14. NUTRITION

Prepared by

E. M. Roth, M. D., Lovelace Foundation

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For missions of duration no longer than 30 days, it has been recommended that dietary needs of man in space are essentially those of men of similar physical stature on earth (25,92). Extension of this approach to longer missions cannot be made with any degree of assurance. A more thorough understanding of physiological and environmental problems related to nutrition is required before recommendations can be made for dietary packaging and storage design in missions of long duration.

Basic Nutritional Requirements

The data of Figure 14-1 represents the allowances for normal maintenance and performance as well as prevention of disease which the Food and Nutrition Board of the National Academy of Science-National Research Council has recommended. These allowances,which are at present under review by the NAS -NRC, all exceed the minimul maintenance requirement with the possible exception of energy.

Table 14-1

Recommended Daily Dietary Allowance for Average U.S. Male Performing Moderate Physical Activities in a Temperate Environment

(After NAS-NRC (67))

Age (years)	Weight (kg)	Height (cm)	Calories (kcal)	Water	Protein (gm)	Fat (gm)	Carb (gm)	Calcium (gm)	Iron (mg)	Vit A (I. U.)	Thiam (mg)	Ribo (mg)	Niacin (mg equiv)	Ascorbic Acid (mg)
25	70	175	2900	1 ml/kcal expended	70	97	437	0.8	10	5000	1.2	1.7	19	70
35-55	70	175	2600	1 ml/kcal expended	70	85	389	0.8	10	5000	1.0	1.6	17	70

In addition to these allowances, it has been suggested that the energy requirements of the Apollo mission and anticipated stresses of space flight can be met with the following alterations to the NAS-NRC recommendations (11):

a) Energy. 2800 kcal/man/day.

b) Protein. NAS-NRC recommended allowance of 1 g/kg of body weight/day. For the present population of astronauts, the diet should therefore contain 10.5 to 13.0 gm nitrogen/man/day.

c) Fat. Maximized to conserve weight and space but limited to 150 g/man/day and 50 percent of total calories to avoid physiological consequences such as ketosis and nausea.

d) Carbohydrate. Content of poorly digested carbohydrates minimized to decrease intestinal fermentation and fecal residues; crude fiber content limited to 1 percent of total dry solids.

e) Water. The water requirements for space operations exceed in many situations, the 1 mg/kcal recommended as a standard allowance for temperate climates. (See Water, No. 15.)

f) Minerals. (bulk). The NAS-NRC recommended allowances are adequate: (in g/man/day) calcium, 0.8; phosphorus, 1.2; magnesium, 0.35; sodium, 4.0; potassium, 3.0; iron, 0.10. It has been recommended that water consumption of >4 liters/day would require 1 gram additional NaCl for each liter of water (23). Potassium should be limited to about 1 gram/1000 cal/day.

g) Vitamins. To be given as a separate tablet or capsule. The following supplement, per man/day: thiamine, 2 mg; riboflavin, 3 mg; niacin, 20 mg; pyridoxine, 5 mg; pantothenic acid, 10 mg; folic acid, 0.5 mg; vitamin B_{12}, 2 μg; biotin, 0.5 mg; choline, 1 g; vitamin A, 4000 U.S.P. Units; vitamin D_2, 400 U.S.P. Units; vitamin K_1, 1 mg; ascorbic acid, 70 mg; and alpha tocophero, (?) 1 gm/day. (See below.)

The protein level may be higher and the B_{12} lower than new NAS-NRC allowances may specify (8). It should be recognized that addition of these vitamin supplements are quite in excess of the recommended NAS-NRC allowances (23). They undoubtedly will not produce toxic or undesirable effects, but may really serve no useful purpose (48). They have been recommended to cover any unanticipated environmental or operational condition which may affect the storage or metabolic utilization of vitamins in the basic diet. Starvation is another consideration which must be anticipated. (See below.)

