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U. S. Army Natick Laboratories
Contract No. DA 19-129-AMC-621 (N)
Project No. IA0-13001-A91A

# PHASE I REPORT

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## PHASE I REPORT

## I. INTRODUCTION

The purpose of this contract is to determine the optimum design of microwave ovens to support the Speed Field Feeding concept. The study is to proceed in two stages: Phase I, in which the contractor is to make a through study of the cooking system requirements and determine how all requirements can be accomplished, and Phase II in which the contractor is to study all problems and determine the optimum methods of solving them. This report will summarize the work on Phase I of the study contract.

At tHe present time, it is planned that the Speed Feeding System will be comprised of two major units, a Mobile Bakery which will service 5000 troops per day with bread and pastry and a Mobile Kitchen which will cook 3 meals per day for 200 men. The Bakery and Kitchen are to be self-sufficient units built into a standard military pod which may be mounted on a truck or trailer or air transported for field emplacement.

## II. DISCUSSION

### A. The Mobile Bakery

1. The Bakery will be comprised of two similar pods, a Bread unit which will be required to bake 150 pounds of bread per hour, and a Pastry unit which will be required to bake 50 pounds of cakes, cookies or rolls per hour. It is intended that the microwave components of these two separate units will be identical so that either unit may be substituted for the other providing maximum field

flexibility. In view of the large quantities of bread or pastry per hour which the units must produce, it is definitely felt that a continuous conveyor type microwave oven is most practical. A mixer-extruder either for pastry or for bread will continuously extrude dough onto the microwave oven conveyor belt. The dough will pass through the microwave oven in a period varying between 3 and 10 minutes depending upon the product being baked. A browning unit will be utilized within the microwave oven to produce a browned crust on breads and rolls.

2. A series of tests were performed to check the feasibility and baking characteristics of several types of bread and pastry mixes. The military instant bread mix No. DA-19-129-AMC-114/N/ along with General Foods, General Mills, and Pillsbury cookie and cake mixes were used in a series of evaluating experiments at both 2450 mc and 915 mc. Various power levels and cooking techniques were tried at both frequencies.

A hot gas source to simulate gas turbine exhaust temperatures was designed and constructed. This device was used in tests to determine the feasibility of browning bread with hot air which would be supplied by a heat exchanger mounted in the gas turbine exhaust manifold.

3. The bread baking experiments have yielded the following information and conclusions:

   a. Both frequencies can produce satisfactory bread, cakes, rolls, and thick "cake-like" cookies.

   b. At 915 mc very thin dough such as pie shells or

2450 mc. At 2450 mc the thin items occasionally exhibited localized over-heating.

c. Browning with the simulated gas turbine exhaust was not very successful. It appears that the desiccating effect of the hot air produces a burning rather than browning action on the bread crust. A decidedly more satisfactory browning can be accom..ished using infra red heating located directly above the surface of the bread while baking.

d. When bread and cakes were baked on a polyethylene coated paper it was found that the bottom surface of the bread or cake tended to be moist and soggy because of trapped moisture. A more desirable texture was obtained when these items were baked on a porous newsprint-type paper. A porous paper with a high wet strength should be used for baking to eliminate this excess moisture problem.

4. An important part of the Speed Field Feeding concept is that each unit be self sufficient, capable of generating its own power and cooling requirements from commonly available field fuels. This aspect of the Speed Feeding System has been throughly reviewed. The major problem is one of compactness and available space, it now appears that the use of gas turbine for power generation is most feasible and practical. (See Appendix I). We are continuing to investigate "total energy system" packages which provide electric power, hot water, steam, hot air and cold air from a single unit utilizing a gas turbine as a prime

power source.

5. Phase I of this study contract contains a list of specific questions regarding the Mobile Bakery to be investigated. Many of these questions have been covered or touched upon by the previous general discussion. For convenience each question will be answered individually below.

   a. What size conveyor is required to produce the specified amount of finished bread and pastry products?

      The bread dough will be extruded in an 18 inch width. To be conservative a 3.5 minute oven dwell time will be used in the calculations. The minimum requirement for baking is 150 pounds of dough per hour or 2.5 pounds of dough per minute. Using specific gravity of .75 for freshly made instant bread dough, a sheet of dough 18 inches wide and .5 inch thick would weigh 2.9 pounds per foot. To satisfy these conditions the microwave length of the oven must be 3 feet.

   b. What style of conveyor mechanism is optimum?

