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TECHNICAL REPORT
70-43-FL

FREEZE-DRYING OF FOODS FOR THE ARMED SERVICES

by

J. M. Tuomy

February 1970

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Food Laboratory
FL-107

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J. M. Tuomy

Project reference:
1J6-62708-D553

Series: FL-107

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FOREWORD

Freeze-drying has become an accepted method of food preservation within the last 15 years. For the military services, in particular, it has special advantages possessed by no other presently used method of preservation. As a result, a large share of the military research and development effort on foods has been concerned with studying the freeze-drying process, the characteristics of freeze-dried foods, and the utilization of freeze-dried foods in Armed Forces' feeding situations.

This report presents in broad terms, the present status of freeze-drying; the advantages and disadvantages of freeze-dried products; and some of the factors to be considered in their formulation, processing, and packaging. A selected bibliography is included as a source of technical details of the freeze-drying process.

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ABSTRACT

This report reviews the development and use of freeze-dried food products for the Armed Services. It covers the various products and ration systems that have been developed, the basic parameters of freeze-drying and freeze-dried foods, commercial freeze-drying facilities, compression of freeze-dried foods, and development of freeze-dried foods for astronaut feeding. The report is non-technical and includes a selected bibliography for persons wishing to go more deeply into the technical aspects of freeze-drying.

INTRODUCTION

Feeding the Armed Forces of the United States is a world wide operation that must provide millions of meals each day under almost every conceivable condition. Since the operational capability of a fighting man can rise or fall depending upon his food intake, a great deal of attention is paid to the nutritional adequacy and palatability of his food. By regulation, the standard ration (3 meals for 1 man for 1 day) must contain 3600 calories[1/] and be nutritionally adequate. However, calories and nutritional adequacy do not make a food palatable and, since food is an important morale factor, it behooves the military commander to supply his men with the most acceptable foods possible.

Feeding of military personnel can be grouped into two broad categories. The first is feeding troops in garrison or similar situations where trained personnel and suitable equipment are available to prepare practically all of the types of foods used by the civilian population. The second category is feeding troops operating away from garrison in situations ranging from the mere lack of refrigeration or similar facilities to where individuals or small groups are operating under stress conditions, such as combat.

Garrison feeding is similar to civilian institutional feeding and uses the A ration which is fresh, frozen and preserved foods. However, the size of the operation magnifies problems of procurement, warehousing, and distribution. Because of these problems the Armed Forces have special requirements for many foods which will not permit buying off-the-shelf items. However, military feeding, like institutional feeding, is moving toward the use of convenience foods which require less preparation and reduce transportation requirements.

For the second category, feeding is accomplished through the use of operational rations. This ranges from the B ration, similar to the A ration except that it requires no refrigeration, to survival rations and individual combat packets. It is in the operational ration area that most of the Armed Services' research and development effort on foods has been expended. For this usage, foods must be designed and packaged to withstand the extremes of climatic conditions found throughout the world. Also, minimal weight and cube are important. To meet these military requirements, the Armed Forces have turned to dehydrated foods to improve the feeding program. Freeze-dehydration, one of the newer processes in food dehydration, gives great promise for military use. Not only are freeze-dried foods finding their way into the A rations, but their light weight and storage stability make them excellent items for operational rations.

HISTORY OF FREEZE-DEHYDRATION

Dehydration has been used throughout recorded history for the preservation of food. Even today there are a large number of foods commonly used which are preserved by reducing their moisture content for storage at ambient temperature.

1/ Army Regulation 40-5

Dried fruits, such as raisins, and dry sausage, such as pepperoni, are sold in large quantities and are accepted by consumers as standard products. In the underdeveloped nations, dried foods, particularly dried meat and fish such as "charqui" in South America and "biltong" in South Africa, are very common since refrigeration is scarce. Armies have always used dehydrated foods, especially for operational rations, because of their low weight, concentrated nutrition, and stability. Pemmican, jerky and parched corn are common terms in American history. Almost without exception, these dried foods are totally different from their fresh counterparts. They must be accepted by consumers as a product in their own right, such as with dried fruits.

The object of dehydration is simply to reduce the moisture content of the product to a point where spoilage organisms cannot live and multiply. Moisture is evaporated with heat before the spoilage organisms can make the food unusable. The combination of heat and moisture loss so alters a food product such as meat that it cannot be rehydrated to resemble the original product.

During World War II, U. S. military forces used many dehydrated foods, but quality generally was poor due to lack of technical know-how and quality control. Dehydrated eggs and potatoes were among the poor products which gave dehydrated foods a very bad name. After the war military strategists projected the need for greater mobility of combat troops. It was realized that the saving of weight and cube, and stability of dehydrated foods would contribute to achieving this mobility. A review of dehydration processes showed that none of those commercially available could be improved to the point where the great majority of foods dried by them would be acceptable to the American serviceman. This was particularly true of meats where only a few dried items such as chipped beef and dry sausage could be considered at all acceptable to the American taste. This led to consideration of freeze-dehydration.

The first reported use of freeze-drying was in 1909 for the preservation of biological substances. Its use as a laboratory tool, particularly for pharmaceuticals and biologicals, led to large scale drying of blood during World War II. A little work was done in foods, but the costs were considered much too high to permit any commercial applications. Research was initiated by the Armed Forces in the early 1950's on the possible use of freeze-dried foods for operational rations. Sparked by military interest and purchases in the late 1950's and early 1960's, industry interest increased for commercial exploitation of the process. Today the United States has a considerable food freeze-drying capacity.

DEVELOPMENT OF FREEZE-DRIED PRODUCTS FOR THE ARMED SERVICES

The paramount advantages of freeze-dried foods for the Armed Services are light weight, storage without refrigeration, and a high degree of acceptability to the using troops. The water content of raw foods ranges from approximately 70 percent by weight for meats to 90 percent or more for vegetables. Thus, 70 to 90 percent of the weight can be eliminated by dehydration, amounting to significant logistical savings. Water is available or can be made available almost any place in the world so that rehydration at the point of use presents

few problems. Many studies, as well as field experience, show that freeze-dried foods have excellent stability even under adverse storage conditions when they are properly packaged and protected from oxygen and moisture. In general, freeze-dried foods receive higher preference ratings in the Armed Forces than do comparative canned foods. However, they receive equal acceptance ratings with frozen foods only under certain conditions and with certain products.

Initial development was slanted primarily toward two specific ration systems to be used in different situations. These are the Meal, Quick Serve intended for use by small groups of men and utilizing no trained mess personnel and the Meal, 25-Man, Uncooked intended for use where field kitchen facilities and trained personnel are available. A third area of development has been for special feeding situations including long range patrols where resupply is uncertain and for the astronaut feeding program. Although neither the Quick Serve Meal nor the 25-Man Meal system have been adopted for regular procurement, various individual products resulting from the development program have been introduced into the supply system.

Most foods can be freeze-dried with excellent results. However, there are some exceptions. Leafy vegetables, such as lettuce, lose their crispness in the process. Products such as liver have no fiber structure to maintain their shape when dry and become a powder. In some cases, the quality improvements from freeze-drying is not great enough over that from other drying processes to justify the higher cost of freeze-drying. For Armed Service use, meats, poultry, and fish along with some vegetables and fruits, are the principal freeze-dried products which fit into the various feeding systems.

In the early years of development, costs of freeze-dried products were considerably higher than those dried by more conventional methods. With increased capacity and experience, costs have lowered. It is projected that with properly designed plants and volume production, costs will decrease to a point competitive with other methods of drying.

Quick Serve Meal

The Quick Serve Meal (Fig. 1) consists of 21 menus (7 day cycle) and has been approved by The Surgeon General as a sole diet for up to 120 days. Present module size is for 6 men and includes food service items such as paper trays. Each box weighs about 9.2 pounds and has a volume of about 0.56 cu. ft.

Early in the development of the Quick Serve Meal, it was decided that the only freeze-dried products which would be used would be those in which a satisfactory product could not be obtained by other drying methods. This meant that a combination item such as beef stew would be made up by combining freeze-dried meat and peas with air dried carrots, potatoes, and other ingredients. These products rehydrate in 15-20 minutes in hot water, but take considerably longer in cold water due to the relatively poor rehydration characteristics of air-dried products.

The products are packaged in flexible containers placed in a chipboard carton and are rehydrated in the package. The packages are nitrogen flushed to reduce the headspace oxygen to below 2 percent. Advances in technology since the ration was first developed have provided superior products which can be rehydrated in either hot or cold water in about 5 minutes and will decrease the size of the 6-Man module by about one-third.

The Quick Serve Meal has been field tested several times with results excellent. Troop acceptance has been high and the ration has met all of the design criteria. It has not yet been type classified or procured in quantities larger than needed for test purposes.

Meal, 25-Man, Uncooked

The Meal, 25-Man, Uncooked (Figs. 2 and 3) was designed to replace the B-ration. The B-ration consists of about 100 non-perishable items similar to those available commercially. There are logistic problems in supplying the various ingredients of the B-ration. The 25-Man Meal, on the other hand, is packed in modules which contain all of the food products needed for a meal, except bread. All of the products either are dehydrated or have low moisture. Field kitchen facilities are needed, but meal preparation time and the need for trained personnel are minimized.

All of the items in the meal are nitrogen packed in flexible packages. The boxes weigh about 19 pounds each and have a volume of about 0.7 cubic feet. As with the Quick Serve Meals, advances in technology are expected to decrease the volume and improve the quality of the meals.

Food Packet, Long Range Patrol

The Food Packet, Long Range Patrol (Fig. 4) has been type classified standard A and is being used extensively in Vietnam. It is a light-weight individual packet for use for periods up to 10 days without supplementation. There are eight different freeze-dried meal components, such as Chili and Beef Stew, which will rehydrate with hot water in about two minutes or with cold water in about five minutes, or which may be eaten dry. The freeze-dried foods are packed in flexible containers. Rehydration is accomplished in the flexible package. In addition to the main meal components, the packets contain candy, cereal bars, coffee, and cocoa. The packets average over 1000 calories each. Everything is flexibly packaged and the packets have an average gross weight of 11.3 ounces and a volume of 70.6 cubic inches.

Miscellaneous Freeze-Dried Products

A number of freeze-dried products have been integrated into feeding systems, primarily into the B-ration. Most of them are components of either the 25-Man or Quick Serve Meals. These include fish squares, shrimp, pork chops, beefsteaks (Fig. 5), beef patties, and chili con carne. All are packaged in cans under nitrogen with less than 2 percent oxygen in the headspace.

It is expected that flexible packaging with vacuum will replace the cans which will result in volume savings of up to 50 percent. Pork chops and chili con carne (Fig. 6) in flexible packages were successfully production tested in early 1969.

FREEZE-DRYING PROCESS

The basic principle of freeze-drying is sublimation or the change of ice to water vapor, bypassing the liquid state. This action can be seen on a sunny winter day when snow gradually disappears or "evaporates", although the temperature is below the freezing point of water.

In normal drying processes such as by hot air or vacuum, moisture in the center of the mass being dried migrates to the surface where it evaporates, leaving behind anything dissolved in it. As a result, food tissues shrink and the surface is case-hardened with a layer of salts, soluble proteins and other constituents which formerly were dissolved in the water phase. Most air dried foods, particularly meat, are tough and leathery, and will not rehydrate in any reasonable time.

With freeze-drying, the moisture is sublimed from the product being dried and there is substantially no transfer of liquid from the center of the mass to the surface. Instead, the product is frozen and the ice changes directly to vapor without going through the liquid state. As drying proceeds, the ice layer gradually recedes toward the center leaving behind vacant spaces formerly occupied by the ice crystals (Fig. 7).