The need for an important vitamin supplement to this diet has been prompted by the finding of hemolysis in the crews of the Gemini program associated with exposures to atmospheres of 5 psia - 100% oxygen and simultaneous deficiency of tocopherol in the plasma (3, 27). Similar tocopherol deficiencies in the diet and plasma of test subjects fed "Gemini diets" for 6 weeks have also been reported (8). (See discussion of Table 10-41.) The similarity of the hematological findings to those of vitamin E responsive anemias (20) and the autohemolysis (red cell destruction) of acanthocytosis (a hereditary disease of red cells with spiked surfaces) (47) suggests that supplementation of the diet with high levels of tocopherol and other antioxidants may offer prophylaxis against the blood disorder. Daily intakes of 1 gm of tocopherol /day for 2 weeks have increased plasma and adipose tocopherol levels several fold without toxic side effects (59). Studies are required to determine if such supplementation is actually effective in altering the blood disorder or restoring plasma tocopherol to normal levels in actual or simulated flights. Further supplementation of ascorbic acid and other antioxidants should be considered.

Factors affecting energy utilization and requirements for protein, carbohydrates, vitamins and minerals in flights of longer duration have been discussed, but more definitive experimentation is required before formal recommendations can be made (13, 23, 33, 98).

h) Trace minerals. The use of a variety of foods in the diet will assure the presence of at least some trace minerals. It is unlikely that an influence of marginal supply of these would be manifest in several weeks, but it would be desirable to ascertain mineral and water content so that intake level may be known for future reference.

In case of mission contingencies with high potential for stressful environmental and exercise variables, consideration of optimum diets and survival rations is in order (13, 14, 16, 19, 52, 79, 89, 90, 97, 100, 103). These nutritional factors may play a role in prolonging life until rescue is possible. New high-energy, non-fat nutrient sources are being studied for survival rations and diets where logistic problems are present (64). The relationship between the composition of food and obligatory minimum water requirements is discussed in the section on Water, (No. 15).

The use of algae and bacteria as food in regenerative life support systems has been recently reviewed (68, 69).

Metabolic, Logistical, and Operational Trade-Offs

The manipulation of dietary components to solve logistic and other operational requirements is based on an understanding of the weight, volume, energy, gas, and other tradeoffs (78, 96, 102). The following data present a basis for these tradeoffs.

Metabolic Factors

Metabolic processing of various food mixtures can be described quantitatively in a series of equations for which the numerical constants have been empirically derived. Two basic assumptions are: (a) all of the food used is carbohydrate, fat, or protein, each of which is characterized accurately enough by a single set of average properties; (b) all foods are reduced to standard end-products, namely, carbon dioxide, water, and urinary nitrogen. From the equations of Table 14-2, one may predict for any given mixture of carbohydrate (C), fat (F), and protein (P); the heat energy (H) produced in the body, the oxygen (O_2) consumed, and the carbon dioxide (CO_2), water (W) and the urinary nitrogen (N) excreted.

In using these equations as well as the graphs and nomograms which follow, it should be realized that the greater the deviation from the normal dieting preparations, the more insecure these data become. Not enough is really known about the subtle interactions which may arise with use of some of the abnormal ratios presented in these figures. Nutritional experts should be consulted for permissible limits of composition when use of any abnormal mixture is anticipated.

Figure 14-3 shows the effect of changing the constituent proportions of a 2800 Calorie (kcal) diet on the weight of the food (without packaging), the oxygen required for metabolism, and the resulting CO_2 and water.

