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USAF School of Aerospace Medicine
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FOREWORD

The work described in this report was accomplished by the Food Laboratory of the U. S. Army Natick Laboratories under Military Interdepartmental Purchase Requests (MIPR) Nos. AM5-40037 and AM6-40061, initiated by the 6570 Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. First Lieutenant Elwood W. Speckmann and Dr. Aiton E. Prince were monitors. The work was transferred to the Physiology Branch, USAF School of Aerospace Medicine, in March 1966, and all work was combined under MIPR AM6-40061 and project No. 7758. Dr. John E. Vanderveen was appointed monitor. The report, covering the period between 31 December 1964 and 30 September 1967, was received for publication on 13 December 1967.

The following investigators in the Food Laboratory contributed to the developmental effort: Captain R. Flentge, Patricia Donovan, Arthur Anti, and Dr. F. Barrett. Personnel of the Behavioral Science Division, Pioneering Research Laboratory, and the Food Chemistry Division, Food Laboratory, also participated.

The spray-drying facilities of Brady Enterprises, East Weymouth, Mass., and the pilot plant agglomeration equipment of Blaw-Knox Food and Chemical Equipment Division, Buffalo, N. Y., were used in the study. Carnation Research Laboratories, Van Nuys, Calif., was the contractor for the instantized vanilla-flavored diet.

This report has been reviewed and is approved.



GEORGE E. SCHAFER
Colonel, USAF, MC
Commander

ABSTRACT

Nutrient-defined formula diets have been developed for possible use in aerospace metabolic experiments or on experimental or operational missions. The diets include an aseptically canned liquid, a freeze-dehydrated diet, an instantized dry diet, compressed tablets and bite-size pieces, a chewable candy, and a baked cookie product. Whenever possible, only the most purified ingredients of known nutrient composition were used in the diet formulations. Taste-panel evaluations, chemical analyses, and human and animal feeding tests showed that many of the diet formulations were of acceptable organoleptic and nutritional quality. Further work is needed, however, on these and other forms of nutrient-defined formula foods which can meet the exacting nutritional and other specifications established by the Air Force and NASA for aerospace feeding systems.

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I. INTRODUCTION

The provision of food for present and future manned flights in space represents an application of a broad base of interdisciplinary research in the life and physical sciences. Nutrition, physiology, gnotobiology, bacteriology, psychology, food science, and food engineering and packaging are some of the special fields which have contributed knowledge pertinent to the nutritional support of man in space. Some of the many parameters to be considered in the development and evaluation of space feeding systems are environmental, physical, and psychologic stress; effects of prolonged environment on diet; physiologic and metabolic requirements for food and water; packaging; sensory, stability, and nutrient properties; and approval of the Food and Drug Administration for the use of new foods.

Fortunately, available technology has enabled aerospace crews to be fed adequately while flying over or orbiting the earth. In assessing these achievements, it must be remembered that it was possible to utilize a vast background of "earth based" nutritional information, including simulator studies, in planning for orbital space feeding systems.

It is clear, however, that many complex nutritional problems remain, especially since the Air Force mission requires an extension of manned operational capabilities in near-space and far-space. As an example of these problems: The optimal nutritional requirements for space travel are not known; nor do we have feeding systems capable of supplying food for

prolonged space voyages of many months' or years' duration. Thus, if national goals relative to space defense and exploration are to be met, research must continue to provide the necessary answers.

The diets described in this report offer many advantages for use in the conduct of precise biologic and metabolic studies in space and on earth. Nevertheless, they are considered to be prototype models. The progress made in their development clearly indicates that it is feasible to custom-formulate or tailor-make experimental or operational diets to exacting nutritional or other specifications.

Development of space foods

This program was undertaken because a survey of formula diets in 1963 indicated that none were sufficiently nutrient-defined, available in a variety of edible forms, nor capable of meeting other space food requirements. This effort was initiated early in 1964 and is still in progress.

In the historic development of foods for aerospace missions, it was only proper that natural or conventional foods receive initial priority and attention. Certainly, there was no reason to doubt the guiding philosophy that familiar conventional-type foods would impose less psychologic and physiologic stress on man in space than nonnatural foods. Some of the early considerations given to the conventional foods concept have been discussed by Finkelstein, Taylor, and Hayes (9-11, 28). As a result, the Air Force initiated and supported a

considerable amount of developmental effort on the natural foods approach at the Food Laboratory, U. S. Army Natick Laboratories (NLABS) (14, 15). In addition, Hollender (16) has reported on certain technologic aspects of preparation, handling, and storage of foods produced for space flight. Recent studies by Speckmann et al. (26) and Calloway and Margen (3) have affirmed that conventional-type space meals containing precooked, dehydrated, and bite-size compressed foods are acceptable and nutritionally adequate for human subjects for periods of several weeks' duration. It is important to emphasize that Calloway and Margen concluded that their liquid formula diet appeared to be as acceptable and as nutritionally adequate as the Gemini diet tested.

Formula diets

Since formula diets offer certain advantages, it was felt that their development should not be neglected. In fact, the NAS-NRC Space Science Board, in 1963 and 1964 meetings (19, 20), recommended the use of formula diets for early space missions because they can be designed with these advantages: simplicity of feeding; ease of packaging, handling, and storage; minimization of residue; control of flatus; and facilitation of metabolic studies.

It is pertinent to this report to distinguish between a formula diet and a nutrient-defined formula diet. A formula diet is a general term encompassing all diets containing a combination of natural, synthetic, or purified food ingredients mixed together according to a formula usually designed to achieve some sort of nutritional state. Common examples are prepared infant formulations, canned liquid weight-control diets, some hospital diets, and animal feeds. To the authors, a nutrient-defined formula diet designates a refinement of the formula diet concept, whereby only the most purified ingredients of known nutrient composition are used whenever possible, and careful nutritional composition controls are maintained over ingredients and the final product. Unpurified natural materials are excluded, if possible, because analyses of these complex ingredients are usually incomplete. Such nutrient-defined formula diets have been

used widely in animal experimentation where they have been known as semisynthetic or semipurified diets.

Formula diets with various degrees of nutrient definition are not new, but their widespread use in human metabolic studies or by the public is of recent origin. The use of liquid formula diets for human metabolic studies has been discussed by Kuhl et al. (17), Ahrens et al. (1), Feinstein et al. (6, 7), Piché et al. (22), Scrimshaw (25), Hashim and Van Itallie (13), Sarett (24), and others. Commercial liquid formula diets have also been employed in clinical studies (Roberts, 23; Christian et al., 2). Some of the Air Force studies concerned with liquid diets have been reported by Finkelstein and McGhee (8), and Speckmann et al. (27).

Other published information on aerospace nutrition may be found in the proceedings of the 1964 *Conference on Nutrition in Space and Related Waste Problems* (21). Some of the work presented in this report has been published (5).

Theoretically, the near ultimate in nutrient definition has been achieved by chemically defined diets which contain L-amino acids, purified simple carbohydrates, ethyl linoleate as the essential fatty acid, vitamins, and minerals. While humans have been fed these chemically defined diets for limited periods of time (Couch et al., 4; Winitz et al., 30-32), problems of diet acceptance, high osmolarity, and long-term nutritional adequacy remain to be investigated and solved.

Food items and specifications

The Military Interdepartmental Purchase Request (MIPR) prescribed the development of nutrient-defined diets in various solid and liquid forms (appendix A). Prototypes were prepared of a liquid diet which could be aseptically canned; a dehydrated diet, suitable for consumption as compressed, dry, bite-sized pieces or as a liquid after reconstitution; a chewable candy; and a baked product. With the initial food items, the formulations were adjusted so that the consumption of 500 to 600 gm. of diet on a dry basis per day would

furnish approximately 2,800 kcal., normally distributed as follows: 10% to 15% from protein, 30% from fat, and 55% to 60% from carbohydrate. This distribution met the requirements of the NAS-NRC Food and Nutrition Board (18). It was recognized that individual variations might require adjustment of caloric intake in order to maintain body weight. To alleviate stability and flavor problems, vitamins and minerals were not included in the original diet formulations. Both can be administered in appropriate amounts in capsule form to meet the NAS-NRC requirements. In the most recent formulations, macromineral balance has been achieved by ingredient adjustment and by mineral supplementation to meet these requirements.

The MIPR specified that the diet be: acceptable over a long period of time, low in residue, not unduly thirst-producing, non-gas-producing, easily digested and well-utilized, able to withstand a range of temperatures (0° to 100° F.) for a period of 6 months or longer when adequately packaged, able to withstand vacuum packaging, and capable of being sterilized.