Physical Relationships

Fig. 8 is a schematic diagram showing the physical relationships involving pressure and temperature which make freeze-drying possible. Point A is the boiling point of water at normal atmospheric pressure. Point B is the boiling point of water at about 28,000 feet above sea level. Point C is the triple point at which ice, liquid and vapor are in equilibrium. The pressure at the triple point for pure water is approximately 4.6 mm. At any pressure between 4.6 and 760 mm, ice will melt as the temperature rises, changing to the liquid state. Then the liquid will change to vapor at the boiling point for the particular pressure concerned. However, below the triple point pressure, ice will sublime to vapor without ever going through the liquid phase. In a closed system, vapor coming from the ice would raise the pressure above the 4.6 mm resulting in the normal solid to liquid to vapor process. To maintain sublimation, the vapor must be removed from the system as it is formed.

Process in Practice

In the freeze-drying process, the food products are placed on trays, frozen, and placed in the dehydrator chamber. Vacuum is drawn in the chamber to below the triple point pressure. When it reaches the operating level, heat is applied. Pressure in the chamber is maintained below 1.5 mm of mercury and usually below 0.5 mm. Temperature of the heat source is maintained in the vicinity of 100°F. for experimental food products where the interest is in the food product rather than the process itself. This is a convenient temperature since most products will dry overnight when it is used, yet it is mild enough to cause little heat damage. Higher temperatures are used to speed up the drying process in commercial operations. The vapor is removed by condensation on a cold surface.

Types of Heating

Basically, there are two types of heating used. In conduction heating the tray containing the product is in direct contact with the heating surface. Most of the heat is conducted directly to the product although some is obtained by radiation from surrounding surfaces. Conduction is not used to any great extent since it tends to promote hot spots which cause local overheating of the product.

In radiant heating the tray is suspended between two radiating surfaces. Heating is much more uniform than it is with conduction. Thus, higher temperatures can be used which result in faster drying. The advantages of radiant heating are increased when perforated or expanded metal trays are used with products having a large enough particle size to be held on such trays. Solid trays are often painted black on the bottom and sides for better heat absorption.

Basic Problems

The two basic problems in freeze-drying are heat transfer to the product, through the previously dried portion to the ice interface, and the vapor transfer from the ice interface through the dried portion to a condensing surface. A technical discussion of heat and mass transfer is beyond the scope of this report, but the problems they present can be easily visualized.

Due to their structure, freeze-dried foods are excellent insulating materials. Thus, transferring heat from the surface to the ice interface must be done through a layer of insulation formed by the previously dried material. If heating conditions are held constant, the drying rate becomes slower. Thus, thickness of the piece is critical in determining total drying time. Additional heat input tends to overheat the dried portion which will cause product deterioration.

Vapor transfer takes place because of random molecular movement and the molecules tend to flow across a gradient from high concentration at the ice surface to low concentration at the condensing surface. The vacuum pump does not "pull-out" the water molecules. Structure of the dried product impedes the movements of the molecules and if the concentration build-up is too high at any local spot, the pressure is raised to the point where the ice melts and the process is no longer freeze-drying at that particular spot.

When the drying cycle is completed, the vacuum is usually broken with nitrogen in order to minimize exposure of the product to atmospheric oxygen. The products are then packaged in cans or flexible packages under nitrogen or with a vacuum. Operations should be carried out in a low humidity room or the products will pick up enough moisture to decrease their storage life.

General innovations have been proposed in freeze-drying primarily to reduce costs by speeding up the process. Although none of these innovations are in general commercial use at present, future use may be found for them.

Spiked Dehydrator Plates

In Canada, the idea of using spiked dehydrator plates was proposed and tested. In this system, the pieces of product to be dehydrated were pierced by metallic spikes which conducted the heat into the center of the product, obtaining better heat transfer. Spiked plates were successful in reducing drying time and were particularly effective with thicker pieces of a product such as meat. However, maintenance of the plates is difficult and sanitation presents formidable obstacles.

Accelerated Freeze-Drying

In Great Britain, a method called Accelerated Freeze-Drying based upon work originally done in Sweden was developed and tested. Several units using this system were built for commercial use, but none are known to be operating in the United States at the present time. Accelerated Freeze-Drying is a method for increasing heat transfer to the product. This is accomplished by pressing the product between two heated plates where the pressure causes more intimate contact between the product and the heat source. Since the solid plates would inhibit transfer of the moisture vapor from the product, expanded metal sheets are placed betwen the product and the plates. The method is successful in decreasing the drying time, but the complicated installation necessary to provide for a movable plate inside a vacuum chamber causes problems in maintenance and significantly increases capital costs.

Microwave Heating

The use of microwave heating in the freeze-drying process is under study. Theoretically, microwave energy would speed heat transfer since it passes through the dry food layer and is absorbed directly by the ice. Thus, the outer dry layer stays cool while the ice is sublimed. Energy can be applied at a faster rate without causing product deterioration due to heat, thus shortening the drying cycle. However, microwave equipment is complicated and expensive. No commercial installations are using it at present.

Carrier Gas Sublimation Process

A drying method, carrier gas sublimation process, has been tested to a limited extent. There is evidence that it could be applied to commercial production. The process consists of passing a stream of dry gas through a bed of frozen product. It does not require sub-atmospheric pressures. This process can be used on a continuous production basis as opposed to the batch processing of current freeze-drying methods. The resulting product is equal to that currently obtained.

Evaporative Freezing

Evaporative freezing is used with a few freeze-dried products and can occur through improper operating procedures or equipment malfunctioning. When the atmospheric pressure on a liquid such as water is reduced, the liquid vaporizes to an increasing extent as the pressure is lowered. No matter how it is done, vaporization requires the input of heat. This heat must come from either an external source, the surrounding container or equipment, or from the liquid itself. In the case of evaporative freezing, the pressure reduction and vaporization take place very rapidly and most of the heat comes from the liquid. Since no heat is being added to the system, the temperature of the water drops $1^{o}F$. for every BTU per pound removed from it. The freezing process itself requires 144 BTU's per pound of water to convert it from liquid to solid with no change in temperature. When the pressure is rapidly lowered below the triple point of water, enough heat is removed to convert the remaining water to ice. From Fig. 8 it can be seen that when the pressure is reduced below the triple point of water, the liquid state cannot exist and sufficient vaporization takes place to complete the freezing process. At this point, the process changes from vacuum drying to freeze-drying. It is estimated that about 15 percent of the weight of a piece of meat will be reduced by evaporative freezing. The process can be reversed if pressure is increased for any reason during the freeze-drying process. It should be noted that in the evaporation stage, the product is losing water by evaporation from the surface, and water from the interior is migrating to the surface. Thus, the process is equivalent to normal air or vacuum drying causing some product shrinkage and deposits of solubles carried by the water to the surface. As a generalized statement, evaporative freezing will cause uncooked foods to have unsatisfactory quality characteristics while cooked foods are affected to a much lesser degree. With freeze-dried cottage cheese, a superior product is produced but this is an exception and evaporative freezing is not advocated in most instances.

PHYSICAL PROPERTIES OF FREEZE-DRIED FOODS

Properties of a freeze-dried food are the result of the physical structure of the original product and the overall freeze-drying process including freezing conditions. Very little shrinkage occurs during the process so that the physical dimensions are practically unchanged. Thus, the products have very low densities since from 60 to 90 percent of their weight has been removed. Since the resulting structure is similar to that of a sponge, the products rehydrate rapidly.

Effect of Structure

In muscular tissue, such as beef steak, or plant tissue, such as a string bean, there is a fibrous structure or skeleton which will retain its shape when the water is removed. If such a structure is not present, as in a glandular product such as liver, the product may freeze-dry in a perfectly satisfactory manner, but the end product will have no structure and cannot be rehydrated back to the original shape and texture. In general, freeze-dried products are very brittle and must be carefully handled if piece integrity is to be maintained.

Effect of Freezing

Since freeze-drying removes the ice from a frozen product without altering the external or internal structure, the size and shape of the individual ice crystals will determine the size and shape of the voids left when the ice is removed. In turn, the characteristics of the ice crystals are established by the freezing process and the storage conditions of the frozen product before drying. Slow freezing will form large crystals while fast freezing will form small crystals. In slow freezing, which from a scientific standpoint includes almost all normal commercial freezing operations, the ice crystals are formed outside of the individual fibers drawing the moisture from the fibers. In effect, the fibers are dehydrated. The forming ice crystals compress and deform the fibers. In rapid freezing, such as might be attained when thin sections of a material are immersed in liquid nitrogen,the ice crystals start forming within the fibers and being spear-like, perforate the fibers. In fast freezing, the fibers are not appreciably deformed or compressed.

As a practical matter in commercial production of freeze-dried products, freezing of individual pieces and even of sections of pieces varies from very slow to, in rare instances, fast. The resulting product structure is a mixture of varying sized pores and interconnected channels through the fiberous structure.

Ice crystals are formed from pure water so that during the freezing process the concentration of soluble salts, proteins, sugars, etc. is increased in the unfrozen water. Eutectic solutions are formed which have much lower freezing points than does pure water. Some of these solutions are not frozen at the product temperatures usually encountered in commercial freeze-drying. Fruits with high sugar contents are an extreme example of this condition and freeze-drying then becomes difficult since the unfrozen solutions tend to foam during the process. Successful freeze-drying of these products depends upon maintaining extremely low product temperatures during the drying process. However, for most products eutectic solutions only cause a slight shrinkage which does not affect the final product quality to any great extent.

Density

In any discussion of density, a differentiation must be made between density and apparent density. Apparent density in this case refers to the packing factor which includes the voids between discrete pieces and can vary widely depending upon size of the pieces, shapes, irregularities, etc. In many cases it has been found that two producers supposedly using the same specification for the same product will not be able to pack the same weights into a given can. Reasons for this are not always evident, but in most cases it seems to be due to differences in the true density of the product and is related to raw materials and processing.

As has been pointed out, the density of freeze-dried foods depends upon the water content of the original food. Advantage can be taken of this to control the final density. This can also be a control on the speed of rehydration and on the mouth feel when the product is eaten dry. For example, by adding more water to the formula for a beef stew, the dried product will be more fluffy and will rehydrate very rapidly. The amount of rehydration water can then be controlled so that the rehydrated product will have the best consistency for acceptance. In addition, the product will rehydrate rapidly with cold water which is a distinct,

even necessary, requirement for military combat rations. Even the density of pork chops or meats can be decreased by pumping the fresh meat with water similar to the way hams, bacon, and other cured meats are injected with liquid cure solutions. On the other hand, density can be increased by decreasing water in the formula for combination items, by formulating with drier or completely dry ingredients, or by predrying using other means. In this sense, cooking of meat can be considered a predrying operation since the moisture content will decrease from 70-75 percent to 55-60 percent with a corresponding decrease in volume during cooking. The difference in density brought about by cooking can be illustrated by the difference between raw and cooked freeze-dried shrimp. A 603 X 700 can will hold 13 ounces of the cooked product, but only 9 ounces of the raw. The difference in apparent density obtained by formulating with dry ingredients can be illustrated by two types of chili con carne. When dry ingredients (freeze-dried meat, air dried beans, and dry seasonings) are mixed together, a 603 X 700 can will hold at least 29 ounces. However, when formulated chili is freeze-dried, 24 ounces of product will fill the can. Most of this difference could be eliminated if the chili were dried in blocks which could be fitted snugly into the can.