Table 14-2

Metabolic Factors Related to Composition of Food

(Adapted from McHattie[58])

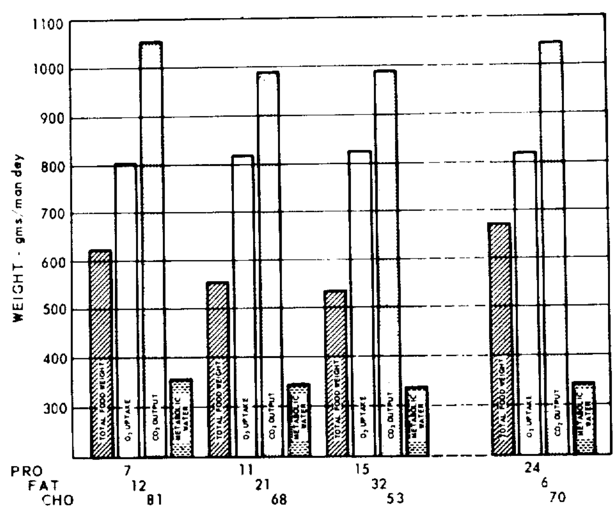
$H = 4.182C + 9.461F + 4.316P$	in kcal/unit time
$O_2 = 0.829C + 2.019F + 0.967P$	in liters/unit time
$CO_2 = 0.829C + 1.427F + 0.775P$	in liters/unit time
$W = 0.555C + 1.071F + 0.413P$	in grams/unit time
$N = 0.1628P$	in grams/unit time

where

C is carbohydrate metabolized in grams/unit time

F is fat metabolized in grams/unit time

P is protein metabolized in grams/unit time



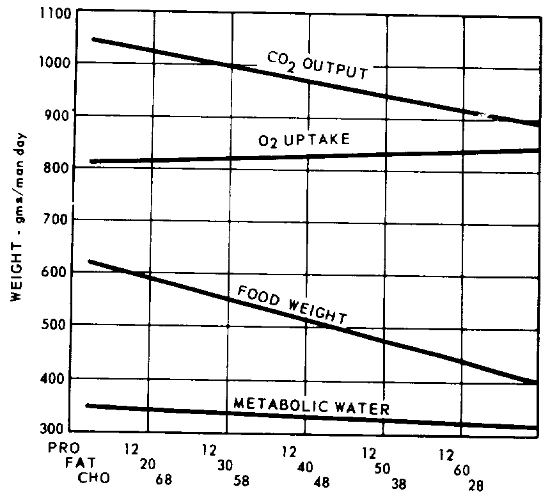
Proportions of {Protein, Fat, Carbohydrate} in a 2800 kcal Diet (% of total kilocalories)

Figure 14-3

Metabolic Effects of Altering the Components of a 2800 kcal Diet

(Adapted from Wu and Yakut[102] by Finkelstein[25])

Figure 14-4 shows the changes in food weight, oxygen consumption, CO_2 production, and metabolic water which result from changing the composition of a fixed protein diet. When the protein intake is 12%, the effect of changing the proportions of carbohydrate and fat is that more oxygen is needed to metabolize a high fat diet and less CO_2 is produced. The weights of the food and of the metabolic water decrease as the proportion of fat increases. (See also Oxygen-Carbon Dioxide-Energy, No. 10).



Proportions of Protein, Fat, Carbohydrate in a 2800 kcal Diet (% of total kilocalories)

Figure 14-4

Metabolic Effects of Altering the Components of a 2800 kcal Diet with Fixed 12% Protein

(Adapted from Wu and Yakut[102] by Finkelstein[25])

Figure 14-5a shows the effect of the carbohydrate: fat weight ratio (w_c/w_f) on the gross weight of food intake per man-day for a diet of 3000 kcal/man-day (12 KBTU/man-day) with different ratios of protein to fat weight (w_p/w_f). The interior chart gives correction factors for diets other than 12 KBTU/man-day which are multiplied by the ordinate to give appropriate gross food weights. The data are in more useful engineering terms than those of Figures 14-3 and 14-4. The figure assumes that the heat of combustion of carbohydrate is 7.10 KBTU/lb protein-7.15 KBTU/lb and fat - 16.25 KBTU/lb and that the energy balance equation is:

$$7.1\,w_c + 7.15\,w_p + 16.25\,w_f = 12\ \text{KBTU/man-day} \qquad (1)$$

Figure 14-5b represents data similar to those of Figure 14-4 for a diet of 3000 kcal/man-day or 12 KBTU/man-day. It permits a rapid evaluation of the total mass of food plus respiratory gases supplied to an astronaut per day. Permitted to cover a wide range of possible diets, it is shown as a series of curves including a line of constant food weight. Only a single constant food line at 1.28 lbs/man-day is plotted. In addition, the respiratory quotient is also presented, which is defined as the number of pound-moles of CO_2 formed per pound-mole of oxygen burned. To equal unity implies that no hydrogen is available within the food for physiological combustion. It is observed that an unacceptable all-fat diet presents the minimum weight-of-food penalty to the space vehicle. The correction factor in the interior of Figure 14-5a may again be used to determine weight penalties for other metabolic rates in Figure 14-5b.

Figure 14-5

Weight of Diet Made Up of Ordinary Food Items That Must Be Eaten with Different Proportions of Carbohydrate, Fat, and Protein to Provide 3000 Calories/Day

(After Rutz[78])

a.

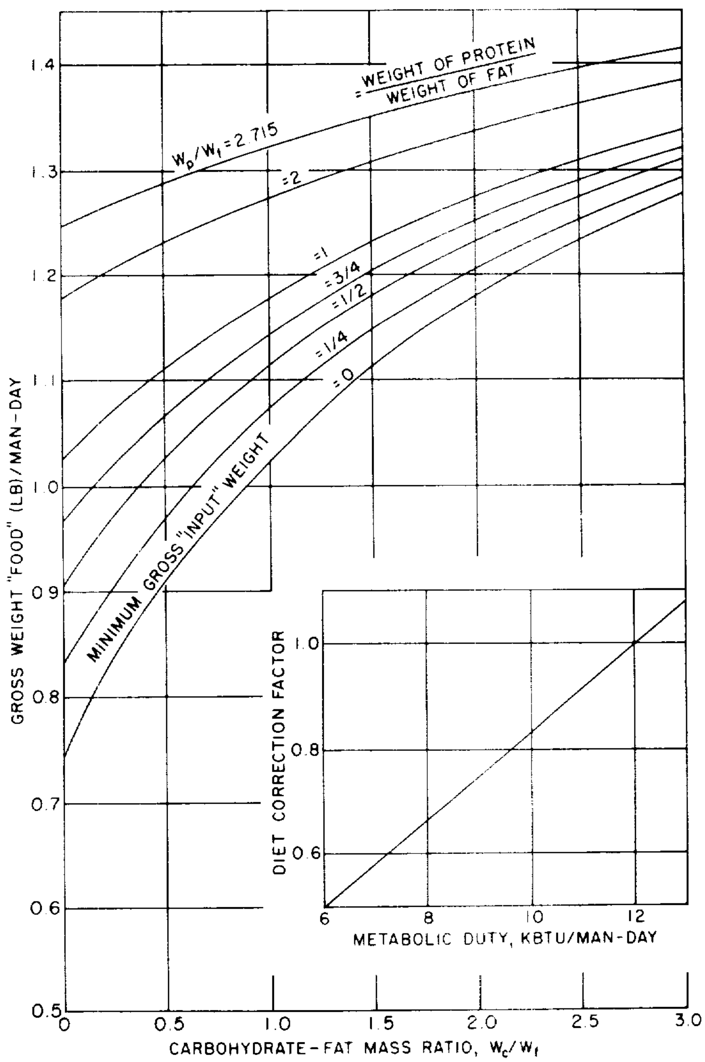
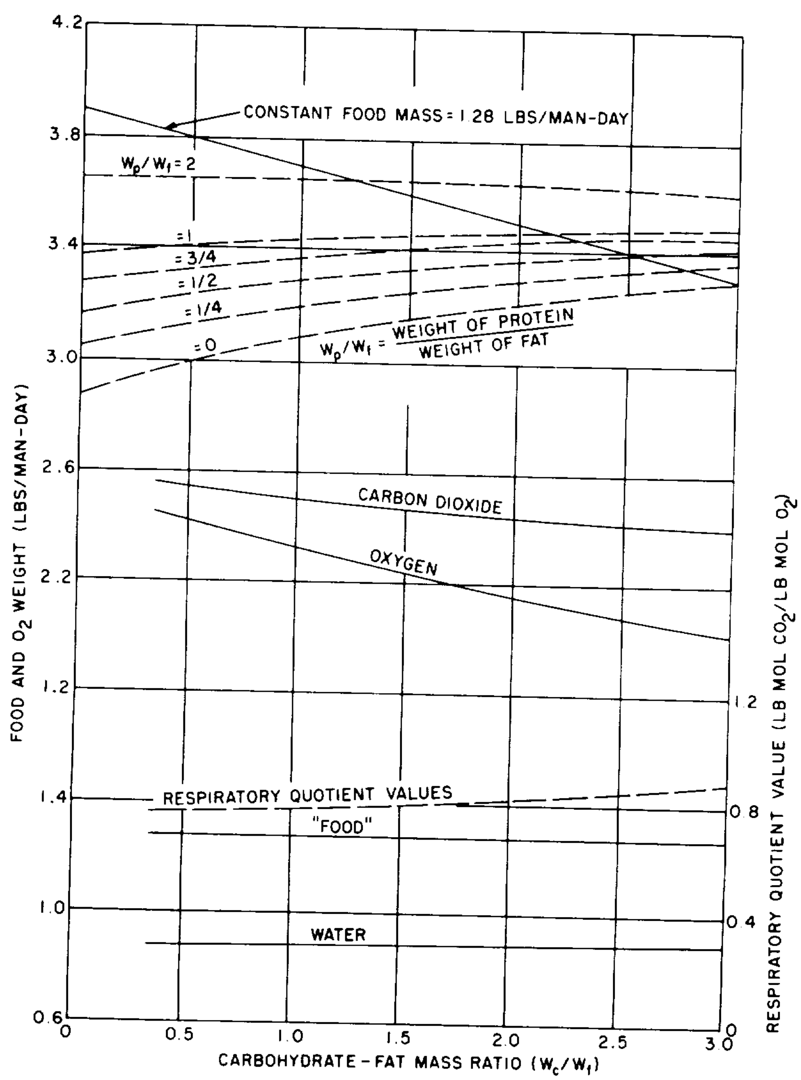