Characteristics considered desirable in the nutrient-defined formula diet included: (a) ease

of preparation—a maximum of 2 minutes' time and effort required; (b) a noncrumbling consistency, if dry, and if a liquid, ability to pass through a 60-mesh sieve, and a foam level of less than 3%; (c) capability of meeting microbiologic standards of less than 10 coliforms per gram, 20 enterococci per gram, and freedom from coagulase-positive *Staphylococcus*, *Salmonella*, and fecal coliforms, by standard technics (for dry forms); (d) conformance to a weight allowance of 1.9 lb. and a volume allowance of 157 cu. in. per man per day.

II. PROCEDURES

Liquid and freeze-dehydrated diet

Development of a liquid formula diet began with the formulation and small-scale laboratory production of a simple basic diet composed of 5% purified proteins, 6% fat, 24% carbohydrates, 65% water, and small quantities of stabilizing, emulsifying, and flavoring additives. The composition of early laboratory-produced diets is given in table I. An improvement in nutrient definition is shown by the ingredient composition of the more recent diets given in table II.

TABLE I
Early laboratory-produced diets

Ingredient	Percent										
	4	—	—	—	—	—	2	2	2	—	1.5
Egg albumin	—	4	—	—	—	—	2	2	2	—	1.5
Sodium caseinate	—	—	4	—	—	—	2	—	—	2	1.5
Calcium caseinate	—	—	—	4	—	—	—	—	—	2	0.5
Lactalbumin	—	—	—	—	4	—	—	2	—	—	—
Casein-lactalbumin (Ca Sal)	—	—	—	—	4	—	—	—	2	—	—
Isolated soy protein (water-dispersible)	—	—	—	—	—	4	—	—	—	2	—
Starch*	3	3	3	3	3	3	3	3	3	3	3
Corn syrup, 42 DE	19	19	19	19	19	19	19	19	19	19	19
Vegetable oils (corn oil or Crisco)	6	6	6	6	6	6	6	6	6	6	6
Water	67	67	67	67	67	67	67	67	67	67	67
Flavor and emulsifier	1	1	1	1	1	1	1	1	1	1	1
Total	100	100	100	100	100	100	100	100	100	100	100

*Redisol, Instant Gel, Snowflake, or Clearjel.

TABLE II
 NLABS nutrient-defined liquid formula diets

Ingredient (percent)	1*		2*		3	4†		5	6	7	8	9‡	10‡	11*	12*
	C and V	C	C	V	CM	C	V	V	V	C	V	V	V	V	C
Sodium caseinate	5.00	4.59	4.57	4.50	4.64	4.57	4.57	1.54	1.00	0.96	1.00	1.00	1.00	1.01	1.00
Calcium caseinate	—	—	—	—	—	—	—	2.06	2.01	1.93	2.01	2.01	2.00	2.01	2.01
Potassium caseinate	—	—	—	—	—	—	—	1.02	2.01	1.93	2.01	2.01	2.00	2.01	2.01
Sucrose	4.00	5.11	7.10	3.00	6.70	7.10	6.06	6.97	4.51	5.79	4.01	3.01	7.00	5.04	6.02
Dextrose	—	—	6.09	—	—	6.09	7.10	6.98	5.01	4.82	6.52	3.01	6.80	5.04	5.02
Dextrin	—	—	3.05	—	—	3.05	3.05	3.07	5.01	2.89	2.01	3.01	3.00	4.08	3.01
Lactose	—	—	2.03	—	—	2.03	2.03	—	2.01	2.41	4.01	4.01	—	2.12	2.50
Starch	2.00	2.04	2.03	2.00	2.06	2.03	2.03	—	2.01	1.93	2.01	2.01	2.00	2.01	2.01
Corn syrup, 42 DE	16.00	7.6	—	17.50	8.25	—	—	—	—	—	—	—	—	—	—
Corn syrup solids, 42 DE	—	6.12	—	—	3.09	—	—	—	—	—	—	—	—	—	—
Vegetable oil, partially hydrogenated (Mello-Mix†)	—	6.12	6.09	6.00	6.19	6.09	6.09	—	—	—	—	—	—	—	—
Corn oil	6.00	—	—	—	—	—	—	—	—	—	—	—	0.20	0.20	0.20
Safflower oil	—	—	—	—	—	—	—	0.20	0.20	0.19	0.20	—	—	—	—
Triglyceride, c† (MCT)	—	—	—	—	—	—	—	5.94	—	—	—	—	—	—	—
Triglyceride, c-10† (MCT)	—	—	—	—	—	—	—	—	6.02	5.79	6.02	6.02	6.00	6.04	6.02
Water	67.00	68.37	71.07	67.00	69.07	71.07	71.07	72.23	70.21	71.36	70.20	70.20	70.00	70.49	70.20
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Miscellaneous ingredients	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Salt, gm. per 100 lb.	—	—	—	—	—	—	—	48.20	47.10	—	47.10	47.10	47.00	100.70	100.30
Emulsifier (Drew Mulise 90†), gm. per 100 lb.	50.00	51.00	50.80	50.00	51.50	50.80	50.80	51.20	50.20	48.20	50.20	50.20	50.70	50.40	50.20
Chocolate powder,‡ gm. per 100 lb.	681.00	681.00	681.00	—	681.00	681.00	—	—	—	635.60	—	—	—	—	681.00
Malt,‡ gm. per 100 lb.	—	—	—	—	862.60	—	—	—	—	—	—	—	—	—	—
Vanilla flavoring,‡ gm. per 100 lb.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cream soda,‡ gm. per 100 lb.	50.00	51.00	47.70	50.00	—	47.70	3.00	48.20	47.10	—	47.10	47.10	47.00	47.30	47.10
	—	—	—	—	—	—	—	1.00	1.70	—	1.00	1.00	1.00	1.00	1.00

C — Chocolate.

V — Vanilla.

CM — Chocolate malt.

*Supplied to SAM for simulator studies.

†Sent to NASA Manned Spacecraft Center.

‡Formulated for ARIEM.

§See appendix 2.

The protein sources used were sodium caseinate, lactalbumin, egg albumin, calcium caseinate, potassium caseinate, isolated soy protein, and various combinations of these proteins. Egg albumin, alone or in combination with other proteins, resulted in a palatable diet but was eliminated as an ingredient because of coagulation problems during heat processing. In addition, there was also the problem of avidin binding the vitamin biotin when egg albumin was used. Eventually, the choice of protein sources was narrowed to the water-dispersible sodium, potassium, and calcium caseinates because they could also be used to supply minerals (Na, K, and Ca) and aid in achieving a desired mineral balance.

Carbohydrates in the form of glucose, sucrose, lactose, dextrin, corn syrup or corn syrup solids (hydrolyzed corn starch), and modified starch were used individually or together. In recent formulations, corn syrup products have been excluded because of lack of sufficient nutrient definition. Also, because of evidence of lactose intolerance in a small percentage of the population, it was decided not to use any lactose in the most advanced formulations.

As with semipurified animal diets used in nutrition research, corn oil and other vegetable fats of known origin and good stability were

considered satisfactory sources of fat in the early diets. As development advanced, these fats were replaced in large part with purified medium-chain triglycerides (MCT) plus an adequate source of essential fatty acid. The MCT was obtained as a purified C₈-triglyceride or as a mixture containing mainly C₈ and C₁₀ triglycerides. A typical fatty-acid analysis of the latter is: C₆ - 0.1%, C₈ - 79.5%, C₁₀ - 19.8%, C₁₂ - 0.5%, and C₁₄ - 0.1% (MCT lot No. 1220, Feb. 1966). Safflower oil and corn oil served as sources of linoleic acid, but ethyl linoleate could have been used to supply essential fatty acid at a level of 1% to 2% of calories. The emulsion stability was dependent on the type and combination of ingredients used in a particular formulation; however, a combination of emulsifying agents in the form of monoglycerides, or monoglycerides and diglycerides, and homogenization usually produced the most desirable results.

A flavoring guide for the liquid diets is given in table III. Because of general popularity and acceptance, chocolate- and vanilla-base flavors were used exclusively in the large batches of canned liquid diet. The vanilla flavor was obtained by use of a synthetic vanilla product in combination with a synthetic cream soda. Because the synthetics did not

TABLE III
Flavoring guide for liquid diets

Flavor	Vanilla	Banana	Butterscotch	Caramel
	(gm. per 10 gal. of liquid diet)			
Vanilla*	47.40	28.40	—	—
Cream soda*	0.47	—	0.47	—
Banana*	—	0.47	—	—
Coconut*	—	0.28	—	—
Butterscotch*	—	—	0.56	—
Mertaste*	—	—	2.84	—
Caramel*	—	—	—	47.40
Salt	47.40	47.40	47.40	47.40

Table prepared by Flavor Laboratory, Arthur D. Little, Inc., Cambridge, Mass.

*For names of manufacturers, see appendix 2.

give an acceptable chocolate flavor, it was decided to use a high quality dairy-grade chocolate powder until better synthetic chocolate flavors could be obtained.