Effect of Drying Temperature

Since drying time is highly dependent upon the rate of heat imput, commercial freeze-dryers operate their driers at the highest possible temperature. However, most, if not all, foods are damaged by heat in the dry state with the extent of deterioration depending upon the food, temperature, and time. As long as the process remains true freeze-drying the undried portion is always frozen. But freeze-dried foods are excellent insulators so that the temperature gradient from the undried frozen center through the dried shell to the surface can be very high. Therefore, the dried portions can be subjected to high heats for considerable periods of time with the process still being true freeze-drying.

A large number of studies at Natick Laboratories have shown that the lower the dry product temperature is maintained, the higher the end product quality. As a practical matter with the commercial production of beef, if the product temperature is kept below 150°F., the end product is of excellent quality. Above 150°F. the product quality deteriorates quite rapidly. With pork the critical temperature is in the vicinity of 130°F. Most commercial producers program their heating cycles to start out as high as 200-250°F. gradually decreasing the temperature so that the product temperature stays below 150°F. or 130°F. as applicable.

The most obvious effect of high product temperature in the dryer is a browning reaction which adversly affects flavor, odor, and color. A little browning with beef can be considered desirable since it results in a roast beef flavor. However, as browning progresses the flavor becomes bitter. With pork, undesirable flavors become evident even before the color changes. Once the reaction has started, it tends to continue during storage of the product.

The second important effect of high temperatures is a reduction in the rehydration ratio[1/] of the products. This makes them tough and dry tasting.

Effect of Oxygen

Conventially dried foods are relatively insensitive to oxygen. However, oxygen has a deleterious effect on freeze-dried foods. Most scientists will agree that any oxygen in contact with the food will cause product deterioration. However, there is considerable disagreement as to how much oxidation can occur before consumer taste panels will notice the difference in flavor, and what practical limitations can be imposed considering present industrial capabilities and product costs. Probably much of the confusion is due to the fact that foods are natural products with widely varying compositions. Some constituents are natural antioxidants while others are pro-oxidants. Thus, each freeze-dried food has a different response to oxygen. Furthermore, the rate of oxidation depends upon temperature as well as oxygen concentration so that studies conducted at refrigeration or freezer temperatures will not give the same results as those conducted at higher temperatures.

The effect of oxygen on freeze-dried foods is classified as oxidative rancidity resulting in off odors and flavors. With meats the effect is not quite the same as rancidity developing in fresh meats which manifests itself in the fatty portions. Instead, the freeze-dried meats subjected to oxygen develop a hay-like odor and flavor in the lean or protein portion. In the early stages, the odor may be evident only when the package is first opened, and it then dissipates rapidly. The product may lack flavor rather than possess an off-flavor. In the later stages of oxidation, both the odor and flavor are generally objectionable.

The susceptibility of freeze-dried foods to oxygen is related to their open structure which permits the molecules to come into intimate contact at reactive sites. Considerable research has been undertaken to determine the mechanism by which oxygen combines with the foods so that steps can be taken to make the foods less susceptible. Antioxidants have been added to some commercial items with increased shelf life reported. There are, however, no cases known where these antioxidants give complete protection and the products still must be given additional protection from oxygen.

Most investigators have accepted the limitation of 2 percent or less oxygen in the headspace gas or its equivalent in vacuum for satisfactory storage stability of all freeze-dried foods. The 2 percent maximum has been used by the Armed Forces in the development of rations and for large scale procurements for field use, without the use of any added antioxidants. This limit is well within the capabilities of industry and experience has shown that the products have satisfactory storage stability. However, as more becomes known about the reactions of individual products with oxygen, and industry capability to obtain low oxygens is improved, it is probable that limits will be set for individual items rather than using a blanket 2 percent limit for all items. Investigations into the storage stability of combination meat products used in the Food Packet, Long Range Patrol show that most of the items must be packed at 2 percent or less oxygen.

[1/] Rehydrated weight of product divided by the dry weight.

However, two items, beef with rice and chili con carne are less sensitive to oxygen than the other items. Extension of this work is indicating that the effect of temperature on oxygen uptake varies with different product.

Determining the amount of oxygen in the headspace gas actually is an indirect method of controlling oxidation and leaves much to be desired. In the first place, it gives no indication as to exposure of a product to oxygen before it was sealed in the container. Secondly, if the test is conducted at some time subsequent to sealing the container, any oxygen uptake by the product is subtracted from the headspace and does not show in the results. Thus, the oxygen test must be combined with good quality control practices to insure good product control. It will, of course, detect a faulty package and is the best method presently available for controlling oxidation.

Effect of Moisture

Freeze-dried foods are extremely hygroscopic and must be handled under low humidity conditions. Military specifications generally limit the moisture content to 2 percent or less and, as with oxygen, results of storage studies and large scale field use have been satisfactory. Deterioration due to moisture is not microbiological, but rather caused mainly by non-enzymic browning. Extent of browning will depend upon the composition of the particular food, temperature, and the moisture content. Slight browning can occur in some products at moistures less than 2 percent during high temperature storage, and the amount will gradually increase as the moisture is increased. With other products very little, if any, browning will occur with moistures of 10 percent or higher. The browning reaction not only causes color changes, but also results in off-flavors and odors.

If the moisture limitation could be raised, significant savings could be made in the freeze-drying process since removing the last 10 percent moisture in the product is the most difficult and costly. However, any increase must be made on individual products after careful study and consideration of the end use of each product. Some products such as dehydrated beef stew become inedible in a short time when held at over 4 percent moisture under military storage conditions. Others, such as compressed cooked beef, remain satisfactory for a considerable period of time at 10 percent moisture. Since a broad range of products have been tested and used by the Armed Forces with the 2 percent moisture limitations, there is reluctance to make any change without positive proof that the products will stand up.

Microbiological Problems

Deterioration of freeze-dried foods is not caused by microbiological action since the moisture content is too low. However, consideration must be given to the microbiological condition as with any food. The freeze-drying process and subsequent storage have been shown to decrease the microbiological population of foods under certain conditions. However, the process cannot be considered a sterilization process and many organisms are viable when the product is rehydrated. Once it is rehydrated, the food must be handled as any other fresh or cooked food or it will spoil.

In the handling and processing of the foods the same sanitary requirements must apply as would be in force with the equivalent fresh or cooked products. In addition, freeze-drying as currently practiced, is a batch operation which requires hand labor and exposure before and after the process which is not followed by cooking or retorting. Thus, serious contamination could occur if suitable precautions are not taken.

Public Health Aspects

Since the low moisture of freeze-dried foods prevents microbiological growth, a faulty container is not necessarily dangerous to health as is such a container with canned foods. Under ordinary conditions, a faulty container might allow the entrance of oxygen which will oxidize the product and moisture. This will cause off-flavors, but the product is still edible although some persons may be very sensitive to rancidity and subject to intestinal upsets. The products will not pick up enough moisture from the atmosphere to support microbiological growth.

ORGANOLEPTIC PROPERTIES OF FREEZE-DRIED FOODS

Research and consumer tests have shown that most freeze-dried products tend to rate lower in organoleptic characteristics such as odor, flavor, and texture than do their fresh or frozen counterparts. This is particularly true of flavor and texture which are usually considered the most important characteristics to the consumer. However, proper product design and processing result in freeze-dried products which receive excellent consumer acceptance and many are hard to distinguish from the fresh product.

Flavor

The lower flavor ratings are usually characterized as a "lack of flavor." This results from the loss of the more volatile flavors in the freeze-drying process. Preliminary work has been done to collect the flavors and add them back to the dried product, particularly in the case of fruits. Other means of fortifying or accenting flavors are used. The most common method of improving the flavor of meat products is through the use of gravies and sauces. When they are used properly, the resulting meat product can approximate that made from fresh ingredients. This is particularly true of combination items such as stews and chili.

Texture

Recent studies have shown that freeze-drying tends to toughen meat fibers. Toughness of meat has been and continues to be the subject of many experimental studies which range from animal breeding investigations to the addition of enzyme tenderizers to the cut meat.

Studies conducted with beef and pork showed that the time-temperature relationship in cooking is critical in obtaining a uniformly tender product. Apparently, due to successive coagulation of the various proteins, the meat becomes progressively tougher as the temperature is raised to about 165°F.

Under 165°F. cooking temperature has almost no tenderizing effect. However, above 165°F. the meat becomes more tender as cooking continues. Tough connective tissue does not necessarily follow the same pattern. However, the amount of cooking necessary to tenderize coagulated protein will usually tenderize the connective tissue. More recent studies have indicated that the temperature which results in the toughest freeze-dried meat is not the same as the temperature at which the same meat is toughest when not freeze-dried. For example, a study of turkey white meat shows the toughest meat is obtained at an internal cook temperature of approximately 160°F. When the product is freeze-dried, the toughness peaks at about 170°F. with very little tenderizing taking place if the meat were cooked at below this temperature for up to 6 hours. Therefore, the time-temperature relationship must be considered in commercial freeze-drying.

Additional texture factors must be considered with freeze-dried foods. In rehydration, the water is absorbed as in a sponge, going into the fibers and cells slowly. Since the water is not bound tightly, improper cooking of a rehydrated product can leave the food dry. Or when a cooked, dehydrated product is rehydrated and eaten, it may be very juicy on the first chew and dry after that since the water is not tightly bound and is released in the first chew. Proper processing controls can alleviate this problem.

Improvement of Organoleptic Properties

With the early freeze-dried combination items, products were made up by combining dry ingredients. This method allowed cost reduction by utilizing the most economical drying process for each ingredient. However, it was found that a superior product was obtained by freeze-drying the formulated combination item. Besides giving much faster rehydration, this method results in products which receive higher taste panel ratings. Costs have been minimized by the increased knowledge of the freeze-drying process, the increased production volume in the industry, and greater use in package filling. The main disadvantage is that density is decreased. This can be controlled to some extent by proper formulation and the amount of water used during product formulation.

Tenderness of cooked freeze-dried meat has been found to depend upon the quality of the meat to some extent. However, as mentioned above much more important is the cooking of the meat. The cooking process should be designed specifically for freeze-drying.

A very important part of improving the organoleptic properties of cooked meats is in designing the correct sauce or gravy to be used with them. The sauce or gravy must supplement flavors lost in freeze-drying, but must not interfere with rehydration.

Little work has been done on improving the organoleptic properties of freeze-dried raw meats. The use of tenderizers has been investigated to some extent and shows promise. However, the work is not far enough along to draw definite conclusions. One of the most important areas of improvement is in the development of recipes and cooking methods. Such things as breading, holding in gravy, etc. do much to alleviate dryness and toughness. This is an area which deserves much more study.

DESIGN AND PREPARATION OF PRODUCTS FOR FREEZE-DRYING

One of the most important aspects of freeze-drying is the design and preparation of the products. The process of freeze-drying is simple and straight forward. Simple precautions to keep oxygen and moisture from the final product will assure storage stability. But design and preparation of products for freeze-drying are much more complicated and very critical.

Design of Products

Products should be designed specifically for freeze-drying with particular attention to the nature and limitations of the process and the end use of the product. When freeze-drying first became popular in the late 1950's many ill-conceived products were tested and even marketed only to fail. In many cases high costs were blamed for the failures. This was only part of the reason. Flavor and texture were not good and the products did not give the consumer enough convenience or price advantage over competing products.

It is obvious that products which do not freeze-dry well should not be used. Freeze-dried sausage, for example, will not rehydrate. Cured meats such as ham can be freeze-dried and will rehydrate, but have a tendency to develop off-flavors under the severe storage requirements of the Armed Forces, although there have been some successful ham products on the commercial market.