Figure 14-5 (continued)

b.



A detailed review of metabolic interchanges in synthetic diet construction is available (18). Figures 14-6a to i are nomograms which permit rapid evaluation of these basic interchanges. The utility of the individual nomogram is clarified by the use of detailed descriptions of the manipulations required to solve typical problems. These explanations are an integral part of each figure.

Figure 14-6a:	Dietary protein requirements based on body weight in pounds or kilograms.
Figure 14-6b:	Percent calorie distributions of carbohydrate, fat, and proteins at total caloric intakes of 3200-2000 Kcalories per day.
Figure 14-6c:	Gram or pound quantities of all possible ratios of carbohydrate, fat, and protein to supply a daily caloric intake from 3200 to 2000 Kcalories.
Figure 14-6d:	Complete dry diet weight (pounds) for all possible weight ratios (grams or pounds) of carbohydrate, fat, and protein in caloric range of 3200 to 2000 Kcalories/day.
Figure 14-6e:	Oxygen consumption (pounds or liters) for all possible weight ratios as qualified under Figure d.
Figure 14-6f:	Carbon dioxide production (pounds or liters) for all possible weight ratios as qualified under Figure d.
Figure 14-6g:	Metabolic water production (pounds) for all possible weight ratios as qualified under Figure d.
Figure 14-6h:	Complete dry diet (in.^{3}/man/day) for all possible weight ratios as qualified under Figure d.
Figure 14-6i:	Nomogram for estimating the density - volume factor required for calculating the bulk weight of the diet in lbs/ft.^{3} for all possible weight ratios as qualified under Figure d.