Salt was added to the diets for flavor enhancement and to supply sodium. As shown in table II, in the more recent formulations salt was supplemented at levels of 47 to 100 gm. per 100 lb. of liquid diet. When used at the 100 gm. per 100 lb. level, each 8 oz. can (258 gm.) of diet contains approximately 0.57 gm. of salt or 0.16 gm. sodium.

Four large and 7 small batches of the liquid diet were processed in five steps: formulation and mixing, homogenization, high-temperature short-time sterilization (292° F. for 8 seconds), cooling and homogenization, and aseptic canning. After processing, representative cans were selected for taste panel evaluation and chemical analysis.

Freeze-dehydrated diets were prepared by pouring the liquid diets into trays, then freezing and dehydrating the mixture in a freeze dryer. The dry diet was then cut or compressed into small bite-size pieces or ground into a fine powder. In studies on decreasing reconstitution time with water, the liquid diet was subjected to sonic homogenization for 1- to 10-minute periods before freeze-dehydration.

Instantized dry diet

To obtain a dry product with the many advantages inherent in products having rapid wettability and capability of reconstitution to the liquid state, several experimental batches of diet were processed by spray-drying and agglomeration. Two approaches were employed:

1. A contract was awarded for the production of an instantized vanilla-flavored diet according to the NLABS formula and specifications. Because of the proprietary nature of the technology, it was agreed that details of the processing would not be revealed. The diet formula was as follows:

Component	Percent
Calcium caseinate	6.7
Sodium caseinate	3.0
Potassium caseinate	7.1
Medium chain triglyceride, C ₈ -C ₁₀ *	20.0
Corn or safflower oil	1.0
Starch*	8.3
Dextrin*	15.9
Sucrose	17.8
Glucose	18.8
Salt	0.7
Emulsifier (of choice)	0.4
Vanilla flavor*	0.3
Total	100.0

Cream soda flavor,* 2.0 ml.

*For manufacturers of the individual components listed, see appendix 2.

2. A series of exploratory processing studies was undertaken. Spray-drying was conducted in a Mojonier cylindrical spray-drying system with a water evaporation capacity of 450 lb. per hour. Although the basic concepts of spray-drying are well known, it has not been possible to develop design equations based on the properties of the material to be dried. Thus, evaluation tests were conducted to determine optimum operating conditions. It must be remembered, however, that the conditions developed by test runs are generally suitable only for the particular material under test and for the particular spray-dryer employed.

Exploratory spray-drying and agglomeration test. In this first test series, six experimental spray-dryings were conducted with surplus cans of vanilla- and chocolate-flavored NLABS liquid nutrient-defined diet No. 4. While the diets showed some signs of separation into phases as they were poured from the can, they became smooth, uniform mixtures with slow-speed agitation and heating to 110° F. in the feed tank. The conditions of the spray-drying process are given in table IV.

Since attempts at reconstitution to the liquid state of the spray-dried material required considerable blending, it was decided to determine if agglomeration would result in an instantized product. While only a small amount of material was available, the quantity

TABLE IV

Exploratory spray-drying conditions for NLABS nutrient-defined diet No. 4

Test	Flavor	Inlet air temp.* (*F.)	Outlet air temp. (*F.)	Orifice/ core	Spray pressure (p.s.i.g.)	Gas flow† (cu. ft./ hr.)	Powder moisture (%)	Bulk density (gm./cc.)
1	Vanilla	345	260	64/27	1,500	—	0.8	0.26
2	Vanilla	370	275	64/27	1,500	—	—	—
3	Vanilla	320	250	64/27	1,500	—	1.2	0.29
4	Vanilla	320	265‡	64/27	1,500	0.1	0.8	0.22
5	Chocolate	315	235	64/28	1,500	—	2.0	0.27
6	Chocolate	315	235	64/28	1,800	0.1	1.2	0.19

*Inlet air flow to dryer 5,500 SCFM at 50° F., 100% relative humidity.

†Nitrogen at 2,000 p.s.i.g.

‡Not steady.

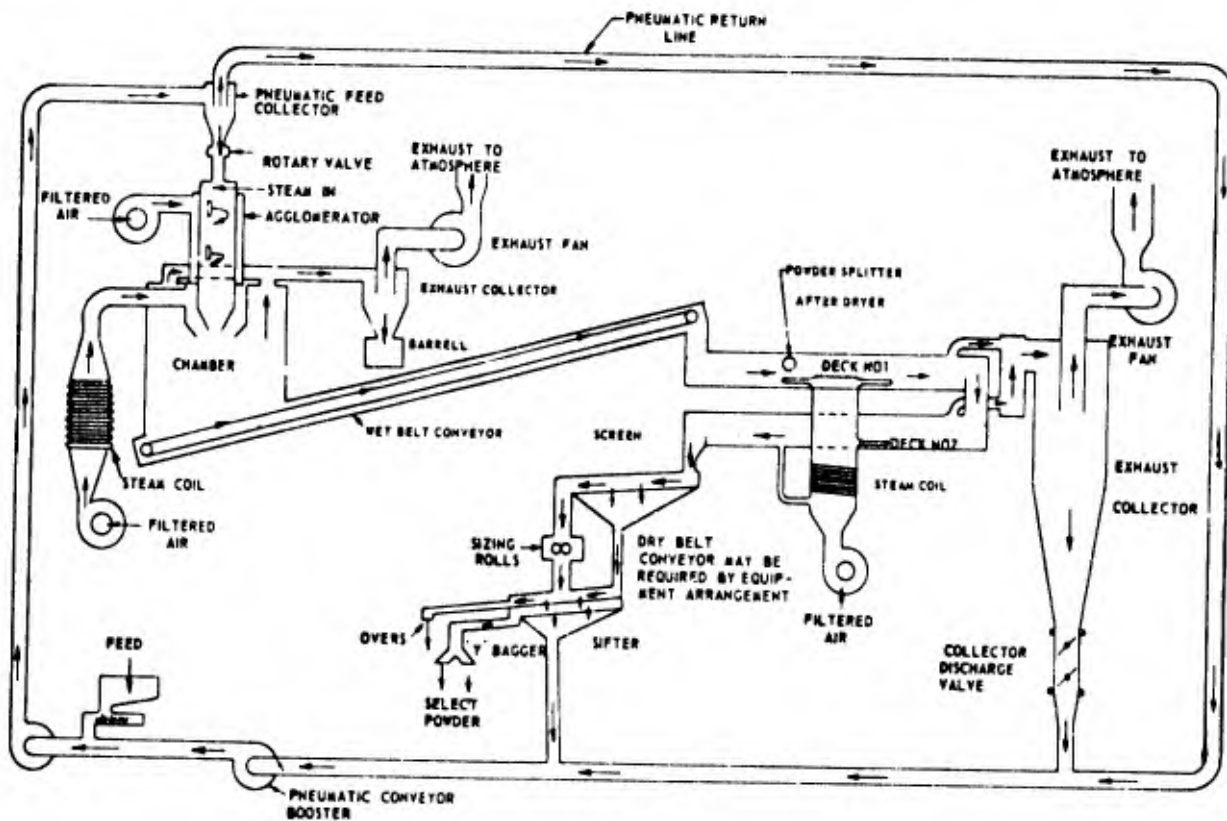


FIGURE 1

Schematic flow diagram for the Instantizer agglomerator (courtesy of Blaw-Knox).

was considered sufficient for a preliminary test to indicate whether or not the product would agglomerate and be suitable for a full-scale Instantizer test. Therefore, all available material was processed in the Instantizer agglomerator (fig. 1). In this process, the small particles were uniformly wetted and brought into intimate contact with each other to form agglomerated clusters of a spongelike structure. After the wetted particles attained a uniform moisture equilibrium, they were passed through a drying zone to reduce moisture content. In the final steps, the agglomerated material was cooled and fed to a sifter. The agglomerates were separated into *select*, *oversize*, and *fine* products.

The first operation of the test agglomeration procedure was to sift the spray-dried diet through a 16-mesh screen to take out any hard lumps. Microscopic examination of the sifted material showed it to be in the form of small transparent and opaque spheres, typical of spray-dried products. When small amounts of the material were dropped through a bench-scale steam spray apparatus, the diets picked up moisture. It appeared that considerable moisture would be required to agglomerate the material, however.

Operating conditions for agglomeration tests *A* and *B* (spray-dried vanilla diet) and for tests *C* and *D* (chocolate diet) in the first test series are given in table V. The feed for

test *B* was the unsifted material which passed through the agglomerator in test *A* and which showed very little agglomeration. In this test, hot air was passed to the upper agglomerating chamber with increased steam pressure. The intent was to diminish the condensation formed on the inside walls of the upper agglomerating barrel and reduce the buildup and formation of the large balls. At the same time, the objective was to wet the material sufficiently for agglomeration. In test *C*, a small agglomerating barrel was used with the intention of reducing the surface area of the agglomerator. More steam was also added in an attempt at better agglomeration of the material without producing big lumps. For test *D*, a Teflon flow sheet was inserted on the inner wall of the short agglomerating barrel, to allow it to run at a higher steam pressure without having the material stick to the agglomerating chamber wall and produce the large lumps. As in the previous tests it was desirable to wet the material sufficiently to prevent its touching the walls, and thus promote the formation of agglomerates.