In many cases the freeze-dried product does not offer enough advantages over the same or equivalent product dried by other means. For example, a spray dried egg mix used by the Armed Forces is an excellent product at reasonable cost. Therefore, higher cost freeze-dried scrambled egg is not warranted. However, a freeze-dried scrambled egg product is proposed for future combat rations where, the superior quality, no cooking, and logistical advantages of the freeze-dried product overcome the cost differential.

A product designed for the American consumer market usually will be quite different from the same product designed for an 18-22 year old soldier in a stress situation. One striking difference is that the Military designer is frequently attempting to put more calories into less weight and cube while still obtaining a product which is highly acceptable to his "customers." The consumer market at present minimizes calories. The military also requires greater storage stability for its products.

Raw Materials

The freeze-drying process cannot be expected to upgrade raw materials or to increase acceptance of a product. Actually, freeze-drying often will accentuate minor defects so that they become major deficiencies in the final product. Gristle becomes hard when freeze-dried and will not soften in the rehydration water. Furthermore, when muscle fibers end at gristle, it is difficult for rehydration water to penetrate the fibers with an unrehydrated spot resulting. Variety and maturity of fruits and vegetables affect the quality of the dried product. Some varieties of potatoes will not maintain piece integrity when rehydrated in combination foods such as stew.

Fat

A common factor which prevents good rehydration of meat and meat combination items is fat smearing or too high a percentage of fat. Fat acts as a water repellent. Thus, it must be handled in a product so that the water can get past it to reach the fibers. A striking example of this was found during development of the combination items for the Food Packet, Long Range Patrol. Small quantities of vegetable oil were added to the products to increase the calorie content. Rehydration time with hot water was increased from 2-3 minutes to as much as 10 minutes. On the other hand, when the same quantity of solid beef fat was coarsely ground and added without excessive mixing, the rehydration rate changed very little and the decision was made to use beef fat rather than oil.

The fat content of ground meat products such as beef patties and pork sausage should be held below about 25 percent. To prevent fat smearing the products must be handled and mixed as little as possible with the product temperature kept low. It has been found that cooked corn meal mixed with ground meat provides very rapid rehydration. Varying the quantity of corn meal from 0.5 percent to 11 percent changes the rehydrated texture of the product from firm to mushy. This technique permits a large number of products such as fish patties, meat balls, and pork sausage links to be successfully freeze-dried.

PACKAGING OF FREEZE-DRIED PRODUCTS

Since freeze-dried foods are sensitive to atmospheric oxygen and moisture, the products must be packaged with the shortest exposure time possible. Furthermore, the packaging material must be impervious to moisture and oxygen.

Cans

The tin can meets the protective criteria and is currently used for packaging freeze-dried foods. The cans are filled with product, evacuated, back-flushed with nitrogen to less than 2 percent oxygen and sealed. Gasket material on the lids is not the same as that which is required for cans to be retorted since freeze-dried foods are not further heat processed. Small sized cans can be vacuum packed. At the vacuum required for product stability (27 or more inches of mercury), most large cans will collapse. Nitrogen packaging is done in two ways. Holes are drilled in the can lids and the cans closed in the usual way. They are then placed in a vacuum chamber, evacuated, and flushed back with nitrogen. The cans are then tip soldered. The more common method is to run the filled cans through a sealing machine which applies only the first clinch. The partially sealed cans are placed in a vacuum chamber, evacuated, flushed with nitrogen, and sealed completely. Care must be taken that the first closing operation does not seal off the can to such a degree that the nitrogen cannot completely fill the can.

Cans have several disadvantages for Armed Forces use. Round cans waste at least twenty percent of the space they occupy due to their shape and add unusable weight. In addition, brittle products such as meat patties and fish squares do not fit tightly into the round cans, allowing the products to move during shipment, causing breakage and powdering.

Flexible Packages

Flexible containers are the most promising packages for freeze-dried foods. They do not waste the space that a can does. They can be either gas packed or vacuum packed and, in the case of vacuum packing, the products are held in place so they do not break up during transit. If the proper films are used, the packages are impervious to moisture and oxygen. Films used for flexible packaging, are customarily 3 ply laminates, such as a polyolifin-foil-mylar. Since flexible packaging technology is new, package integrity is not equal to that of cans. In addition, the freeze-drying industry does not have flexible packaging equipment versatile enough to handle packages of different sizes and shapes at desirable production speeds.

In nitrogen packing, the packages are evacuated and flushed, removed from the chamber, and sealed on an external sealer. The sealing bar may be contained and operated in the vacuum chamber. With vacuum packaging, the sealing bar must be in the chamber.

Flexible packages are placed in chipboard intermediate containers to protect them from damage, improve the external appearance, and provide for easier packing in the shipping case. When the packages are shipped without the chipboard container, they must be packed very carefully to prevent movement within the case and subsequent damage to the packages.

TESTING FREEZE-DRIED FOODS

In the development of freeze-dried food items for Military use, one of the most important criteria is consumer acceptance. All new products must be judged acceptable by a consumer panel after storage at 100°F. for 6 months. Additional tests are run for one year and often longer at 40°, 70°, and 100°F.

Taste Panels

The taste test panel is the only positive, although subjective, test of product quality. In general, there are three main types of taste testing panels. The consumer panel is designed to determine how much the consumer likes the product and why. The technological panel is composed of technologists who are familiar with the product and can spot differences which would not be very apparent to the casual consumer. The flavor profile panel is composed of highly trained personnel and is capable of assessing the various flavor notes which make up the overall flavor.

Consumer taste panels are widely used in industry and laboratories to determine likes and dislikes. They are not a "sharp" analytical tool in that they normally will not pick up small differences in food products. Therefore, they have limited use in the early stages of development work. However, the final product must be acceptable to the consumer.

Technological taste panels are used in development work and in comparing products. Sometimes they are used for evaluating preaward samples and in comparing production with preaward samples. Panelists should be objective in their evaluations, and if properly instructed, will give very good, reproducible results.

Flavor profiling, developed by Arthur D. Little, Inc., is used primarily as a developmental tool in food laboratories. Members of flavor profile panels are intensively trained and can be considered flavor experts. At the present time such panels are seldom used for routine quality control work although they may be used in special cases such as for determining the source of off-flavors. Texture profiling is receiving some attention, but it has not yet reached the status of flavor profiling.

Since taste panels are subjective, use and interpretation of their results must be carefully controlled. Unless the panels are conducted and the results evaluated by persons trained in experimental and panel work, serious errors can be made.

Chemical and Physical Tests

Chemical tests used routinely with freeze-dried foods are those for headspace oxygen and moisture in the product. Other tests, such as for fat, may be used as required.

Military specifications usually specify a moisture test in accordance with Official Methods of Analysis of the Association of Official Agricultural Chemists. Most freeze-dryers use rapid moisture methods for routine control in the plant, generally units which utilize infrared heat and give results in 15 minutes. When properly calibrated against the oven drying method, these units can be expected to have an accuracy of about $\pm$ 0.5 percent.

Oxygen in the headspace gas of freeze-dehydrated products can be determined by one of at least three methods: micro orsat, gas chromotography, or polarographic.

The orsat determination of oxygen in a gas, which has been used for many years, is rapid and accurate. Equipment used for the test can be portable and used under plant conditions. Gas chromotography is accurate, but requires more elaborate equipment with more highly trained personnel to operate it than is necessary with the other two methods. The polarographic method is incorporated into several portable instruments now in the market and is quite accurate. However, carbon dioxide, which is often given off by freeze-dried foods during storage, will adversely affect the sensing units, so the use of this method with freeze-dried foods is limited to the freshly packed containers.

When the products are vacuum packed, the vacuum can be determined by direct methods, indirect methods, or by visual examination.

In direct measurement, the can or flexible package is pierced using a special gauge with a rubber seal around the piercing device. The results are read directly as vacuum in inches. With cans, this is a standard method that has been used for many years in the canning industry. However, the sampling technique is not as easy with flexible packages since it is far more difficult to seal off the entrance hole. One method used successfully has been to place a self-adhesive rubber patch on the package and pierce it with a hypodermic needle attached to a vacuum gauge of some type. This same method can be used to draw off samples of headspace gas for analysis.

The most common indirect method of measurement is called a flip test. The can or package to be tested is placed in a bell jar or similar container where it can be observed as vacuum is drawn on the container. When the vacuum in the container reaches approximately the same vacuum as is in can or package, the can lid will "flip" outward or the film of the package will relax. This method is only approximate and is seldom used in military specifications. It has the advantage of being non-destructive.

Visual examination for vacuum is used primarily for flexible packages. It consists of determining whether or not the film clings tightly to the product. This is a "go-no-go" examination that is non-destructive.

COMPRESSION OF FREEZE-DRIED FOODS

Since freeze-drying removes water without appreciably shrinking the product, freeze-dried foods have a very low density. Since volume as well as weight is an important consideration with military rations, research effort has been directed toward compressing freeze-dried foods while maintaining their rehydration qualities. Progress has been made which indicates that it is a possible and even practical goal. Potential volume savings can be up to 5 to 1 with meat products and as high as 16 to 1 with some vegetables.

The term "compaction" has been used where the foods are compressed or otherwise made as dense as possible before dehydration. It is also used when the dry product is shaken or otherwise made to settle in the container. The term "compression" is used when the dry product is mechanically formed into a bar or cube with a press or pelleting machine.

Compaction is currently used with certain fruits and leafy vegetables before freeze-drying. Generally, these products are forced into a mold, frozen, and sawed into blocks for freeze-drying. Foods for astronaut feeding are carefully compacted to a uniform density to improve packaging characteristics and to standardize calorie content.

Ideally, a food bar for military rations should have a double purpose. If conditions permit, it should be rehydratable with either hot or cold water in a reasonable time to closely approximate the original product. If conditions do not permit rehydration, it should be edible as is. The bar cannot be so hard that it cannot be eaten or so soft or brittle that it cannot be handled. Furthermore, the salt and spice levels must be carefully adjusted so that the bar will be acceptable regardless of the form in which it is consumed. Compressed bars intended for eating as is and which will not rehydrate to the original form can be useful in certain situations and a group of such bars has been developed (Fig. 9).

It has been found that most freeze-dried foods can be compressed without shattering if a plasticizer is added to the dry product. Glycerol, for example, works very well in amounts of 10 to 15 percent by weight, but adds a sweet taste which is undesirable with many foods. Water is the best plasticizer found. Foods having moisture contents of 8 to 12 percent can be compressed using pressures ranging from 1000 to 5000 pounds per square inch. There are two disadvantages in using water. First, with the present state of the art, the freeze-drying process cannot be stopped at a particular or accurately controlled

intermediate product moisture. The water must be added to the dried material by spraying or other means. Secondly, the products must be redried after compression to below 2 percent moisture to obtain good stability. In most cases the redrying is done by hot air or vacuum.

Even using plasticizers, the problem of rehydration still remains in many products. Compression destroys the numerous pathways in freeze-dried products which allow rapid rehydration. The compressed bar is often impervious to moisture. In addition compression tends to break up fat cells in a product, coating every particle with water repelling fat.

Several compressed freeze-dried products have been developed which will rehydrate rapidly. These include peas, cherries (Fig. 10), meat balls, shrimp, and diced meat compressed. Considerable work is being directed on the water penetration of compressed products and in development of additional bars which will rehydrate rapidly.