      A belt type conveyor utilizing an open mesh silicone rubber coated fibreglass belt appears at the present time to be the best choice. Since new materials suitable for use with microwave devices are under constant study, alternate choices may be available at the end of Phase II. A variable speed electric drive motor with speeds from .25 foot per minute to 2 feet per minute is suggested. It may be desirable to control the oven conveyor speed by the mixer-extruder unit output.

c. Do the power intensity fields in the ovens need tapering so as to achieve rapid heating at first and slow heating to finish? What is optimum?

From the present experimental baking tests there appears to be no necessity for tapering the fields in the oven. To produce an effectively tapered microwave field would be a design problem which hardly seems justified in view of the doubtful benefits to be gained.

d. Is gas turbine electric power the best portable power source considering all factors?

One of the major problems to be solved in the design of the power source is space. The gas turbine enjoys a considerable advantage in compactness and for this reason is probably the best choice (see Appendix I for additional discussion).

e. What is the design configuration of the best electric power source and will it fit under the bread baking conveyor?

Present thinking calls for the power generator to be placed under the conveyor belt platform on the front wall of the pod. The size of a 50 kilowatt gas turbine generator is compatible with this space. More detailed design analysis will be done in Phase II of this study contract.

f. What is the best method for browning bread?

Consideration should be given to straight resistance heaters or gas heaters if turbine exhaust is insufficient.

As stated above, browning with simulated turbine exhaust has not been outstandingly successful. It is recommended that infra red units within the baking portion of the oven be planned for browning.

g. What is the best microwave heating frequency for each oven and what are the maximum power requirements? Are power level controls required?

For baking a dough layer .5" in thickness, either microwave frequency can be used. Considering oven dimensions and pod space limitations 2450 mcs would be preferable. It has also been noted that 2450 mcs will bake thin items more rapidly.

Bread baking will be the maximum cooking load and requires .057 kilowatt hours per pound of bread dough. Thus 150 pounds of bread dough per hour will require 8.5 kilowatts. Based on 70% efficiency, a 12 kilowatt microwave oven will be required.

It is proposed that a high-low switch be used for full power and approximately two thirds power. The other variables will be belt speed and belt loading. This will simplify controls for operating personnel and take care of a wide range of unforeseen needs.

h. What is the optimum microwave power source design for each oven? It must be very easy to maintain, of simple design, rugged and assembled into replaceable packages so that the bakers can change modules if a part fails.

The simplest system for generation of the microwave power is a magnetron. Since the magnetron is a self-contained power oscillator it presents the most technically advantageous and least expensive power source for microwave cooking. A magnetron system consists of the following major components: Magnetron, high voltage transformer, rectifiers, filament transformer and magnet assembly. These components are easily designed as replaceable modular units of modest size for magnetrons of the order of 3 kilowatts power output.

i. What minimum electrical operational indicators are required to show proper operation or module failure?

The operation of the magnetron can be controlled by push operated on and off switches with "on" and stand-by" conditions indicated by lights. Monitoring of the magnetron anode current will be most indicative of the magnetron performance. Abnormal operation or unfavorable load impedences would be reflected in this current.

j. Is there any advantage of using high frequency electricity from a direct drive turbine generator?

The main advantage of the direct drive turbine generator is mechanical. The direct drive permits elimination of the reduction gear unit which is expensive, heavy and a maintenance problem. Present development work on the direct drive turbine generators would result in 3200 cycles per second power. This frequency could be used for operation of the Bakery units.

The use of high frequency electricity would reduce the size of the main high voltage power supply and filtering components. Ripple frequencies would be high and more easily filtered. The pod lighting could be fluorescent lights which work more efficiently on high frequency electricity.

Off-setting these advantages is the disadvantage that most motors, control equipment, and other commonly available accessories do not operate from 3200 cycles per second power. It would be required that the high frequency power be rectified and accessory components selected which operate from DC voltages.

k. What method can be used for starting up the conveyors when they are not loaded with products?

The microwave oven should be designed so that full microwave power can be applied with no product on the conveyor. When product is run the first one or two minutes and last one or two minutes of production may be overcooked and have to be discarded. Since we are talking about continuous operation for several hours of production this discard is only a small percentage of the total product.

l. What will be the heat and noise levels inside the Bakery truck?

Both of these items are of concern to us. Ventilation, perhaps air conditioning, and soundproofing techniques will be utilized to insure reasonable working conditions within the Bakery truck. Further details on these problems will be presented in the Phase II report.

m. How much will the ovens weigh complete with electric power source?