Full-scale spray-drying and agglomeration test. The objective of the second test series was to utilize the information obtained in the first test series to produce at least 100 lb. of spray-dried and agglomerated instantized diet. Spray-drying was used as a pretreatment in order to encapsulate the fat and to improve wettability before the agglomeration process.

TABLE V

Operating conditions for Instantizer agglomeration test (exploratory)*

Conditions	Vanilla diet		Chocolate diet	
	Test A	Test B	Test C	Test D
Duration of test (min.)	2	1	3	1.5
Steam nozzles (in.)	0.062, 0.031	—	—	—
Steam pressures (lb.)	7.5, 2.0	—	—	—
Material fed (lb./hr.)	300	360	400	400
Density (lb./cu. ft.)	16	15	16	12.5
Moisture (percent)	1.7	1.3	1.5	1.9

*Blaw-Knox FA-1 Instantizer and 2-deck after-dryer.

In actual practice, a number of experiments were conducted to develop a suitable spray-dried component formulation and a stable emulsifier system, and to define spray-drying conditions. As a result of these tests, the final spray-dried component formula was as follows:

<i>Spray-dried component</i>	<i>Percent</i>
Calcium caseinate	12.3
Sodium caseinate	5.5
Potassium caseinate	13.0
Fat (MCT, C ₈ - C ₁₀)	36.8
Corn oil	1.3
Dextrin*	28.0
Lecithin*	1.8
Salt	1.3
Total	100.0
Vanilla flavor* 0.34 lb. per 100 lb.	
Cream soda flavor* 1.67 gm. per 100 lb.	

*See appendix 2.

The above ingredients were mixed with water to prepare an emulsified slurry containing 40% solids and homogenized at 2,500 p.s.i.g. before drying. The spray-drying conditions were an inlet air temperature of 320° F., an orifice-cone-nozzle combination of 62/28, and a spray pressure of 1,500 p.s.i.g.

Formulation of 300 lb. of diet was completed by the mixing of components as follows:

<i>Complete formula</i>	<i>Percent</i>
Spray-dried component	55.0
Dextrin	8.4
Glucose	18.8
Sucrose	17.8
Total	100.0

Two trials were conducted at the spray-drying facility to test the feasibility of dry-mix methods of agglomeration. In the first "water process" test, 1.5% water was added to the sucrose in the dry mixer. The spray-dried component was added with mixing. Then, the glucose and dextrin were incorporated into the mixture. The second batch, identified as "steam process" was prepared by mixing the sugar and the spray-dried component in the dry mixer under a nearly saturated atmosphere obtained by purging steam into a heated air stream leading to the mixture. The dextrin and glucose were added later to the mixture. The two batches of diet subjected to the above mixer agglomeration tests were not further processed, but were evaluated for effectiveness of the agglomeration.

Large-scale agglomeration tests were conducted with the Instantizer and a 2-deck stainless steel after-dryer, using the 300 lb. of spray-dried diet prepared as previously described. Operating conditions for the seven test runs are given in table VI.

Compressed tablets and bite-size pieces

Ground, freeze-dried diet, flavored and unflavored, and spray-dried agglomerated diets have been compressed into tablets and bite-size pieces. Concentrated fruit, meat, and vegetable flavors were incorporated into the tablets. Much of this work was conducted by the Plant Products Division of the Food Laboratory.

TABLE VI

*Operating conditions for Instantizer tests (full-scale)**

	Test A	Test B	Test C	Test D	Test E	Test F	Test G
Duration (min.)	2	5	5	10	4.5	15	6.5
Feed rate (lb./hr.)	360	325	336	348	334	384	193
Density (lb./cu. ft.) (loose)	22.8	22.8	22.8	22.8	22.8	22.8	22.8
Moisture (percent)	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Temperature	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient

*Blaw-Knox FA-1 Instantizer and 2-deck stainless steel after-dryer. Relative humidity 51% for tests A, B, C, D, E, and F, 40% for test G.

Baked diet

The ingredients used in the nutrient-defined cookies and the basic formula are shown in table VII. The dough was prepared by the

TABLE VII

Formula for a nutrient-defined baked cookie

Ingredients	Percent
Egg albumin	6.0
Purified soy protein	6.0
Sucrose	24.0
Pregelatinized starch	24.0
Vegetable fat (high m.p.)	24.0
Flavor	0.3
Water	15.7
Total	100.0

cream-mass method to insure a good emulsion and proper incorporation of ingredients. A cream mass was prepared by blending together the fat and sucrose; water was slowly added and the mixture whipped until smooth. Liquid flavors were added at this point and whipped in. If dry flavors were used, they were blended with the dry ingredients and folded into the cream mass. The mixture was blended until a stiff dough was formed which cleaned the sides of the bowl. The dough was rolled to a thickness of 1/4 inch and cut into small circles or squares. A high-temperature short-time bake was carefully controlled to prevent undesirable hardening.

Nutrient-defined formula candy

Nougat candy-making procedures were modified to produce a product composed of egg albumin, sodium caseinate, sucrose, corn syrup, and vegetable fat. The latest formulation, a chocolate-peppermint candy, is prepared by the procedure as follows:

PART A

695 gm. Sucrose
 385 gm. Corn syrup, 42 DE
 (dextrose equivalent)
 260 gm. Water
 4 gm. Salt

Cook to 300° F. and add to part B in a thin stream with mixer on low speed.

PART B

77 gm. Egg albumin
 115 gm. Water
 300 gm. Corn syrup, 42 DE
 (at 140° F.)

Make a solution containing the egg albumin and water. Heat the corn syrup to 140° F. Whip the mixture for 1 minute in a high-speed mixer. Add part A. When thoroughly mixed, slowly add part C with mixing.

PART C

510 gm. Fat, high stability
 (at 140° F.)
 240 gm. Sodium caseinate
 75 gm. Cocoa powder*
 10 gm. Atmul 142*
 6 gm. Lecithin*
 2 gm. Peppermint oil*

Mix together and heat to 160° F. before adding to the mixture of parts A and B. When completely mixed, pour the mass on a cold slab lined with silicone paper. Cut into squares when cold.

*See appendix 2 for manufacturers.

A listing of ingredients on a percentage basis is given in table VIII.

TABLE VIII

Ingredients of a nutrient-defined candy

Ingredients	NLABS No. 1 (percent)
Egg albumin	3
Sodium caseinate	9
Corn syrup, 42 DE	25
Sucrose	26
Vegetable fat (high m.p.)	19
Safflower oil or ethyl linoleate	1
Chocolate flavor and emulsifier	3
Water	14
Total	100

Diet evaluation

Both small technical taste-panel ratings and large consumer taste-panel tests were used to evaluate the organoleptic quality of the various diet formulas and flavors. In both types of tests, the performance ratings were based on a 9-point hedonic scale. The numerical ratings and their descriptive words are as follows: 1 - dislike extremely, 2 - dislike very much, 3 - dislike moderately, 4 - dislike slightly, 5 - neither like nor dislike, 6 - like slightly, 7 - like moderately, 8 - like very much, and 9 - like extremely. All diets tested were served at room temperature.

NLABS liquid diet 1, an early formulation, was evaluated for nutritive value, water intake, and fecal output, by an animal feeding test. In this test, a total of 70 male weanling rats of the Charles River COBS strain were divided into seven equal-weight groups of 10 rats each, and individually maintained in a temperature- and humidity-controlled room. The diets fed included a natural ingredient commercial rat feed, two nutrient-defined dry diets, NLABS No. 1 liquid diet, two commercial liquid diets, and a synthetic amino acid liquid diet that was chemically defined. It was necessary to supplement the diets which did not

contain vitamins and minerals to make them nutritionally adequate. All diets were fed ad libitum for a 30-day experimental period. Analytic values for the diets are given in table IX.

III. RESULTS AND DISCUSSION

Figure 2 shows prototypes of nutrient-defined diets in the form of a sterile canned liquid, freeze-dehydrated squares, cookies, and candy, which have been developed for possible space feeding applications.

Liquid diet

Because of requests for a convenient diet for use in metabolic tests, a main developmental effort was focused on the liquid diet. As a result, there has been steady improvement in nutrient definition and nutritive balance. These advances are shown in the nutrient composition values shown in table X. Starting with diet 5, the use of MCT provided a high degree of fat definition in terms of known fatty acid composition. In addition, the macro-mineral balance of calcium, phosphorus, potassium, and sodium was improved by adjusting the amounts of the various caseinate salts and sodium chloride.