FOOD FOR SPACE TRAVEL

Freeze-drying has played an important part in development of foods for astronauts. Space travel has certain features which are unique and present real problems in design and development of food products. Although the quantity of food produced for space travel is very small, information gained in their development already has had many applications for mass produced foods.

Highly acceptable, yet lightweight foods were required for the space program. This, dictated major dependence upon freeze-dried foods. Access to water for rehydration of foods is not a major problem since water can be recycled or obtained as a by-product from the fuel cells.

Tighter parameters are used in developing space foods in comparison with those for foods for combat. Acceptability, adequate nutrition, and wholesomeness are among the principal design parameters. The last parameter dictates extraordinary precautions that must be taken during manufacture to prevent any microbial contamination of the products.

Weightlessness (zero gravity) does not affect the normal chewing, swallowing, and digestion processes. However, crumbs and fluids can become free floating and are potential hazards to electrical equipment and breathing of the astronauts. Thus, in the early space flights, foods consumed in the fluid or semi-fluid state were rehydrated and eaten from a closed container system. Foods that are consumed dry must be coated in such a way that they will not crumb or dust when eaten under weightless conditions. During 1968, it was demonstrated that it is possible to eat wet foods with a spoon from open containers under zero gravity condition. This was first tried on a limited basis in the Apollo 8 and 9 flights and was so successful that for Apollo 11, ten different food items were planned and packaged for spoon consumption (Fig. 11).

Two general types of foods have been developed for space feeding: rehydratable and bite size, which are eaten as is (Fig. 12). A third type, wet packed foods sterilized in flexible packages, show promise although they do not have the weight advantage of dry foods.

Rehydratable foods are carefully formulated products such as precooked beef stew or applesauce. These are freeze-dried and will rehydrate rapidly in hot or cold water and then can be forced through a feeding tube by pressure on the flexible container. The original products of this type were rather finely ground and did not resemble a stew or similar product. However, they would rehydrate rapidly in cool water. Further developments such as over-cooking the meat which promotes rapid rehydration led to the current products in which the principle restriction on component piece size is the diameter of the feeding tube.

Preparation of the rehydratable foods is no different than the preparation of any combination food except in the intensive and extensive quality control used in controlling raw material quality, formulation, and processing variables. In order to obtain the correct weight and block size for individual servings, the product is usually frozen in "logs" and then sawed to the correct thickness. Occasionally, the wet product is cast into molds of the correct size and then frozen. The frozen product is freeze-dried using low levels of heat.

There is a wide variety of bite size items available ranging from main course stews through desserts (Fig. 13). Most of them are freeze-dried except candy even if only to remove moisture added during coating (i. e. compressed cheese cake), and most of the rehydratable products can be adapted to the bite size. Two of the more important design characteristics are texture and mouth feel. It must be remembered that almost all freeze-dried foods are very brittle and friable. Unless the products are properly made, they will crumble into dust at the least pressure or shock. On the other hand some of them can be abrasive to the inside of the mouth and eating very many pieces can cause soreness. The sensation of dryness can be considered part of mouth feel. Freeze-dried foods have an affinity for water so that they can absorb moisture from the mouth faster than it is replaced naturally. Judicious use of fats in the product formula is the most common way of improving mouth feel of the bite size items.

One of the most difficult tasks in the preparation of space foods is the control of density so that piece size and weight fall within the very close tolerances deemed necessary. Space capsules are very crowded resulting in intensive competition for every cubic inch of space and every pound of weight permitted. Thus, the foods have to fit into their allocated space and the allotted weight, yet provide the nutrients for which they were designed. Density of a freeze-dried food can vary widely depending primarily on the density of the raw materials. Since these materials are reduced in weight to as great an extent as 1/10 of their original weight, small differences in original density are greatly exaggerated by the drying process. One of the best methods of density control particularly of combination foods is to control the amount of water in the formulation so that the percent solids in the wet mix is constant.

COMMERCIAL FREEZE-DRYING

Freeze-drying is one of the few processes which can be scaled up from laboratory to production with almost no changes in operating parameters. Laboratory driers are generally smaller editions of the production sized units. Basically, all freeze-driers consist of a chamber which contains shelves for the product and which is capable of holding a high vacuum; a source of vacuum; a means of applying heat to the product; and a means of condensing the vapor coming from the product. Main variations in commercial units are found in the arrangement of components, instrumentation, and materials handling.

Common commercial units are large enough to hold 800-1200 pounds of frozen wet product loading 2-3 pounds per square foot of platen (shelf) area. The product can be loaded by individual tray, but the most common method is by rolling a truck containing the trays into the freeze-drier where the trays automatically interleave with the heating platens. The trays can then be lowered onto the platens if heating is to be by conduction or held suspended between platens for heating by radiation. Heating by radiation is usually considered the best method since it gives a more uniform distribution of heat.

Vacuum Systems

Vacuum for the system is obtained either with steam jet ejectors or mechanical pumps operated with electricity. Choice between the two is based upon economic factors and either will perform satisfactorily when properly designed. Most commercial installations use mechanical pumps. Various configurations are used with the vacuum systems in order to obtain the vacuum required in the shortest time with the least cost. A common method is to use a roughing pump to obtain the initial vacuum on a unit and then to change to a holding pump which may maintain the vacuum on several units at the same time. Most commercial systems will hold the pressure in the system below 500 microns for the entire freeze-drying cycle.

Vapor Condensation

Vapor condensing systems are usually of the refrigeration type. Some experimental work has been done with drying systems using a dessicant capable of regeneration. However, there are no known commercial freeze-drying installations using this method. Designs of the condensing surfaces and of the system in general must be carefully made. The ice formed by the condensing vapor is a very good insulator and the efficiency of the system can be impaired seriously by ice build up in localized areas or by under-capacity of the system. Provisions must be made for defrosting the unit between drying cycles. Some of the commercial units have the condensing surfaces in the drying chamber itself. It has been suggested that internal condensers would not work since the drying product could "see" the condensed vapor and there would be a transfer back of the water molecules. However, the systems of this type now in use are giving good results. The other type of commercial unit has the condenser in a separate chamber connected to the drying chamber by a large diameter pipe. It should be pointed out that the water molecules coming from the material being dried are not "sucked out" by the vacuum as is sometimes mistakenly stated. The water molecules move because of a concentration gradient between the product being dried and the condensing surface.

The motion of an individual molecule is random in direction and is impeded by collision with other molecules and with surfaces in the drier. For this reason, the condensing surface should be as close to the product as possible and the pathway should be as open as possible. In some older freeze-drying installations, drying time for given products was decreased more than 50 percent by increasing the diameter of the connection between the drier and the condenser.

Food Preparation

Commercial freeze-drying installations in the United States vary in their food preparation capabilities. Some are associated with food plants and either are equipped or can obtain equipment from the parent company for almost any preparation process required before freeze-drying. Others are primarily contract freeze-dryers and have little equipment beyond that needed for freezing, freeze-drying, and packaging the finished product. In many cases these concerns do not have the knowledge and experience in the preparation of a given product and depend upon a supplier for the prepared product. Problems have been encountered with such an arrangement since the supplier does not necessarily understand the problems in freeze-drying and has furnished products which will not freeze dry properly. Therefore, the freeze-drying concerns are tending to install more preparation equipment. This is particularly true when they obtain contracts large enough to justify the expenditure or rental fees.

Material Handling

Material handling in freeze-drying plants has not been mechanized to a great extent. Products are usually prepared by batch methods and are loaded on trays except where they are fluid enough to be pumped or poured. The trays are loaded by hand into special carts which are also handled manually. Packaging of the finished product either in cans or flexible packages and scaling is by hand. Some progress has been made toward automatic package filling with some products such as powders and combination products which are in the form of small chunks. However, it is not expected that there will be any outstanding advances in this direction until production volumes are large enough to justify equipment costs. In the case of specialized plants which produce only one product such as freeze-dried coffee, equipment can be designed for practically all material handling. With plants which do not specialize, automating material handling is much more difficult and expensive.

Drying cycles

Since drying time is highly dependent upon the rate of heat input, commercial freeze-drying operators run their dryers at the highest possible temperatures. The most common method is to program the heating cycle so that the surface temperature never exceeds a predetermined value. With most meats this maximum value is 150°F. The program is started with a high platen temperature, possibly as high as 300°F which is gradually reduced to 150° at the end of the cycle. Instrumentation for determining surface temperature in freeze-drying plants is not very sophisticated and the methods used only give fairly close approximations. Most programs have been developed by trial and error. Some military specifications contain requirements for maximum surface temperatures during drying with a provision that if platen temperatures are maintained below a certain value, the product surface temperature may be ignored. Usually this maximum platen temperature is 5°F above the maximum desired product surface temperature.

Experimental work is resulting in more and more knowledge of the temperature and time effects of the heating cycle in individual foods. This knowledge is expected to be reflected in future specifications.

Quality Control

Most freeze-drying operations have good quality control. Requirements for oxygen in the container headspace and moisture in the finished product are usually the same as required by military specifications. However, commercial products are not designed to undergo the severe storage conditions which must be considered for military rations so that both oxygen and moisture requirements are frequently relaxed slightly.

Control of the final moisture in the product is accomplished by indirect means. Thermocouples implanted in the center of the frozen product will indicate, by a leveling off at a temperature near that of the platen temperature, that the drying is near completion. Isolating the drying chamber shows the same thing if little or no pressure rise results. When the operator feels that the product is dry, the chamber is opened and the product tested on one of several available commercial rapid moisture testing devices. If the product is not dry enough, the chamber is reclosed and drying continued. Once the drying cycle has been determined for a given product with a given loading, there is seldom any problem with controlling the moisture content of the product upon removal from the dryer. Problems usually arise after that point when the product is exposed to high humidity for a time before packaging.

Control of the oxygen in the headspace of the final package is obtained by first determining the proper evacuation and flushing cycle and then maintaining it. Samples are checked at intervals to make sure there has been no change in the cycle and that there are no faulty cans or packages. Vacuum packed flexible packages can be checked by observing whether the film clings to the product or not.

Packaging

Almost all freeze dry processors fill and weigh containers by hand. This is primarily due to low volumes of any one freeze-dried product. Where volume and nature of the product permit, automatic filling and sealing devices are being utilized.

All commercial freeze-dryers are equipped with canning machinery and usually can handle all common can sizes. Equipment for handling flexible packages is not as common. Originally, most of this equipment was made up by the dryers themselves, but more and more pieces of equipment are coming on the market which can be either purchased or leased.

Since freeze-dried products are sensitive to atmospheric moisture, packaging operations are normally handled in controlled atmospheric rooms. Relative humidity is held to below 30 percent. Even at this humidity, freeze-dried products can take up appreciable amounts of moisture. Because of this and because the products are also sensitive to oxygen, they are handled and packaged as rapidly as possible. If holding them before packaging is necessary, they are placed in steel drums or other suitable containers and held under vacuum or a nitrogen atmosphere.

SPECIFICATIONS FOR FREEZE-DRIED FOODS

A list of military specifications for freeze-dried foods is shown in Appendix A. This list is not complete since new specifications are being added as products are developed. These specifications place limitations on the raw materials and processing as required by the intended use of the product. In addition, there are certain requirements which are peculiar to freeze-drying. Primarily, they control the process itself, the physical characteristics of the product, and the chemical analysis of the packaged product.

Customary controls on the freeze-drying process for meat products include a maximum pressure during drying of 1.5 mm of mercury and very often a maximum surface temperature of the product during drying. Surface temperature is difficult to measure directly so that an alternative is provided giving a maximum platen temperature which may be used with radiant drying. The maximum surface temperature limitation will vary depending upon the product, but, in general, is 150°F with beef and 130°F with pork products.