Secondary Physiological Factors

The space environment imposes several constraints for the preparation, storage, and packaging of food other than just weight and power. The behavioral aspects of food and eating must be considered (5). The number and size of meals must allow for programming of eating with task performance and provide small enough portions to prevent a large bolus of food in the stomach. The nibbling pattern frequently encountered among humans in chronic anxiety-producing situations should be satisfied. Monotony, should, however, be avoided (80, 83)

Careful attention should be given to the selection of specific foods in carbohydrate forms which minimize excessive intestinal fermentation with the resultant production of large volumes of gas (9, 38, 50, 66). Foods with irritant properties must be excluded as must those with high fiber content to keep fecal mass to a minimum in those missions where fecal storage or removal is a problem. The alteration by space diet of fecal mass and bacterial floralshould be considered (11, 24, 28, 29, 30, 43, 44, 45, 46, 56, 57, 74, 75, 81, 84, 85). This factor must be integrated with the waste management system (84, 85).

Palatability, appetite, and organoleptic qualities must be optimized (55, 62). The organoleptic properties of space diets have been measured by several hedonic scales (11, 35, 73, 80, 82, 83, 86, 88, 99). (See Tables 14-9 and 14-10 as examples.) Transfer of these values to the preferences of highly selected and highly motivated crews in the actual space environment requires further study. Formula diets of various types are also under study (11, 21, 36, 44, 61, 81, 85).

Microbiological production standards and stability of foods under the environmental background of the mission must be assured. Practical methods for evaluating production and stability standards are available (11, 22, 34, 37, 51, 70, 71, 93, 94, 95). Table 14-7c covers some of the microbial contamination limits. Data are available on the microbiology of selected dehydrated foods (100). Mechanisms of the oxidative deterioration of space foods are now under study (2, 42). Destruction of tocopherol by oxidation is a major problem. (See above.) (8, 27)

Figure 14-6

Metabolic Interchanges in Food Logistics

(After Cox[18])

a.

A straight line drawn from a point on Scale A or B through the center of target will intersect Scale C to give a daily protein intake equivalent to one gram of protein per kilogram of body weight. This value times the desired protein level per kilogram of body weight gives the daily dietary protein requirement.

EXAMPLE OF USE

Problem – Subject weighs 184 pounds and you wish the diet to supply 1.40 grams of dry protein per kilogram of body weight. How many grams of protein should the diet supply per day?

Solution – A straight line drawn from the point 184 on Scale A through the target intersects Scale C at a protein value of 83.9 grams. 83.9 × 1.4 - 117.5 grams.

Answer – 117.5 grams of protein per day.