TABLE IX
Composition of diets evaluated by rat feeding test

Diet	Form	Moisture	Protein	Fat	Carbohydrate
		(percent)			
Commercial rat formula	Dry	11.0	23.0	4.5	46.5
Protein (15%)*	Dry	3.5	15.0	20.0	57.5
Protein (10%)*	Dry	4.3	10.2	19.3	62.2
NLABS No. 1*	Liquid	69.5	4.3	8.4	17.1
Commercial A†	Liquid	69.3	4.3	10.1	14.1
Commercial B‡	Liquid	74.8	5.4	3.5	13.3
Synthetic amino acid diet§	Liquid	49.1	4.6	0.2	44.7

*Nutrient-defined diets containing casein as the nitrogen or protein source.

†Pillsbury high-calorie drink powder made up to 70% moisture content.

‡Tribute, Mead Johnson Laboratories.

§Chemically defined diet containing synthetic amino acids as the nitrogen source, United Technology Laboratory.

¶Ethyl linoleate supplied as a source of essential fatty acid.

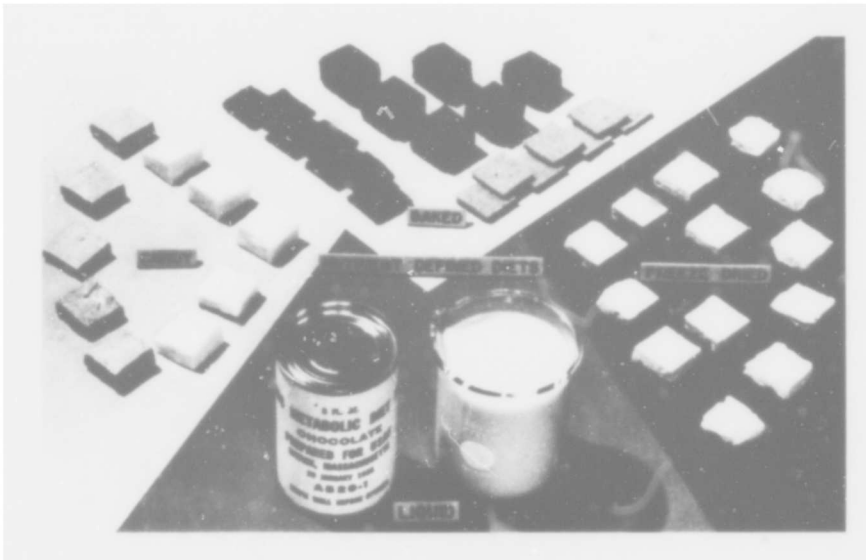


FIGURE 2

Nutrient-defined diets prepared by U.S. Army Natick Laboratories in the form of a sterile canned liquid, freeze-dried squares, cookies, and candy.

The analytic values given in table X also indicate the ease with which such purified diets can be designed to meet exacting specifications. For example, consumption of a daily allowance of seven cans of NLABS No. 10 provides 2,655 kcal., 79 gm. protein, 108 gm. fat, 341 gm. carbohydrate, no fiber, 716 mg. calcium, 722 mg. phosphorus, 1,138 mg. sodium, and 560 mg. potassium in a total of 535 gm. of dry matter. If other variations in intake are desired, modifications can be readily made in the formulation or in the amount of diet consumed.

Of the many flavors tested for acceptability, chocolate and vanilla appeared to be most preferred. Other flavors which obtained suitable consumer or technical panel scores included coffee, chocolate malt, strawberry, and banana. While the initial diets containing milk protein often had a strong, unpleasant after-taste, considerable improvement in diet palatability resulted from the "right" blend of flavoring agents. In all instances, however, intense flavoring or sweetness was avoided in

order to reduce the flavor fatigue which may occur in long-term feeding.

Some means preference scores, based on a 9-point hedonic scale, are given in table XI. The ratings which were close to 6 (like slightly) for the NLABS products resulted from careful attention to flavoring, since these diets scored 4 to 5 before addition of flavoring materials. As shown in table XI, however, despite changes in formulation and flavoring, the chocolate diets quite consistently scored approximately the same. These ratings indicate that it is difficult to attain a preference rating of 7 (like moderately), or higher, with this type of liquid diet.

There is no doubt that humans will accept and subsist on nutrient-defined liquid formula diets for fairly long periods. For example, NLABS formulations 1, 2, 11, and 12 were fed to groups of highly motivated subjects maintained in space simulators for 4- to 8-week periods, by Welch and co-workers (29) at the USAF School of Aerospace Medicine. Each

TABLE X

Nutrient composition of NLABS liquid formula diets

Component	Vanilla No. 1	Chocolate No. 1	Chocolate malt No. 3	Vanilla No. 4	Chocolate No. 4	Vanilla No. 5	Vanilla No. 9	Vanilla No. 10
Dry matter (gm.)	30.5	30.8	33.4	26.8	28.5	26.9	28.5	29.6
Moisture (gm.)	69.5	69.2	66.6	73.2	71.5	73.1	71.5	70.4
Protein (gm.)	4.6	4.7	4.7	3.7	4.2	4.0	4.3	4.4
Fat (gm.)	6.3	6.3	6.7	5.9	5.8	6.0	6.6	6.0
Carbohydrate (gm.)	19.4	19.6	21.6	16.9	18.2	16.6	17.3	18.9
Fiber (gm.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calories (kcal.)	153.0	154.0	165.0	136.0	141.0	136.0	146.0	147.0
Ash (gm.)	0.27	0.34	0.42	0.28	0.35	0.30	0.32	0.32
Calcium (mg.)	10.60	10.80	16.10	14.80	15.10	58.80	40.30	39.64
Phosphorus (mg.)	40.00	50.00	59.10	26.60	23.30	50.25	40.00	40.00
Iron (mg.)	—	—	0.68	2.57	0.58	0.49	0.24	0.24
Sodium (mg.)	120.00	180.00	90.50	71.00	83.00	39.50	64.00	63.00
Potassium (mg.)	8.20	15.50	48.80	26.20	33.80	16.80	29.00	31.00
Magnesium (mg.)	4.20	5.00	32.00	12.70	9.80	4.50	2.00	2.00

Analyses of 100 gm. of product. Specific gravity approximately 1.1 gm./ml. Each 8 oz. can contains approximately 236 ml. diet weighing approximately 268 gm.; pH was found to vary from 6.6 to 6.8.

subject usually consumed one 8-fluid-oz. can of vanilla and one 8-fluid-oz. can of chocolate per meal, with a total of four meals per day. Vitamins, trace minerals, and potassium were given as dietary supplements. The test subjects tolerated the liquid diets without loss in body weight or any discernible ill effects, but were glad to return to conventional solid food.

NLABS liquid diets 9 and 10 were also used as the only source of food except for supplementary vitamins and minerals in an 8-week experiment, "Effect of Phosphate Supplementation on Calcium Balance During Enforced Immobilization," conducted in the climatic chambers facility of the U. S. Army Natick Laboratories by a research group from the Army Research Institute of Environmental Medicine (ARIEM) and Boston City Hospital-Harvard Medical School (12). While the subjects

originally selected the diets as being quite acceptable, preference ratings by the subjects continued to fall as the time on the diet increased. Nevertheless, all six volunteers remained on the diet during the entire 8-week period.

It is clear, however, that while the human feeding experiences indicate that the problem of diet monotony may not be as serious as previously believed, the availability of nutrient-defined formula diets in solid-food form with built-in foodlike texture should increase long-term acceptance.

Dehydrated diet

Freeze dehydration of the liquid diets resulted in dry products which could be reconstituted with water or consumed "as is" in the