Physical characteristic requirements usually include provisions that the product shall not show soft or soggy portions indicating incomplete dehydration; shall not have glazed surface areas or dark cores, both of which indicate melting during the drying process; shall rehydrate completely as indicated by the absence of unrehydrated spots; and shall possess the odor, flavor, and texture characteristics of a good freeze-dried product. For subjective requirements such as flavor, odor, and texture, a preaward sample is often required from each bidder at the time he submits his bid. This sample is evaluated by a trained panel and must be satisfactory if the bid is to be accepted. Portions of the preaward sample submitted by the successful bidder are then used by the inspection service to determine compliance with the subjective specification requirements during production. Preaward samples are used with freeze-dried products because these products are relatively new to industry as well as the inspection service.

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Appendix A

The following military specifications and purchase descriptions for freeze-dried foods were in effect in 1969. Copies of specifications can be obtained from:

Naval Supply Depot
5801 Tabor Avenue
Philadelphia, PA 19120

Specifications	Meat Products
MIL-B-43224	Beef and Potato Hash, Dehydrated, Cooked
MIL-B-43344	Beef, Cooked, Dehydrated
MIL-B-43311	Beef, Diced, Dehydrated, Raw
MIL-B-43240	Beef, Flaked and Shaped, Dehydrated
MIL-B-43213	Beef, Ground, Dehydrated, Cooked
MIL-B-43143	Beef Patties, Dehydrated, Raw
MIL-B-43404	Beef Stew, Dehydrated, Cooked
MIL-C-43274	Cheese, Cottage, Dehydrated
MIL-C-43289	Chicken and Rice, Dehydrated, Cooked
MIL-C-43135	Chicken and Chicken Products, Cooked, Dehydrated
MIL-C-43287	Chili Con Carne, Dehydrated, Cooked
MIL-F-43445	Fish Patties and Balls, Dehydrated, Cooked
MIL-F-43142	Fish Sticks or Squares, Dehydrated, Raw
MIL-G-43275	Ground Beef and Macaroni with Sauce, Dehydrated, Cooked
MIL-M-43506	Meat Balls and Meat Ball Products, Cooked, Dehydrated
MIL-P-43144	Pork Chops, Dehydrated, Raw
MIL-P-43383	Pork Sausage, Dehydrated: Patties and Links, Cooked
MIL-S-43145	Shrimp, Dehydrated, Cooked
MIL-T-43443	Tuna, Dehydrated, Cooked
MIL-T-43451	Turkey, Dehydrated, Cooked
	Plant Products
MIL-C-43547	Cherries, Dehydrated, Red, Tart, Pitted
MIL-C-43449	Corn, Dehydrated, Yellow (Cooked and Uncooked)
MIL-F-43559	Fruits, Freeze-Dehydrated
MIL-P-43453	Peas, Dehydrated, Sweet

Purchase Descriptions	Meat Products
IP/DES 56-7	Beef, Ground, Dehydrated
IP/DES 17-7	Food Packet, Long Range Patrol
LP/PD 203-63	Eggs, Precooked, Freeze-Dried
LP/PD 84-64	Meat Balls, Dehydrated, Cooked
LP/PD 5-66	Pork Slices, Dehydrated, Cooked
	Plant Products
LP/p DES 2-66	Mushrooms, Freeze-Dehydrated

Appendix B

Typical Menu in the Meal, 25-Man Uncooked

Breaded Pork Chops*
Cream Gravy
Mashed Sweet Potatoes
Green Beans
Bread
Military Spread
Jelly
Apple Sauce
Oatmeal Cookies
Coffee, Cream, Sugar

Typical Menu in the Meal, Quick Serve

Hot Cocoa
Chicken and Gravy*
Mashed Potatoes
Green Peas*
Bread
Military Spread
Fruit Cake
Coffee, Cream,Sugar

Freeze Dried Components*

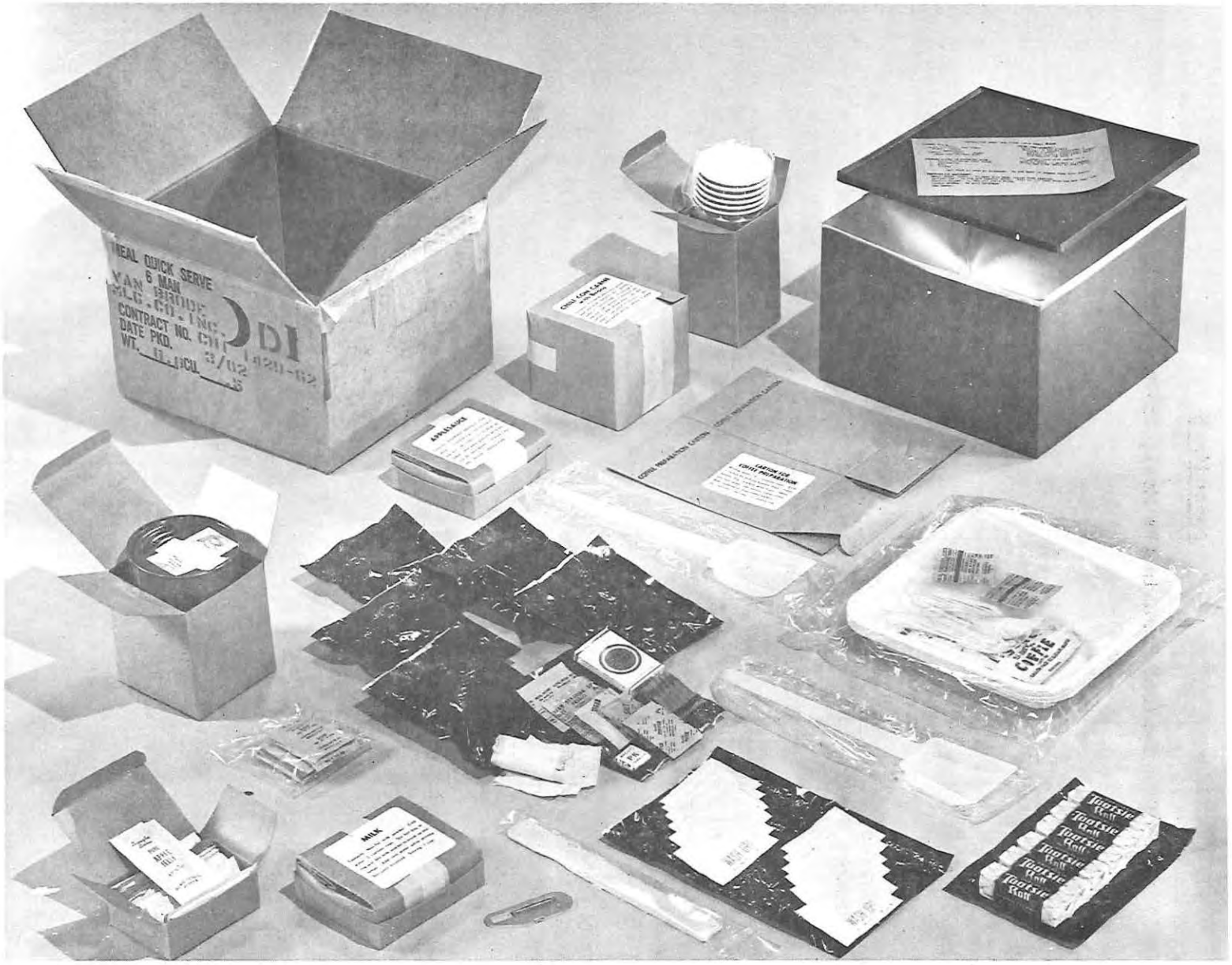

FIG. 1. Meal, Quick Serve. All of the food and food serving equipment for 6 men except water and a water heating device is contained in one box.

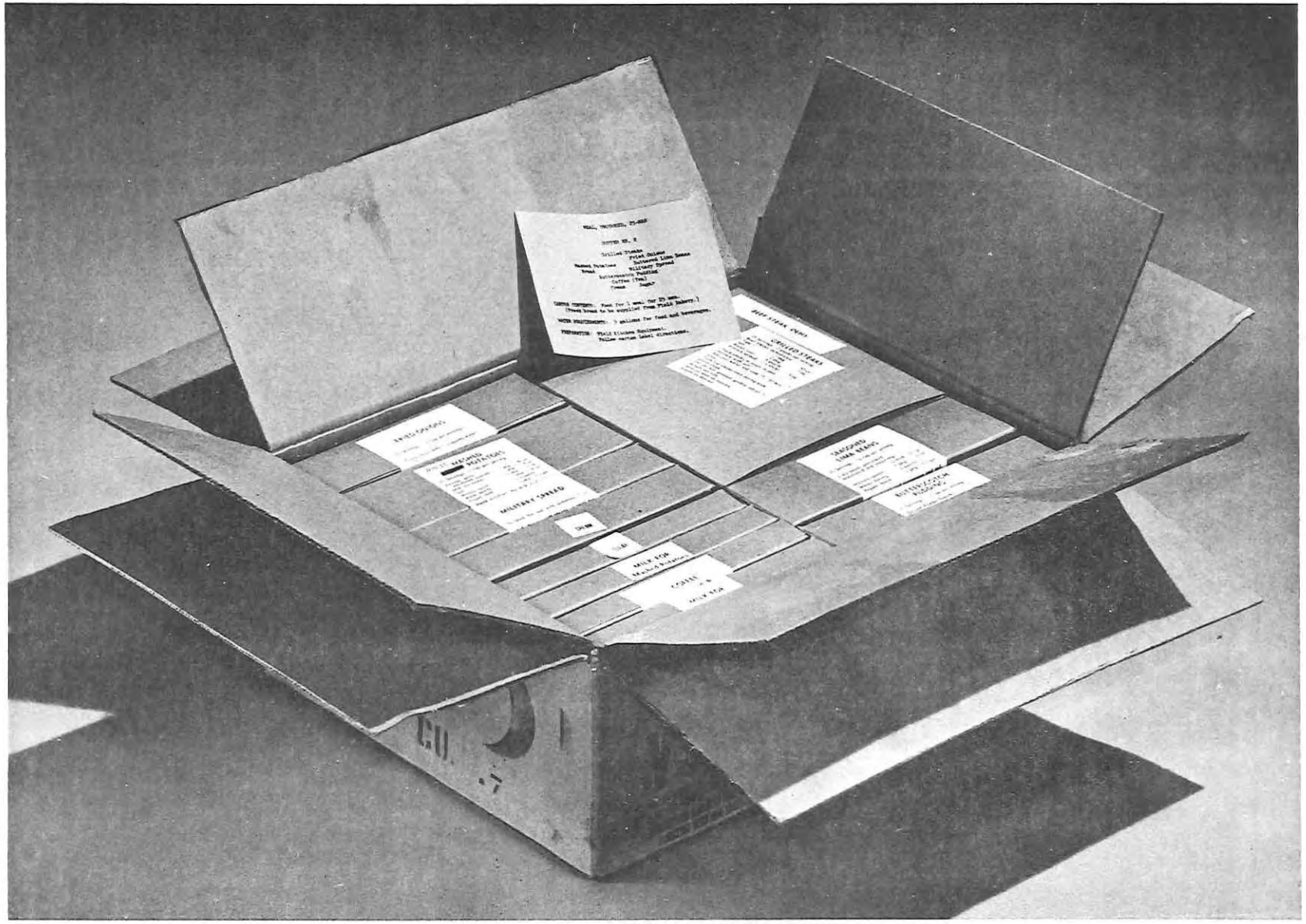

FIG. 2. Meal, 25-Man, Uncooked. The food for 25 men is contained in one box.