This information will not be available until the completion of the Phase II design work.

n. What is the dollar cost of purchase and maintenance based on quantities shown in paragraph A, Objectives?

This information will not be available until the completion of the Phase II design work.

o. What maintenance frequency is necessary?

The microwave oven and conveyor/equipment can and should be designed so that routine maintenance, other than good daily housekeeping practices, is not required more than once per month.

B. The Mobile Kitchen

1. The Kitchen will consist of a single pod. It is intended that the Kitchen provide 3 meals a day for 200 men, and that these meals be served in a 60 minute period. The maximum food load for the microwave oven for any one meal will be 80 pounds of raw meat, 50 pounds of frozen vegetables and 50 pounds of raw potatoes for baking. Cooking time may be staggered so that some food can be coming out of the oven during the time of serving. The microwave oven will be

required to cook raw foods, heat pre-cooked foods, and cook de-frosted frozen foods. Due to the large variety of foods which the microwave oven must process, we feel that batch ovens are indicated.

2. A series of experiments were performed to test the cooking characteristics of meats, vegetables and potatoes. Various cooking techniques and power levels were tried and both 2450 mcs. and 915 mcs.

The microwave cooking of some foods from the raw state presents a problem. In many foods, particularly meats, it appears that once the cooking temperature has been reached a holding period at this temperature is required in order for chemical processes which produce tenderness and flavoring to take place. To solve this problem and also help keep the cooked foods at serving temperatures, we suggest that many foods be cooked in insulated containers. This approach is quite feasible since microwave power readily passes through insulating materials which prevent heat from being lost. In our cooking experiments, simple poly-foam containers were utilized, and excellent results were obtained

3. The food cooking experiments have yielded the following information and conclusions:

   a. Both frequencies can cook the majority of foods. However, 915 mcs penetrates further in bulky items such as roasts, whereas 2450 mcs works better on very small items, such as peas or beans.

   b. The size and shape of a food item can cause unexpected cooking results. The geometry of the food plays a very important role in the rate in which the food absorbs microwave energy and the uniformity of heating.

c. On many items a heating period followed by an equilibrating period is necessary to produce an optimum product. Cooking is a time-temperature relationship, and heating proceeds so rapidly in microwave cooking that holding time is required for tenderness and flavor to develop in some foods.

d. Stirring of the microwave fields and or movement of the item being cooked is very desirable to provide uniform heating of the food.

e. Although not essential, a combination microwave and conventional oven would provide maximum flexibility in preparation of foods. It appears that there are a few items on which simultaneous use of conventional hot air heating plus microwave power would be very effective.

4. Comments on the list of specific questions in the study regarding the Mobile Kitchen are summarized below.

a. Is a batch or conveyor oven better?

As stated above, due to the tremendous variety and relatively small amounts of foods to be cooked, batch ovens are definitely indicated.

b. If it is a batch oven, should there be two or more oven shelves with individual controls to accomplish the wide variety of proposed cooking? What size oven and shelves are required?

The maximum microwave cooking requirements were stated as 50 pounds of potatoes, 50 pounds of vegetables and 80 pounds of meat. The shelf space and microwave power requirements for this cooking load are as follows:

Shelf space and microwave power requirements

| Item | Weight | Shelf Area | Microwave Power |
|---|---|---|---|
| Potatoes | 50 lbs. | 7.5 sq. ft. | 2.5 KWH |
| Vegetables | 50 lbs. | 10.5 sq. ft. | 3.0 KWH |
| Meat* | 80 lbs. | 3 sq. ft. | 6.5 KWH |
| | | 21 sq. ft. | 12.0 KWH |

* Four way beef 4" x 4" x 12"

To cook the above food load in a one hour period we would need 21 square feet of shelf space and 12 kilowatts of microwave power. Present commercially available high power microwave batch ovens range from 2 to 3 kilowatts with shelf areas of 3 to 4 square feet. The possibility of oven designs to meet the above requirements will be studied in more detail during the Phase II portion of this contract.

c. Is gas turbine electric power the best power source considering all factors; what form does the best source take? Can it be contained under the oven?

Previous comments regarding the gas turbine (see section A-5-d and e above) apply to this question.

d. What is the best microwave frequency and how much power is required? How should the microwave power be produced to achieve uniform heating?

Due to the variety of foods which will be processed in the kitchen and the pronounced influence of the food geometry upon its cooking characteristics we feel that each kitchen should be equipped with one oven of each frequency.