TABLE XI

Comparisons of NLABS nutrient-defined diets with other liquid diets

Diet	Number of panelists	Preference distribution									Average preference score
		1	2	3	4	5	6	7	8	9	
NLABS vanilla No. 1	37	1	8	6	4	7	7	2	2	0	4.3
Nutrament vanilla		1	3	5	6	7	8	3	2	2	5.0*
NLABS chocolate No. 1	37	1	1	3	4	3	9	6	7	3	6.0*
Nutrament chocolate		5	4	0	6	4	8	9	3	0	4.9
NLABS vanilla No. 2	30	0	1	6	2	3	8	6	3	1	5.5
Nutrament vanilla		8	2	5	1	5	5	6	8	0	4.9
NLABS vanilla No. 2	30	0	0	4	3	1	9	9	4	0	5.9
USAF-SAM		0	3	4	5	2	7	6	3	0	5.2
Pillsbury vanilla		1	2	3	4	4	8	4	4	0	5.3
NLABS chocolate No. 4A	40	1	1	2	2	7	7	9	10	1	6.2*
NLABS chocolate No. 4B		1	1	1	3	5	7	15	7	0	6.2*
NLABS chocolate No. 4C		1	1	1	3	7	7	14	6	0	6.0*
Nutrament chocolate		4	4	4	7	2	9	6	3	1	4.8
NLABS banana	30	1	1	1	3	3	8	6	6	1	6.0*
Sego banana		8	3	4	8	4	1	6	1	0	4.3
NLABS butterscotch		0	1	4	9	4	3	2	6	1	5.3
Metrecal butterscotch		1	3	0	6	2	6	10	1	1	5.5
NLABS chocolate No. 4	30	1	3	1	3	1	6	6	7	2	6.0*
Pillsbury chocolate		0	2	6	9	0	5	3	3	2	5.0
NLABS chocolate No. 4	36	1	2	3	4	8	7	9	7	0	5.7*
NLABS unflavored		8	7	5	9	7	3	2	0	0	3.8
Nutrament chocolate		1	9	4	2	6	6	6	2	0	4.5
UTL cola	30	3	4	7	3	2	7	3	1	0	4.2
UTL pineapple		1	5	5	2	4	4	9	0	0	4.7
UTL orange		1	3	3	8	3	8	1	3	0	4.7
NLABS chocolate No. 4	36	0	3	3	3	2	7	11	6	1	5.9*
Nutrament chocolate		8	3	2	5	5	8	7	3	0	5.0
NLABS vanilla No. 4	36	0	3	1	4	3	4	10	7	4	6.3*
Nutrament vanilla		0	6	1	8	2	5	6	6	2	5.4
NLABS chocolate No. 12	30	2	2	1	8	8	7	4	2	1	5.0
Nutrament chocolate		3	1	3	6	7	4	2	4	0	4.8
NLABS vanilla No. 11	30	0	1	0	1	4	10	8	5	1	6.4*
Nutrament vanilla		1	5	4	0	5	5	6	4	0	5.1

Consumer taste panel tests conducted by Acceptance Laboratory, Psychology Laboratories, Pioneering Research Laboratory, U. S. Army Natick Laboratories.

*Significantly preferred at the 5% probability level.

dry state. In fact, when consumed as dry, bite-size pieces, the freeze-dried diet often appeared to have less aftertaste and to be more palatable than the original liquid diet. In work on rehydration properties, sonic homogenization of liquid diet before freeze-drying, or fine grinding after drying, or both, decreased reconstitution time in water. Because wettability and reconstitution were not completely satisfactory, a considerable effort was directed toward the production of the nutrient-defined formula diet in dry *instantized* form.

Instantized dry diet

A total of 280 lb. of NLABS nutrient-defined formula diet was instantized by the contracting laboratories. The instantized diet was in the form of durable agglomerates which dispersed and reconstituted very rapidly in water with a minimum amount of stirring and agitation. The ratio of diet to water was 30 : 70 (w/w). The laboratories reported the following analysis of the product:

	<i>Percent</i>
Moisture	1.0
Protein	15.8
Fat	21.0
Carbohydrate (calculated)	60.4
Ash	1.8
Total	100.0
Standard plate count	100/gm.
Coliforms	< 10/gm.
Density	0.2 gm./ml.
Calories (calculated)	4.9 kcal./gm.

Exploratory spray-drying and agglomeration results. While no diet product was produced with the desired degrees of dispersibility, stability, and cluster durability, this series of tests provided the background for the large-scale production. The following comments are mainly taken from the reports prepared during the spray-drying and the agglomeration.

The spray-drying test runs showed that the vanilla product was very sensitive to the drying

conditions. A clear-cut difference in the drying behavior was observed between inlet temperatures of 345° and 370° F. In the latter condition, a rapid, heavy buildup of material took place in the duct leaving the drying chamber, and no suitable sample was obtained. At 345° F. there was a tendency of the material to deposit in the approach; however, it was not nearly so severe as observed at the higher temperature. A sample was obtained representing the 345° F. condition and is identified as No. 1 in table IV.

Based on the above performance, the inlet temperature was dropped to 320° F. and the drying performance showed improvement over the 345° F. condition. A sample was obtained and identified as No. 3. There was no evidence of buildup in the duct leaving the dryer, and the material seemed to be more readily discharged from the cyclone collector. In test 4, an attempt at nitrogen injection was tried at the 320° F. inlet temperature; however, the experimental run was very short, and the charts indicate that an equilibrium condition was never obtained. It appeared that a rapid buildup in the approach occurred and that the cyclone collector plugged almost immediately. It is suspected that severe pulsations may have occurred. While a sample was taken and identified as No. 4, it is felt that this did not represent a good test condition.

The chocolate-flavored diet was very thick and showed signs of separation in the cans. When agitated and recirculated in the makeup tank system, however, it did become a smooth, uniform mix. Following the results obtained with the vanilla, the initial test with the chocolate was made under a low inlet temperature of 315° F. In addition, a larger core was used in the spray nozzle. Under these conditions, the chocolate seemed to perform reasonably well, although there seemed to be a rapid buildup of material on the dryer walls. There was no evidence of deposit in either the approach or the cyclone separator.

For the sixth test condition, the inlet temperature was held at 315° F., and nitrogen was injected into the slurry before it reached the

spray nozzle. At the same time, the spray pressure was increased to prevent a reduction in the slurry through-put due to the nitrogen. The outlet temperatures stayed about the same, indicating an equivalent water evaporation rate. The foam-dried product showed a buildup in the approach and a tendency to plug at the cyclone separator. Inspection of the foam spray, however, showed a pattern which would be classified as good and which would normally be associated with satisfactory performance.

Considering all the results, it seems clear that these products have critical drying properties in conventional spray-drying equipment. The type of characteristic observed—the tendency to form deposits in the ducts when leaving the drying chamber or passing through cyclone separating units—has been observed in products having high fat and sugar content. The experience also indicates that, with foam injection, results probably would have been far superior if the inlet temperature had been dropped even lower to compensate for the better drying characteristic obtained with the foam.

The performance of products of this type with such a high glucose and fat content was better than anticipated. Apparently, the material fits into a class of products which can be processed efficiently once the proper operating ranges and technics have been established. It appears that changes in formulation particularly aimed at increasing the degree of encapsulation and reducing the amount of sugar may greatly widen the operating limits.

The first exploratory tests with the agglomeration equipment were limited by the small amount of spray-dried diet available, but the tests indicated that a large scale Instantizer test would be practicable. In test *A*, after a very short time the vanilla diet material accumulated on the upper agglomerating section and formed large balls. Material which did not touch the walls of the agglomerating chamber was not substantially agglomerated. While conditions were changed in test *B*, there was still considerable buildup of material on the upper agglomerating chamber. There was

such a small amount of material left for this test that the material was collected at the bottom of the Instantizer cone; there was not enough to put through the after-dryer. This product was dried in the vacuum oven for 5 minutes. There was no improvement in the agglomeration of the material.

Tests *C* and *D*, with the chocolate-flavored diet, showed slight agglomeration of the feed material. It may be that the improvement resulted from the measures taken to reduce the size of the agglomerating section of the Instantizer. Nevertheless, there was still excessive buildup of material in the short agglomerating section.

Large scale spray-drying and agglomeration results. This series of processing tests resulted in the production of 300 lb. of spray-dried diet which yielded seven experimental batches of agglomerated diet weighing a total of 227 lb. Dispersibility, measured by dropping 1 gm. of material into a 250 ml. beaker containing 100 ml. of water at 70° F., was very much improved by the agglomeration.

The original spray-dried diet would not disperse into the water except after a long period of agitation. After agglomeration, the select product (−16 +120 mesh) material from tests *A*, *B*, *C*, and *F* dispersed in the water in 10 seconds, but needed slight agitation to suspend itself in the water. Agglomerated select material (−16 +120 mesh) from tests *D* and *E* dispersed very rapidly in 5 seconds, when dropped into the water, and required only slight agitation to suspend the material in the water. The agglomerates were quite fragile. During shipping, there was some breakup of the agglomerates and compacting of the diet with a concomitant decrease in dispersibility.

Returning to the spray-drying operation, some of the problems which had to be solved included too high viscosity and emulsion instability. Because of the viscosity, it was impossible to attain the desired level of 50% to 60% solids in the slurry. Even at the 40% solid level, the slurry was rather difficult to handle and spray-dry owing to the high viscosity. While the potassium caseinate had to

remain in the formula, it was possible to reduce the viscosity by substituting dextrin for all of the Clear-Gel starch.

Studies on comparative emulsion stability with a number of commercial emulsifying agents were conducted at the Food Laboratories. Monoglycerides, diglycerides, and glycerol monostearate at the 1% level were found to be detrimental to emulsion stability. Propylene glycol monostearate and lecithin, alone (1.0% each) or in combination (0.5% each), either had no effect or aided 60-hour emulsion stability. There was also some evidence that lecithin would contribute to the wettability and dispersibility of the diet. As a result of these tests, lecithin in the form of Alcolec 456 H was included in the spray-dried component formula. Homogenization of the spray-dried component slurry at 2,500 p.s.i.g. before spray drying also aided emulsion stability.