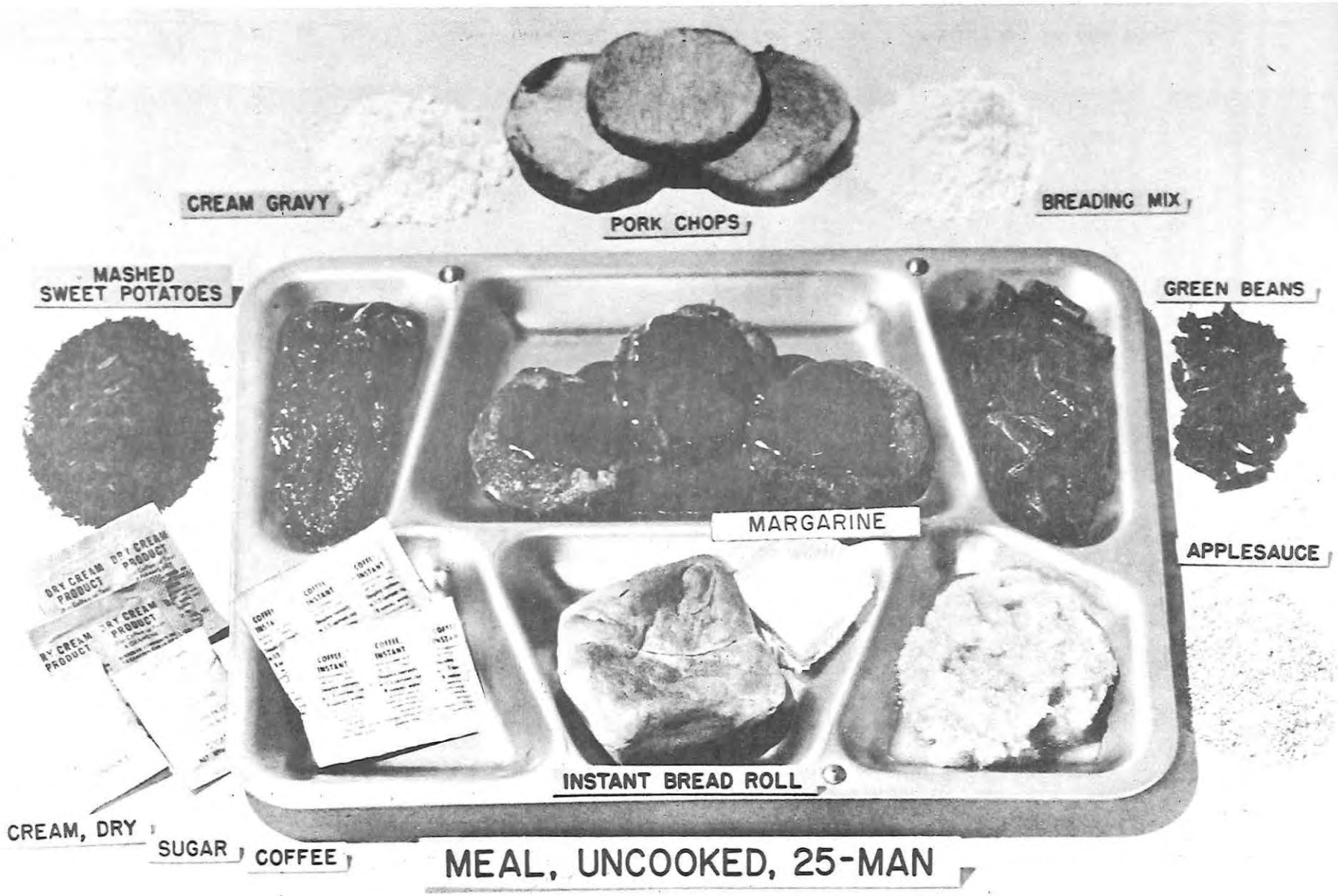

FIG. 3. Dinner No. 6 in the Meal, 25 Man, Uncooked showing both the dehydrated products and the finished meal.

FIG. 4 Food Packet, Long Range Patrol.

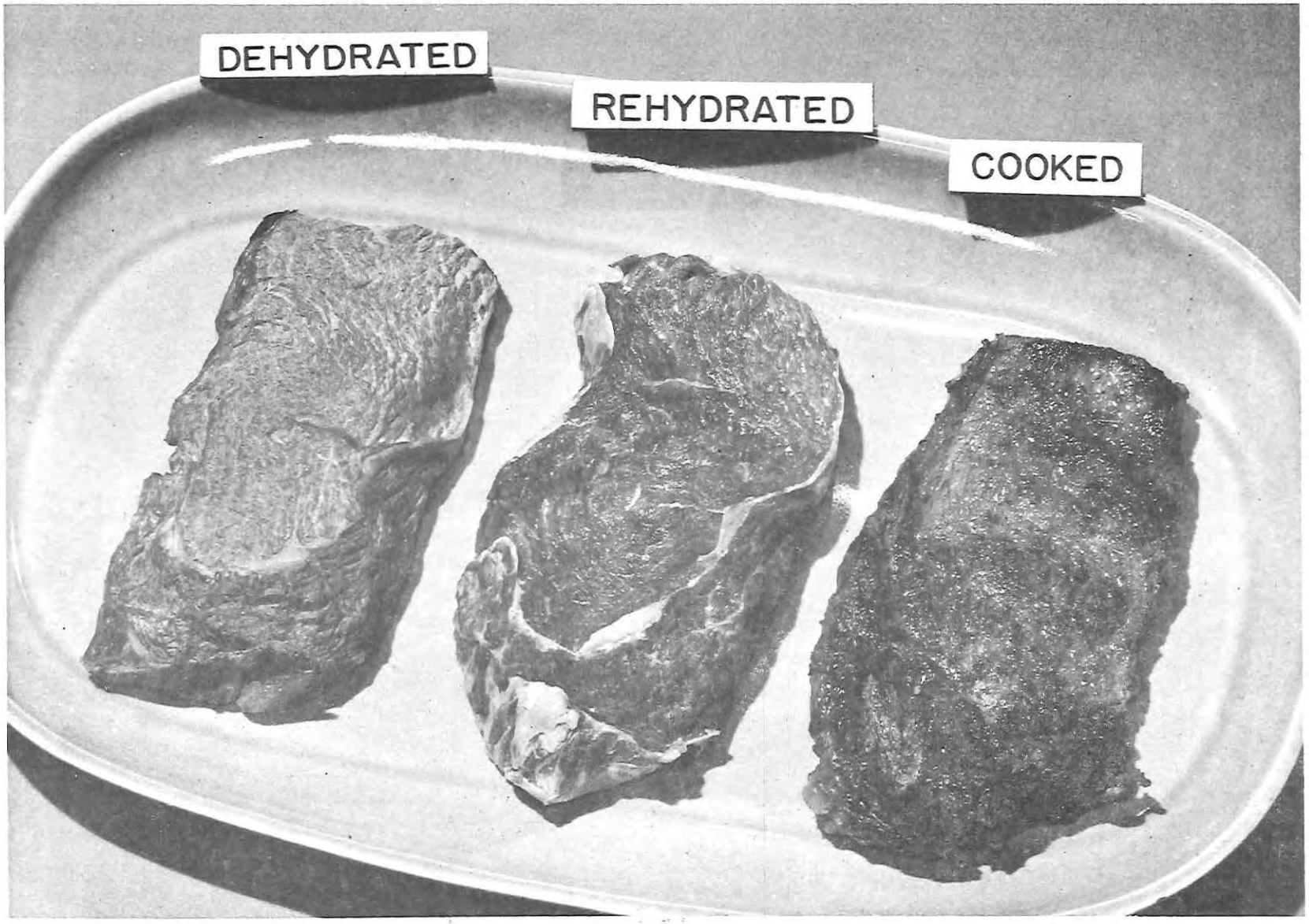

FIG. 5. Dehydrated, rehydrated, and cooked steak showing how the volume is not changed.

FREEZE DRIED RAW PORK CHOPS

FIG. 6. Comparison of dehydrated pork chops packed in cans and in flexible packages.

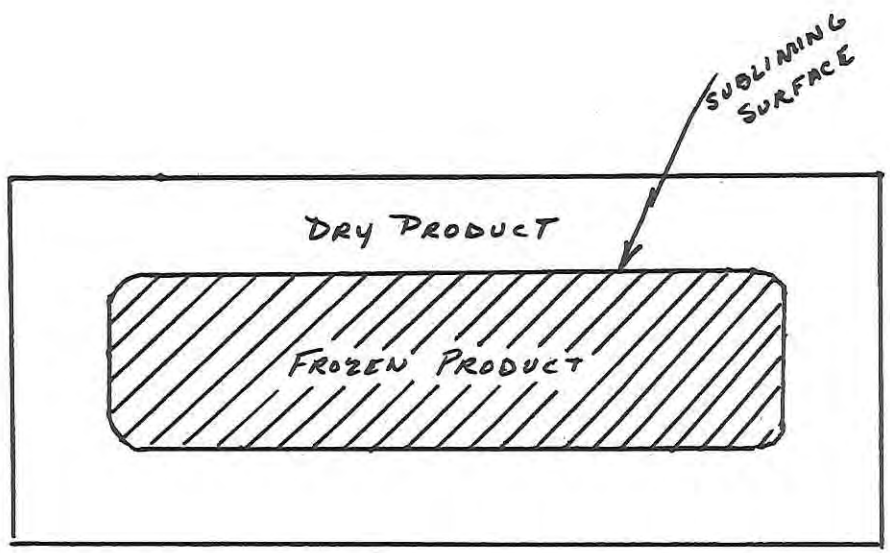

FIG. 7. Diagram showing how freeze drying proceeds throughout a piece of food.