Microwave power is most uniformally distributed in a fully loaded oven if it is introduced from a number of radiating apertures. Additional uniformity may be achieved by the use of stirring devices or by reflecting surfaces which introduce displaced field patterns.

e. What is the optimum microwave power source and what is the design configuration? How does it fit into the oven?

The comments of Section A-5-h above apply in this case. Additional study of the design configurations will proceed in Phase II of the contract.

f. What microwave power controls are required for cooking the variety of foods described?

The microwave ovens should have a high and low power setting. The major variable control of cooking will be the length of time which foods are in a microwave oven. A simple timer which shuts off microwave power will be the other cooking control.

g. See section A-5-i above.

h. See section A-5-j above.

i. See section A-5-l above.

j. See section A-5-m above.

k. See section A-5-n above.

l. What maintenance is necessary on the oven microwave system and turbine and how often?

The microwave batch oven should be a very reliable and trouble free device requiring a minimum of maintenance. If properly designed these units should be able to go as much as three months between routine maintenance periods.

The maintenance aspects of the gas turbine are discussed in Appendix I. We are continuing to review and discuss all aspects of the use of gas turbines with the various manufacturers.

m. What form and design will plug in replacement microwave power modules take and at what cost?

This information will not be available until the completion of the Phase II design work.

n. Can the requirement for the incinerator be included utilizing the exhaust from the turbine electric generator?

Present commercial incinerators operate at combustion temperatures of around 1800°F. The temperature of the exhaust gas from the gas turbine wil be about 900°F.; therefore complete incineration utilizing exhaust gas alone is not possible. Two possibilities suggest themselves; turbine exhaust gas could be used to supplement heating from diesel fuel burners in the incinerator or turbine exhaust gas could be used to simply dehydrate and sterilize moist waste material.

The incinerating problem for the Mobile Kitchen should receive thorough study. Many of the disposable plastic items which the military will be using present a serious problem in incineration; some plastics give off toxic fumes when burned and others simply melt and will clog conventional incinerators.

There are several other possibilities for utilizing the hot exhaust gas from the gas turbine within the Mobile Kitchen.

1. Water can easily be heated utilizing a simple heat exchanger in gas turbine exhaust manifold.
2. Waste water from the sink could be evaporated in a coil passing through the gas turbine exhaust manifold and discharged into the atmosphere rather than be drained upon the ground.
3. The hot air for conventional heating in the oven could be obtained by use of a simple air-to-air heat exchanger in the gas turbine manifold.

## III. SUMMARY

In general it appears that the microwave cooking aspects of the Speed Field Feeding System are feasible. Most of the cooking and baking requirements are within the present state of the microwave cooking art. In Phase II of this study contract we will concentrate on the specific design problems of each of the pieces of microwave equipment. The only major technical problem which we forsee at the present is that of packaging the microwave components in units which are small enough to be compatible with the preliminary Kitchen and Bakery pod designs.

Appendix I

## Power Source for the Speed Field Feeding System

The power requirements for the mobile field kitchen, which is under study, will approximate 40 kw. With allowance for auxiliaries and possible unplanned for usage the rating of the power unit should be about 50 kw.

While prototype units of this size have been produced in both the thermoelectric generator and the fuel cell, the practical feasibility of these devices in this size and use has yet to be demonstrated. The fuel cell for instance is very limited in the fuels that it will utilize. The thermoelectric generators have proven to be very useful in the wattage size, but multi kilowatt size units are not presently available.

The two most attractive means of power generator for this application at the present time are the reciprocating engine generator units and the gas turbine generator set. Among the reciprocating engines either the gasoline engine or the diesel engine may be considered. However, the diesel engine set is the more popular, and therefore more readily available.

Among the gas turbines there are only two manufacturers who are currently building units of the small size required. The variations available with the standard production units are minimal, however there are modifications in the development stage which may offer very attractive advantages for the field kitchen application.

In comparing the gas turbine prime mover with the reciprocating engine there are several points which may be considered.

They are:

1. cost
2. weight & volume
3. fuel economy
4. reliability
5. environmental adaptability
6. maintainability
7. parts availability
8. military standardization & acceptance
9. noise & vibration

From the standpoint of unit cost the self contained diesel engine generator set will cost between $6,000 and $10,000 for the subject application. The actual price of the unit will depend upon the features specified with unit. On the other hand a gas turbine generator set of the same size (and built to military specification) will cost between $20,000 and $40,000. The prices quoted are based on presently produced standard military portable power units. There are modifications which could be made in the gas turbine units which would not affect the units utility in the mobile kitchen that might result in significant savings. This of course is predicated upon a volume purchase of units.

