations, 0.0565 kwh would be required, thus approximately 70% of the microwave is being absorbed. For increased loads this efficiency would increase.

Browning of this bread by use of 400-450°F, hot air after baking was not satisfactory.

Bread was satisfactorily baked and browned in a 2450 Mc cavity type oven with an internal calrod unit. In this series of experiments, the calrod broiler unit was preheated and the loaf cooked 5 minutes at the hi power setting with the calrod unit on for the 1st two minutes of baking time. The 3.05 lb loaf of dough was 15 x 11 x 3/4 inches at start and was 15 x 11 x 3-3/4 inches at the finish, a five-fold volume increase.

A water load test demonstrated the microwave power of this hi-power setting to be about 1.08 kw, thus giving 0.03 kwh per lb of bread dough. This seems misleading but for this thin layer of bread, it seems 2450 Mc may be more efficient than 915 Mc.

The browning was satisfactory.

Porous paper in a perforated container is necessary to prevent sweating and thus sogginess of the bottom portion.

3.2 Cake and Pastry Baking

3.2.1 Cakes

It was established that yellow cake, devils food, lemon flake cake, apple chip cake, and pineapple cocoanut cake mixes (all tried) could be satisfactorily baked in either the 915 or 2450 Mc units. Porous paper on a perforated belt system is necessary to prevent sweating on the bottom.

Minimum time at optimum power levels for weights of batter used was about 4 to 5 minutes.

3.2.2 Pie Crust

Cooking of "Betty Crocker" pie crust shells in either the 915 or 2450 Mc was unsatisfactory.

3.2.3 Cookies

Cookies ("Betty Crocker" refrigerated dough) were not satisfactorily baked at 915 Mc. Better results were obtained at 2450 Mc but uneven cooking and a standing wave pattern was observed.

3.3 Meat Roasting

Initial studies on cooking of boneless beef roast showed considerable variations in heating of various size and shapes of roasts. A method of minimizing these variations was developed.

As an example a 3.6 lb short cylindrical tied beef roast was placed upright on a paper dish and subjected to 5 kw microwave at 915 Mc for 6 minutes. The temperature went from 46°F to, 86°F on the top surface, 135°F on side, and 97°F in the center. At the end of 8 minutes microwave exposure, the respective temperatures were 95°F, 150°F and 103°F. At the end of 10 minutes microwave exposure, the temperatures were 108°F, 180°F and 116°F. The roast was then placed in an expanded polystyrene insulated container and subjected to an additional 1 minute to microwave energy with a resultant surface temperature of 180°F and an internal temperature of 162°F. This is an example of how some products which heat unevenly in a microwave field can be more successfully heated by using the insulated container inovation.

In another study a 2-3/4 lb beef roast was placed in an expanded polystyrene container and exposed to microwaye energy at the lo-power setting in a 2450 Mc cavity oven for 12 minutes. The initial temperature of 41°F was increased to 195°F on the surface and 76°F in the center. After an additional 30 minutes holding time without microwave energy, the center temperatures was 142°F and the surface 157°F.

A 3.3 lb beef roast was similarly treated at 915 Mc with microwave power set at 5 kw. The initial temperature of 41°F was increased after 12 minute exposure to a center temperature of 152°F with a surface temperature of 190°F. After an additional holding time of 4-1/2 minutes without microwave power, the center temperature was 163°F with the surface at 184°F.

From the above two tests, one may conclude that the known greater penetration of microwave energy at 915 Mc as compared to 2450 Mc has been demonstrated. From this we may conclude that 915 Mc power would be more advantageous for roast cooking than 2450.

A 3.27 lb center cut beef chuck roast with bone-in in an expanded polystyrene container was subjected to 2450 Mc microwave power at the lo-power setting for 14 minutes, held an additional 18 minutes with no power. The temperature along the bone was 200°F with the coldest part in the center of the meat at 160°F.

A 3.38 lb lamb shoulder roast with bone-in in an expanded polystyrene container was subjected to 2450 Mc microwave power at the lo-power setting for 22 minutes. The overall temperature was close to 200°F with one small central area at 150°F.

3.4 Potato and Vegetable Cooking

3.4.1 Potatoes

Potatoes (8,110 grams) were placed in an expanded polystyrene container and subjected to 4 kw microwave 915 Mc power for 5 minutes. The center of the potatoes was at 185°F whereas the surface at 160°F and the potatoes were fully cooked. More power would have cooked them quicker.

A similar quantity was cooked at lo-power in the 2450 Mc cavity oven in 5 minutes.

3.4.2 Carrots

Carrots because of their fibrous nature require an extended time after reaching the tenderizing and cooking temperature. This time is required to allow for fibrous structure to break down.

Carrots (470 grams) were placed in an expanded polystyrene container and subjected to 3 kw microwave at 915 Mc for 4 minutes. The temperature rose to 190°F. After 10 minutes holding without microwave power, the temperatures dropped to 175°F and the carrots were cooked.

In another trial 1015 grams carrots in an expanded polystyrene container were exposed to microwave energy at 2450 Mc for 4 minutes with the hi-power setting. The temperature rose to 200°F in the hotest spot. However, other areas, particularly the bottom portion did not come up appreciably in temperature, as after a holding period of 35 minutes. The top carrots, which were 200°F, had dropped to 175°F and were cooked but the bottom carrots were not fully cooked.

3.4.3 Cabbage

Raw green cabbage (608 grams) was placed in an expanded polystyrene container and exposed to microwave power at 2450 Mc at hi-power setting for 3 minutes. The temperature rose to 205°F and dropped to 190°F after 11 minutes holding time. The cabbage was excellent.