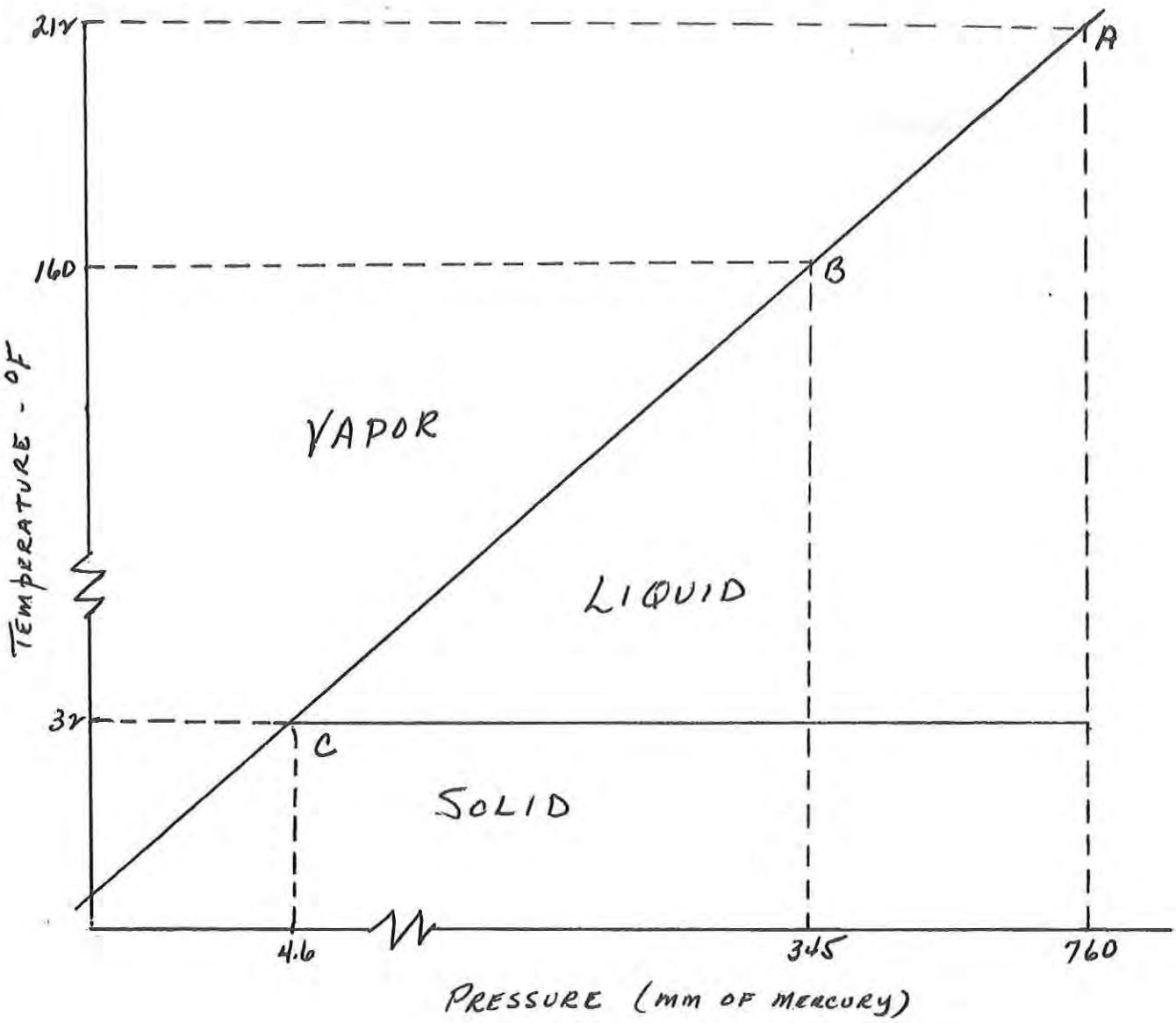

FIG. 8. Schematic relationship between temperature and pressure showing how freeze drying is possible at low pressures.

FIG. 9. Experimental food packet made up of compressed food bars which are to be eaten as is.

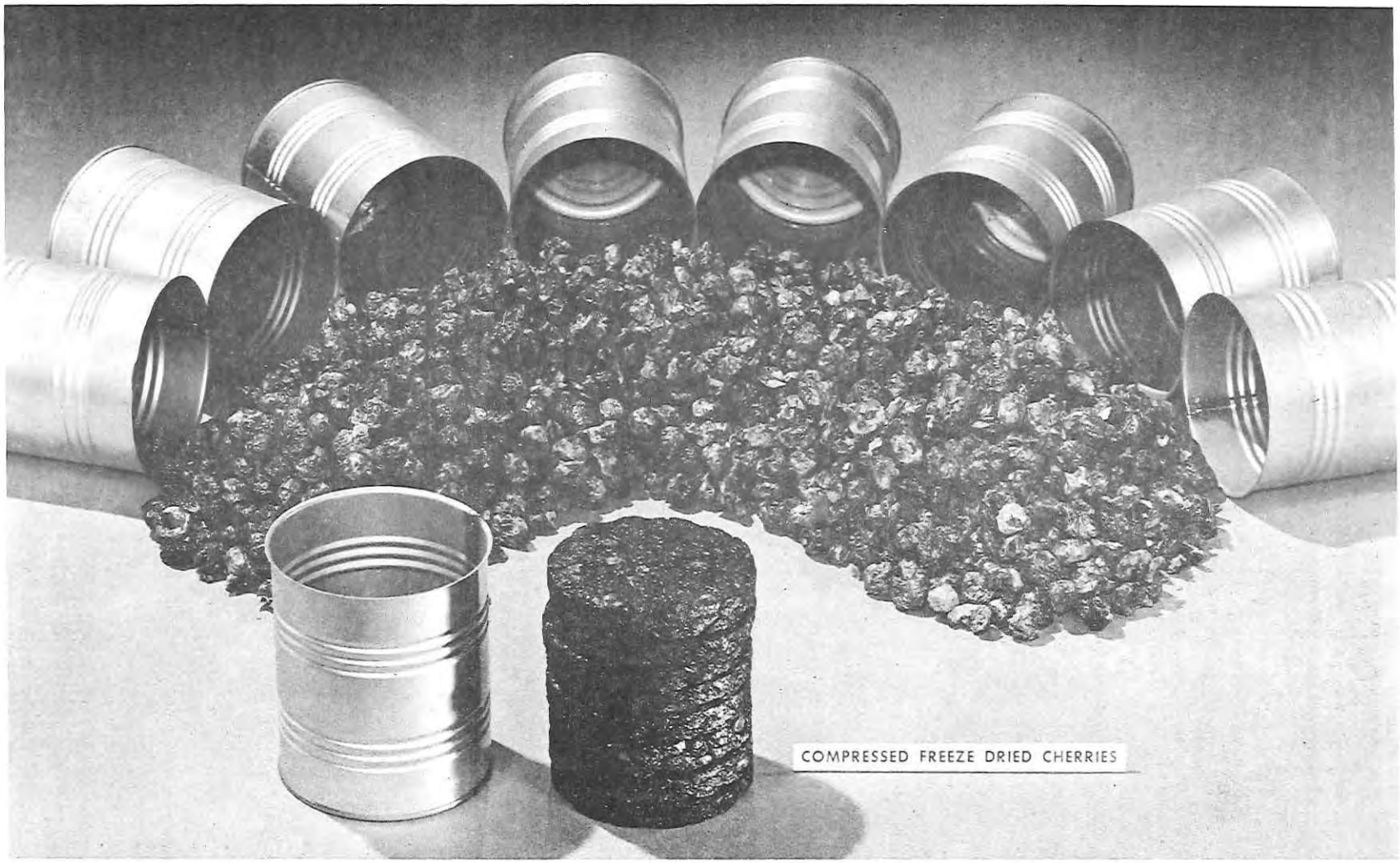

FIG. 10. Compressed freeze-dried cherries for pies showing a volume savings of 1 to 8 of the compressed versus the noncompressed.

FIG. 11. Package used for space flights in which the food is rehydrated and then eaten with a spoon. The valve on the right hand side of the package is used to insert the water for rehydration.

FIG. 12. Rehydratable and bite sized foods for space feeding. Tube through which the astronaut forces the food into his mouth is underneath the Orange Drink label. The pill is for sanitizing the package after it is emptied.

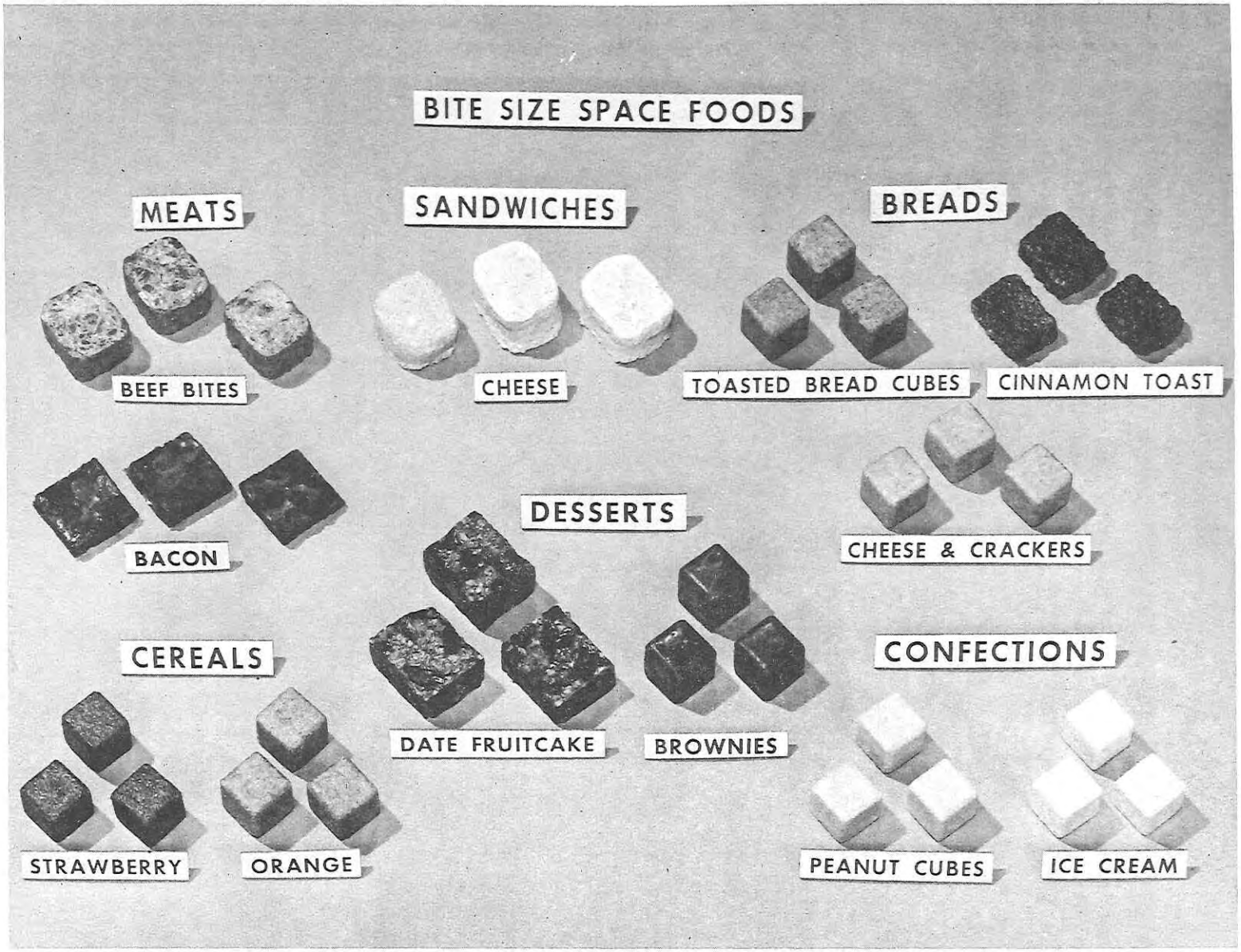

FIG. 13. Various bite size foods for feeding in space.

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

US Army Natick Laboratories
Natick, Massachusetts 01760

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

Freeze Drying of Foods for the Armed Services.

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*

J. M. Tuomy

6. REPORT DATE

February 1970

7a. TOTAL NO. OF PAGES

42

7b. NO. OF REFS

12

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

1J6-62708-D553

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

70-43-FL

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

FL-107

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11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

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13. ABSTRACT

This report reviews the development and use of freeze-dried food products for the Armed Services. It covers the various products and ration systems that have been developed, the basic parameters of freeze-drying and freeze-dried foods, commercial freeze-drying facilities, compression of freeze-dried foods, and development of freeze-dried foods for astronaut feeding. The report is non-technical and includes a selected bibliography for persons wishing to go more deeply into the technical aspects of freeze-drying.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Development	8					
Freeze-dried foods	9		9			
Armed forces (United States)	4					
Astronauts	4					
Parameters			8			
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Compressing	8					
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