Attempts at dry mixer agglomeration of the spray-dried component and added carbohydrate components were not successful. Neither the *wet sugar water process* nor the *steam purging process* resulted in substantial agglomeration. It was, therefore, necessary to utilize the experimental pilot plant and the proven skills of a commercial manufacturer of agglomeration equipment.

In running the agglomeration tests at the pilot plant, difficulty was experienced in airveying the diet because of packing in the cyclone of the airveying feed system which feeds material to the upper agglomerating section of the Instantizer. The packing was attributed to the high fat content.

A complete tabulation of the results of the seven test runs on the Instantizer is given in table XII. Test A was run for a period of only 2 minutes to determine what agglomeration would take place under initial operating conditions. The results were used to establish conditions for subsequent test runs. Recovery of material in this test was poor due to the initial buildup of material in the Instantizer. In test B, recovery of material based on the total amount fed was better than in test A,

and most of this recovery fell into the select material range (-16 +120 mesh). Buildup of material in the upper agglomerating section was slightly progressive over the buildup that had occurred in test A. Test C was run under the reported conditions in an effort to obtain a larger, more stable agglomerate. In this test there was a greater recovery of material in proportion to the amount of material fed, and a fairly high percentage of the recovered material fell into the select material category (-16 +120 mesh). The agglomerates in this test still did not appear to have good stability. There was no progressive buildup of material in the upper agglomerating chamber after the conclusion of test C. The agglomerated material produced in test D, which fell in the select material range (-16 +120 mesh), appeared to be more stable and dispersed in water more readily than did material produced in the previous tests. There was some slight buildup of material in the upper agglomerating chamber. The buildup appeared to be progressive from that which had occurred in the previous three tests. In test E, there was a decrease in the percentage of select material recovered (-16 +120 mesh), but this was due to a greater percentage of material recovered in the *overs* (particles which are too large to pass through the sieve). More *finer* were produced in test F. These were recovered in the after-dryer dust collector.

As reported previously, plugging of the airveying system cyclone and cone which fed the upper agglomerating chamber led to the thinking that a vibrator might be more effective for feeding the material into the upper agglomerating chamber. Test G was run with such a vibrator installed. The material, because of its intrinsic characteristics, did not flow from the vibrator as an *even*, powdery material, but formed soft lumps from the vibrator pan. These did not break up when falling between the agglomerating steam jets. The material in test G did not agglomerate as well as did the material from previous tests. When an attempt was made to analyze the G material which passed through the Instantizer, the screens blinded in a manner similar to that experienced with the original spray-dried non-agglomerated feed material. Therefore, no

TABLE XII
Results of Instantizer* test (full-scale)

Material	Test A	Test B	Test C	Test D	Test E	Test F	Test G
General Instantizer performance							
Instantizer dust collector (lb.)	Trace	Trace	Trace	Trace	Trace	Trace	None
Instantizer dust collector (% of feed)	Trace	Trace	Trace	Trace	Trace	Trace	None
Instantizer, produce, moisture (% on belt)	Not obtained	5.0	5.0	6.9	6.5	6.0	7.0
After-dryer dust collector							
Pounds	Trace	Trace	Trace	1.0	1.0	14.0	4.0
Percent of feed	Trace	Trace	Trace	1.7	4.0	14.6	19.1
Discharge of select material							
Product -16 +120 mesh screen (lb.)	6.0	21.0	25.0	44.0	16.0	64.0	14.0
Product -16 +120 mesh screen (% of feed)	50.0	78.5	89.2	75.8	64.0	66.6	66.7
Product -16 +120 mesh screen (moist. %)	2.0	2.3	2.3	2.1	2.1	1.5	1.5
Product -16 +120 mesh screen (lb./cu. ft.)	19.4	12.4	17.8	15.3	16.5	17.1	—
Amount of material recovered (lb.)	6.5	21.25	25.75	51.0	21.0	81.0	20.0
Percent of feed	54.2	79.0	91.6	88.0	84.0	84.4	95.0
Fines (%)	0.3	Trace	Trace	Trace	Trace	1.4	Trace
Overs (%)	1.2	0.9	2.7	10.1	16.0	2.1	9.5
Losses: Hang-up in Instantizer (lb.)	5.0	4.0	2.0	4.0	2.0	4.0	—
Losses: Percent of feed	41.7	14.8	7.1	6.9	8.0	6.3	—
Screen analysis of select product							
U.S. Standard sieve							
+20 (%)	.5	.7	1.1	4.7	3.1	1.0	—
+40 (%)	32.4	33.3	35.2	38.0	31.8	15.5	—
+50 (%)	21.2	22.3	19.2	24.5	29.2	28.0	—
+70 (%)	23.3	22.6	25.3	19.5	23.0	46.0	—
+100 (%)	16.3	16.3	16.0	10.0	11.5	8.0	—
+140 (%)	5.3	3.8	2.1	2.2	1.4	1.5	—
-140 (%)	1.0	1.0	1.1	1.1	—	—	—

*Blaw-Knox FA-1 Instantizer and 2-deck after-dryer.

accurate, particle-size distribution could be determined.

In all of these tests the microstructure of the agglomerates under the stereoptic microscope appeared as fragile, polygonal particles. Buildup of material on the upper agglomerating

chamber walls in these tests was about normal for an Instantizer operation. The greatest problem in running this material was the fact that it would pack in the airveying feed system cyclone. It was felt that a steeper feed cone than the one now on the laboratory pilot plant unit may eliminate this problem.

Instantized diet acceptance. A sensory panel of 48 consumer-judges evaluated the nutrient-defined and other vanilla-flavored formula diets at NLABS. All dry diets were reconstituted with water and brought to room temperature before serving. The mean preference scores were as follows:

Sample and codes	Mean preference score
NLABS (Blaw-Knox), D and 4	5.2
NLABS (Blaw-Knox), F and 6	4.9
Nutrament, C and 3	4.8
NLABS (Blaw-Knox), E and 5	4.8
NLABS (Carnation), B and 2	3.8
University of California, A and 1	2.3

The first two samples were significantly preferred to A (Univ. of Calif.) and B (NLABS-Carnation). The 3d, 4th, and 5th samples were significantly preferred to A (Univ. of Calif.).

The analysis of variance indicated that there was a significant difference among the 6 samples. The mean preference ratings received by the University of California sample A (3) was significantly lower than the rating for any other diet tested. The mean preference rating of NLABS spray-dried and agglomerated sample D was significantly higher than the rating received by the NLABS (Carnation), diet B.

Compressed tablets and bite-size pieces

Initial acceptance of compressed tablets or bite-size pieces made from various dry formulations of the nutrient-defined diet has been good. For example, the reaction to the taste and initial mouth feel of bite-size pieces from the Carnation-produced instantized diet was quite favorable. All of these products, however, appeared to have the undesirable characteristic of sticking to or coating the teeth.

Vanilla, chocolate, and fruit-type flavors appear to be most acceptable. Meat and vegetable-type flavors have been tried, but the sweetness level in the formulation was probably too high for a suitable flavor combination.

As an illustration of the above, flavored tablets prepared from ground, freeze-dried diet received preference ratings as follows:

Tablet flavor	Average preference score
Lemon-lime	5.9
Grape	5.5
Rye bread and butter	4.6
Butter and cheese	4.4

Baked diet

The nutrient-defined baked cookies had a composition of approximately 12% protein, 29% fat, and 58% carbohydrate on a dry basis. Technical taste-panel and consumer panel studies showed that chocolate, vanilla, and coconut were the most acceptable flavors tested. Freshly baked cookies with the above flavors scored 6.0 to 6.4. Consumer taste-panel evaluations made before and after accelerated storage studies are given in table XIII.

Candy diet

Chewable bite-size formula candy has been included as a menu item in a simulator study at the School of Aerospace Medicine. Some of the earlier candy formulations scored 7 (like moderately) in technical panel ratings. When prepared to meet space-flight qualifications for high-temperature and vacuum-packaging stability, however, consumer panel scores were 5.7. As with the other nutrient-defined diet items, chocolate and vanilla were the preferred flavors. Typical analytic values for the candy,

TABLE XIII
Preference ratings of nutrient-defined baked formula cookies

Flavor	Number of panelists	Average preference score	
		Initial	After 3 months at 100° F.
Vanilla	36	6.4	5.1
Chocolate	36	6.2	4.8
Coconut	36	6.0	4.7

Consumer taste panel tests conducted by Acceptance Laboratory, Psychology Division, Pioneering Research Laboratory, U. S. Army Natick Laboratories. Scores based on a 9-point hedonic scale.