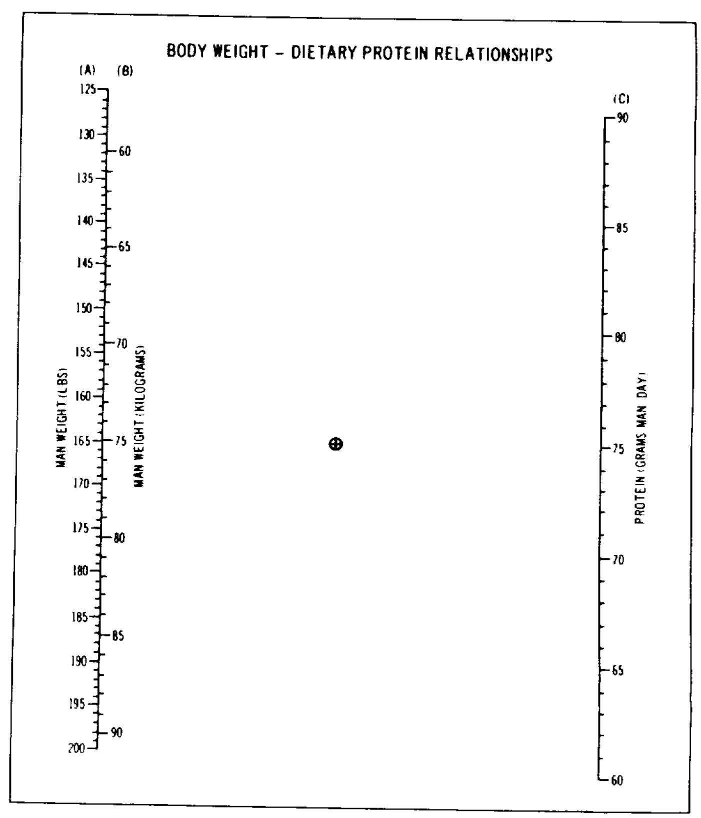


Figure 14-6 (continued)

b.

This figure was designed for the purpose of estimating the weight ratios of carbohydrate, fat, and/or protein required when the stipulation is made that a certain diet must supply a definite percentage of the total calories in the form of a certain digestible dietary constitutent.

EXPLANATION

A straight line drawn from a point on Scale C through the total calorie value of the diet on Scale C' will intersect Scale D to give the percent protein calories in the diet. If certain percentage of protein calories is desired in the diet, this is estimated by drawing a straight line from the desired point on Scale D through the total calorie point on Scale C'. The intersect on Scale C will give the daily requirements in grams of protein per man day. Similar relationships exist between Scales B, B' and C for fat calories and between Scales A, A' and D for carbohydrate calories.

Example 1 – A 2800 Kcal per day diet must supply 15% of the total calories in the form of protein calories. What is the daily protein requirement in grams/man day?

Solution – A straight line drawn from the 15 point on Scale D through the 2800 point on Scale C' intersects Scale C at the 104 point.

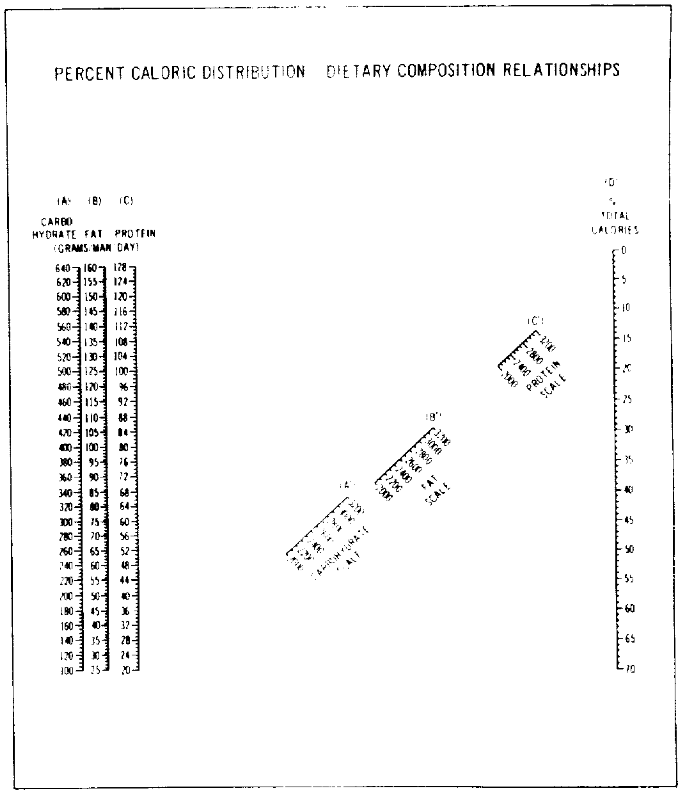
Answer – Approximately 104 grams protein/man day required.