Cabbage, being of a fibrous nature, needs the holding time for the product to be considered cooked.

4.0 Cost Evaluation, Maintenance, & Life of Principal Electronic Components

4.1 Cost of Cooking (Kitchen) Ovens

This study indicates that a total of 12 kw of microwave power will be required, and it is recommended two 6 kw ovens, one at 915 Mc and one at 2450 Mc be used. Each oven would utilize two 3 kw magnetrons feeding one cavity. The highest power oven unit now available commercially is 2.5 kw at 2450, at around $1800.

For 2450 Mc, either Raytheon or Litton might be interested in building a special double oven, with some isolation between tubes, utilizing two 3 kw sources. At 915 Mc General Electric has expressed interest in doing the same. For five initial units, with prospect for supplying many in the future, the price would approximate $6500 each; subsequent units would sell for between $3000 and $3500. The initial cost is based upon $25,000 development cost with $15,000 spread over the first five units, and $10,000 carried by the vendor.

4.2 Cost of Baking (Continuous) Ovens

This study indicated that 12 kw of microwave power will be required. Standard units could not be considered on this device. The closest oven design is Litton's five-wide experimental continuous unit which is much too long for the pod. A new design will be necessary, and we recommend a 3 section oven each powered by a 5 kw tube.

Based upon our estimates for development programs of institutional ovens, which have been similar in concept to this device, the budget for initial work would be about $45,000. Unit cost for five units on a repeat order would probably be in the range of $9,000, so the first five should cost $18,000 each. This does not appear unreasonable for a special purpose highly efficient 12 kw continuous microwave device.

4.3 Maintenance Cost Estimates

4.3.1 Kitchen Ovens (Based on 200 hours use per month)

Microwave tubes

	2 - 6 kw tubes	$1000 cost (1000 hours)	$200 per mo
or	4 - 3 kw tubes	$1000 cost (1000 hours)	
Misc components and hardware			50 per mo
		Total	$250 per mo

Manpower at 4 hours per week — 16 hours per mo

4.3.2 Bakery Ovens (Based on 400 hours use per month)

Microwave tubes

	3 - 4 kw tubes	$1500 cost (1500 hours)	$400 per mo
or	6 - 3 kw tubes	$1500 cost (1500 hours)	
	Belts · $250	(5 months)	40 per mo
	Misc components and hardware		50 per mo
		Total	$490 per mo

Manpower at 4 hours per week — 16 hours per mo

4.3.3 Gas Turbines

The manufacturers were not able to furnish reliable information on maintenance costs and referred us to the military who are the primary users of this device. These records were not readily available to us and we suggest that they be reviewed for information on gas turbine generator maintenance and life.

4.4 Life of Electronic Components

The art of manufacturing in electric motors, dc power suppliers, lights, relays and general controls is such that these devices can be expected to provide a minimum life of 5000 to 10,000 hours of operation.

The oven cavities themselves are essentially mechanical structures which should have many years of life with proper cleaning. A few small plastic trim or insulating materials may require occasional replacement.

The major electronic items which will require periodic replacement are the magnetron tubes. For a tube of this type a reasonable expected life would be 1000 to 2000 hours. Typical manufacturers warrantees are for these periods of time. We have used the 1000 hour figure on the batch type ovens which are subject to frequent on-off cycles and widely varying load conditions. We have used a 1500 hour figure for the conveyor oven which will operate continuously for long periods of time and has a more constant load condition.

5.0 Evaluation of Shielding Requirements

Radiation from the microwave heating is capable of causing interference in electronic equipment (communication receivers and radars) as well as presenting a personnel hazard. Radiated power of the highest intensity will be that of the primary frequency either 2450 or 915 Mc/sec. Radiations may also be present from harmonics or spurious emissions from power supplies and heaters.

The primary frequencies of 2450 and 915 Mc/sec are allocated as Industrial, Scientific and Medical by the Federal Communications Commission and unlimited radiation is permitted on these frequencies. The radiations on frequencies other than the primary frequency must be reduced to a value of 10 microvolts/meter at a distance of one mile from the source. To prevent possible interference, the energy radiated and the bandwidth of emissions shall be reduced to the greatest extent possible. The use of shielded cabinets and the metal truck or trailer pod may be expected to greatly reduce or eliminate interference from spurious emissions. In addition to shielding, the installation of filters in the electrical circuit may be necessary.

The power density presently considered as safe limit for personnel is 10 milliwatt/cm^2. The microwave leakage from the equipment at any point where a person might position himself must be less than 10 milliwatts/cm^2. Chambers containing microwave choke assembly, baffles, and absorbing materials can be used to attenuate the leakage from the process chamber to the safe level.

Experience to date by the various microwave oven manufacturers indicates that meeting these requirements is not difficult and easily achieved with standard shielding techniques.

6.0 Operation and Maintenance Skills

It is not anticipated that special training of cooks will be necessary to operate either the mobile kitchen or bakery. However, since microwave cooking is basically different in time and method from conventional cooking, personnel will have to develop a new framework of experience through observation and experimentation. Relative cooking times and relative difficulty in preparing certain foods in similar for both microwave and conventional cooking, but the shapes, sizes, and consistencies of foods are more critical with microwave ovens. For example, the concept of "holding time" during which foods gain the flavor and texture of the complete cooking process must be appreciated by personnel operating the mobile kitchen.

Maintenance skills required to repair microwave ovens are not unlike skills which are presently available in the armed forces. Microwave tubes and assemblies are similar to radar power supplies. The proposed units are designed in such a way that field repair would consist primarily of simple replacement of tubes and other modular components. It is felt that a reasonably competent electronics technician can perform almost any repairs required if he uses the typical maintenance manual supplied with this type of equipment.