TABLE XIV
Evaluation of potential space diets by animal feeding

Diet (10 rats per group)	Body weight gain (gm.) (average of 30 days)	Food intake, dry basis (av. gm./day)	Water intake (av. ml./day)		Efficiency of utilization*		Fecal output, dry basis (av. gm./day)		
			In drink	In food	Food	Protein		Calories	
Commercial rat feed, dry	154	464	854	58	912	33	1.70	9.3	100
Protein (15%), †	137	347	688	124	812	39	3.38	8.1	10
Protein (10%), dry †	52	260	477	118	595	20	2.50	4.1	9
NLABS No. 1, liquid †	118	368	203	841	1,044	32	2.98	6.0	9
Commercial A, liquid	76	301	330	657	987	25	2.21	4.8	16
Commercial B, liquid	146	381	227	1,132	1,359	38	2.38	9.1	13
Synthetic amino acid, liquid †	54	236	392	228	620	23	3.36	5.9	3

*Food efficiency = body wt. gain (gm.) per 100 gm. dry diet consumed.

Protein efficiency = body wt. gain (gm.) per protein (gm.) consumed.

Caloric efficiency = body wt. gain (gm.) per 100 kcal. consumed.

†Nutrient defined diets. See table IX.

‡Chemically defined. See table IX.

Values adjusted to the standard efficiency of 2.50 for the 10% protein group.

in percent, are: moisture, 9.4; protein, 12.2; fat, 22.5; carbohydrate, 54.9; and ash, 1.0. The product contains approximately 4.7 kcal. per gram.

Animal feeding evaluation of liquid formula diets

An animal feeding test demonstrated that an early NLABS liquid diet was adequate but could be improved. As shown in table XIV, the various dry and liquid formula diets produced marked differences in body weight gain and efficiency of diet utilization in young growing rats. Among the dry diets, the commercial rat feed resulted in the highest animal weight gain, but protein efficiency was low. It is only fair to mention that high protein efficiency could not be expected because this product contained the highest level of protein (23%) from both animal and plant sources. Animals fed the 15% protein nutrient-defined dry diet were superior in overall performance. Along with NLABS nutrient-defined formula diet 1, commercial liquid diet B also produced results indicative of satisfactory nutritive value.

With respect to total water intake from both drinking and diet sources, animals on the liquid diets had a greater total water intake than did rats on the dry diets. Furthermore, among the dry diets, water consumption was greater with the commercial rat feed of 23% protein natural ingredients than with the 15% or 10% protein diets containing purified ingredients. More water was also consumed by rats fed the 15% protein dry diet than by rats which received the 10% protein dry diet. These results indicate a need for careful control of protein intake where water supplies are critically limited. As may be expected, fecal output was much less on the low-residue nutrient-defined and commercial formula diets than on the commercial rat feed containing a high fiber content from certain natural ingredients. Fecal output was least, however, on the chemically defined synthetic amino-acid diet.

The animal feeding results can be presented and interpreted in many different ways. One important conclusion is that a considerable amount of valuable information can be gained by biologic testing of potential space diets.

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APPENDIX 1

Work statement of Military Interdepartmental Purchase Request (MIPR) AM6-40061 dietary specifications: "Specialized Foods for Nutritional Studies and Synthesis and Biological Evaluation of Energy-Dense Compounds."

A. General requirements

The U. S. Army Natick Laboratories shall continue research accomplished under MIPR AM5-40037. Formulate and prepare a nutrient-defined diet with several flavors and in various forms and which is highly acceptable for human consumption. Expand research on energy-dense compounds which can be considered for use as nutritional supplements during long-term aerospace missions.

B. Specific requirements

1. The U. S. Army Natick Laboratories shall provide the nutrient-defined diet in various forms, utilizing various flavors, to include but not limited to the following items: freeze-dehydrated, compressed bite-sized, chewable candy, and baked.

a. The various foods must be designed to withstand a minimum of 6-months storage in suitable containers and remain highly acceptable when consumed under the following conditions:

- (1) Temperature range from 2° to 38° C.
- (2) Relative humidity from 30% to 95%.
- (3) Altitude that will approximate a pressure equivalent to 7.5 km (25,000 ft.).
- (4) An atmosphere that will contain as high as 99% oxygen and not more than 0.5% carbon dioxide.

b. The acceptability of the prototype foods shall be measured in terms of a rating of 6.0 or above on a 9-point hedonic scale of like-dislike when served to taste panel personnel at the U. S. Army Natick Laboratories. The nutritive value of these foods should be as high as is practical, yet consistent with acceptability and other limiting characteristics. The foods shall be non-thirst-provoking, easily digested, non-gas-forming and must be acceptable without heating or cooling. The use of various flavors, forms and appearance will be utilized to the maximum extent possible to increase the acceptability.

c. This diet shall meet the National Research Council's recommendations for daily nutrient intake for the standard man. The total energy of the diet shall be 2,800 kcal. of which 10% of the total calories are derived from protein, 30% from fat, and 60% from carbohydrate. The diet shall contain as low residue as possible. Consideration shall be given to completely sterilizing the diet so that no viable microorganisms, aerobic and anaerobic forms, can be isolated utilizing standard techniques. Each diet shall be analyzed for nitrogen, fat, total energy, fiber, and calcium. Osmolarity of the diet in powder form shall be determined after rehydration. Trace minerals and vitamins need not be incorporated into the diet.

2. The forms of these nutrient-defined foods, with important characteristics, to be considered for this research are as follows:

a. Powder

- (1) Precooked—freeze dehydrated.
- (2) Reconstitution to an acceptable liquid form with 21° C. water within 10 minutes.
- (3) Flavored to simulate as many staple and dessert foods as possible.

b. **Compressed bite-sized pieces**

- (1) **Size 1—1.5 cm. cubes.**
- (2) **Texture and chewing qualities to enhance acceptability.**
- (3) **Edible coating, if necessary, in a ratio of 90% food and 10% coating.**
- (4) **Flavored to simulate as many staple, dessert, and candy foods as practical.**

c. **Compressed taffy pieces**

- (1) **Size 1—1.5 cm. pieces in longest dimension.**
- (2) **Shape of stick, roll, or cube.**
- (3) **Edible coated if necessary.**
- (4) **Flavored as desserts or candy.**

d. **Baked products**

- (1) **Cookies, cake, bread, and others as desired.**
- (2) **Size 1.0—1.5 cm. cube.**
- (3) **Flavored in conformance with food item.**

APPENDIX 2

Product	Manufacturer
Atmul 142	Atlas Chemical Industries, Inc., New Murphy Rd., Wilmington, Del.
Banana flavor, N-594	Dragoco, Inc., King Road, Totowa, N. J.
Butterscotch 7B	Polack's Frutal Works, Inc., Middletown, N. Y.
Ca Sal	Crest Foods Company, Ashton, Ill.
Caramel 8145	Dodge & Olcott, Inc., 79 Ninth Ave., New York, N. Y.
Cocoa powder	Walter Baker Chocolate Co., Div. of General Foods, Devon, Pa.
Coconut F21-1028	Verona Aromatics, Newark, N. J.
Chocolate powder	Borden Company, 350 Madison Ave., New York, N. Y.
Cream soda flavor, N-840	Dragoco, Inc., King Road, Totowa, N. J.
Dextrin, 7078	Corn Products Co., 717 Fifth Avenue, New York, N. Y.
Drew Mulse 901	Drew Chemical Corp., 522 Fifth Avenue, New York, N. Y.
Lecithin (Alcolec 456-H)	American Lecithin Co., Inc., 1948 Chatham, Phoenix Bldg., Long Island City, N. Y.
Malt	Bowey's Inc., 679 N. Orleans, Chicago, Ill.
Mello-Mix	National Dairy Products Corp., 260 Madison Ave., New York, N. Y.
Mertaste (flavor enhancer)	Merck & Co., Inc., 1935 Lincoln Ave., Rahway, N. J.
MCT (medium-chain triglyc- erides) special prepara- tion	Drew Chemical Corp., 522 Fifth Ave., New York, N. Y.; Mead Johnson Research Center, Evansville, Ind.
Peppermint oil	Crescent Mfg. Co., 657 S. Dearborn, Seattle, Wash.
Starch (Clearjel)	National Starch & Chemical Corp., New York, N. Y.
Vanilla flavor, V-12-267	International Flavors and Fragrances, Inc., 521 W. 57th St., New York, N. Y.

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13. ABSTRACT

Nutrient-defined formula diets have been developed for possible use in aerospace metabolic experiments or on experimental or operational missions. The diets include an aseptically canned liquid, a freeze-dehydrated diet, an instantized dry diet, compressed tablets and bite-size pieces, a chewable candy, and a baked cookie product. Whenever possible, only the most purified ingredients of known nutrient composition were used in the diet formulations. Taste-panel evaluations, chemical analyses, and human and animal feeding tests showed that many of the diet formulations were of acceptable organoleptic and nutritional quality. Further work is needed, however, on these and other forms of nutrient-defined formula foods which can meet the exacting nutritional and other specifications established by the Air Force and NASA for aerospace feeding systems.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Nutrition and metabolism Space food Formula diets Liquid foods Freeze-dried foods Dehydrated foods Compressed foods Nutrient-defined diets						