The weight and volume comparison of the reciprocating units versus gas turbine units is normally of little consequence in most commercial applications. However in military applications these parameters assume considerable importance. The cubage or volume comparison of the two prime movers indicates a definite difference. The diesel engine generator set in this size occupies approximately twice the volume of the equivalent gas turbine unit. With the limited space available in the mobile kitchen pods, the gas turbine unit offers a definite advantage on this point.

Likewise, the gas turbine is a much lighter unit than the equivalent diesel powered unit. The ratio being in the neighborhood of six to one. This weight difference becomes particularly significant if the pod is to be air-borne.

The fuel economy of the reciprocating engines is considerably better than that which may be anticipated from a gas turbine. In fact, the fuel economy of a very small gas turbine might be considered to be atrociously poor. This results not only from the metallurgical limit, which restricts all gas turbine efficiency, but also from the increased windage and blading losses which are magnified by the small size of the units. Fuel economies in the range of three to five pounds per kwh may be expected, from these small units while fuel economies of less than one pound per kwh are not uncommon with a diesel engine generator set.

The question of reliability of gas turbines versus diesel engines in these small sizes is not easily answered. The diesel engine has proven to be a reliable workhorse with many years of experience behind it. An industrial diesel engine of large size may last ten to twenty years, often with as long as 10,000 hours between major overhauls. In the case of the smaller units, such as are being considered for this project, 5,000 hours between major overhauls would be uncommon if the engine is operated continuously. However this particular application calls for intermittent use, with frequent starts and stops when in use and long periods of idleness when the kitchen is not in service. Under such conditions, a high degree of reliability can be maintained only at the expense of a continuous and expert preventative maintenance program.

The gas turbine is a relative newcomer to the field of prime movers, however the large gas turbines have firmly established a record of reliability in both continuous and intermittent duty. However the very small gas turbines have been very recently developed and there is little experience behind them. It is probably safe to assume that the actual engine life will be somewhat shorter than that which might be expected of the large gas turbines because of the higher speeds of the small engines. This higher engine speed results in much higher gear speeds which will probably reduce the unit life considerably.

Considering the inherent simplicity of the gas turbine versus the complexity of the diesel engine, it is probably safe to assume that the starting reliability of the small gas turbine will be better than that of a comparable sized diesel engine under field conditions. On the other hand, it is also safe to assume that the frequency of major overhaul will also be higher for the small gas turbine because of the increased bearing and gearing wear.

The problems of environmental adaptability are quite different for the two prime movers. In the case of the diesel engine the major environmental problem is in the question of low temperature idleness and starting. The cooling system of a diesel must be protected against freezing and the lubrication system must be at least preheated to permit start-up lubrication. In the case of a gas turbine the environmental problem is one of high ambient temperatures. A gas turbine's maximum power output is limited by the turbine temperature which in turn is related to the inlet air temperature. There is considerable derating of the maximum power capability of the engine as the ambient temperature increases. Therefore, if the gas turbine is chosen as the energy source for the mobile field kitchen, the rating of the engine should be based on the maximum anticipated ambient temperature. The only requirement fore extremely low ambient temperatures is a starting battery heater, which is standard equipment on most portable military units.

The problems of maintainability of the two engines are also quite different. Both the diesel and gas turbine engines require skilled maintenance personnel. However the gas turbine is a very light and compact device and the usual maintenance proceedure is to change the complete power package and do the maintenance work on the bench. While the diesel engine is larger and heavier and the inclination, at least, is to attempt to perform the maintenance in place. Even with engine changes, the down-time for maintenance should be considerably less for the gas turbine.

Parts availability for either the diesel or gas turbine should be equally good, however because of the lesser number of parts in the gas turbine, the problem of stocking spare parts should be considerably reduced.

The question of military acceptance and standardization from an over-all point of view is of no problem for either prime mover. However the question of acceptance is primarily one of the preference of the specifying agency and their ability to gain approval of their choice.

The noise of either the gas turbine or the diesel can be readily attenuated to an acceptable level, however the vibration problem of the two machines is quite different. The gas turbine must be well balanced to run at all and the vibration problem is primarily high frequency gear vibration or chatter. While the diesel engine has a much lower vibration frequency which is amenable to damping.