Example 2 – A 2500 Kcal per day diet must not contain over 40% of total calories as fat calories. What is the maximum level of fat that can be included in this diet?

Solution – A straight line drawn from the 40 point on Scale D through the 2500 point on Scale B' will intersect Scale B at the 110 point.

Answer – Approximately 110 g. fat per day is maximum level.

check – $\frac{110 \times 9}{2500} = \frac{990}{2500} = 38.8\%$



c.

Problem 1 – What ratios of carbohydrate, protein, and fat will supply 2800 Kcal/day?

Solutions – Any straight line drawn through the 2800 point on Scale D will intersect Scales A B, E F and G H to give, respectively, the required grams or pounds of carbohydrate, protein and fat to supply 2800 Kcal.

This relationship holds for any total K-calories/day level from 2000 to 3200.

Problem 2 – What is the total K-calorie value of any desired ratio of carbohydrate, fat, and protein? For example 350g carbohydrate, 140g. fat and 90g protein.

Solution – Draw a straight line from the 350g point on Scale A through the 140g. point on Scale H. This line will intersect Scale C at the point 2650. A straight line drawn from this 2650 point on Scale C through the 90g point on Scale E will intersect Scale D to give the desired total Kcal value.

Answer – 3010

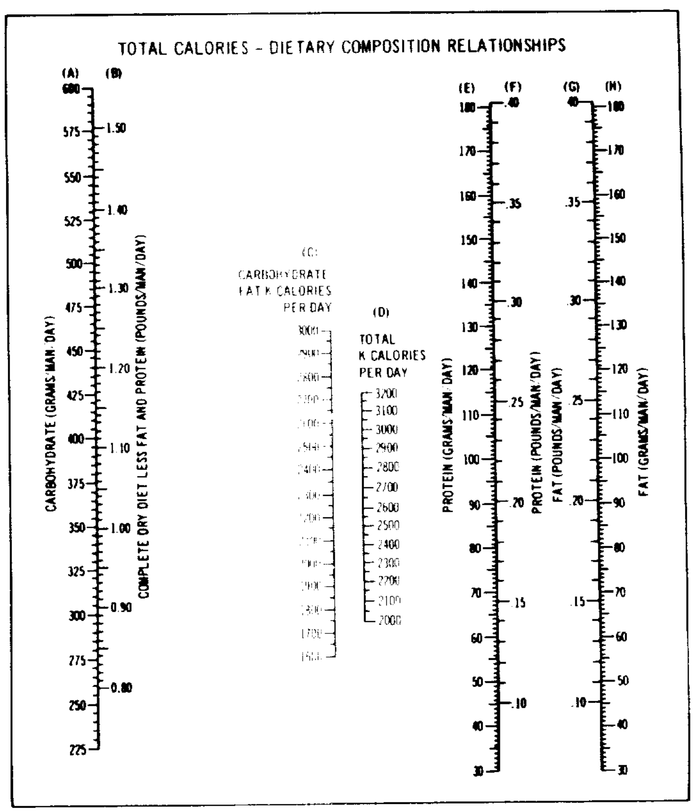
Problem 3 – A diet is designed to supply 100g of protein and 2600 Kcal per day. What ratios of carbohydrate and fat can be utilized to meet the caloric requirement?

Solution – Draw a straight line from the 100g point on Scale E through the 2600 point on Scale D to intersect Scale C at point 2190. Any straight line drawn from this intersect on Scale C to intersect Scales A and G will give ratios of carbohydrate and fat, respectively, that will meet the total caloric requirements.

Problem 4 – A diet is designed to supply 1900 carbohydrate - fat Kcal. per day and a total Kcal/day level of 2600. What is the required protein level?

Solution – A straight line drawn from the 1900 point on Scale C through the 2600 point on Scale D will intersect Scale E to give the desired protein value.

Answer – 168g. protein



(Figure 14-6 (continued)

d.

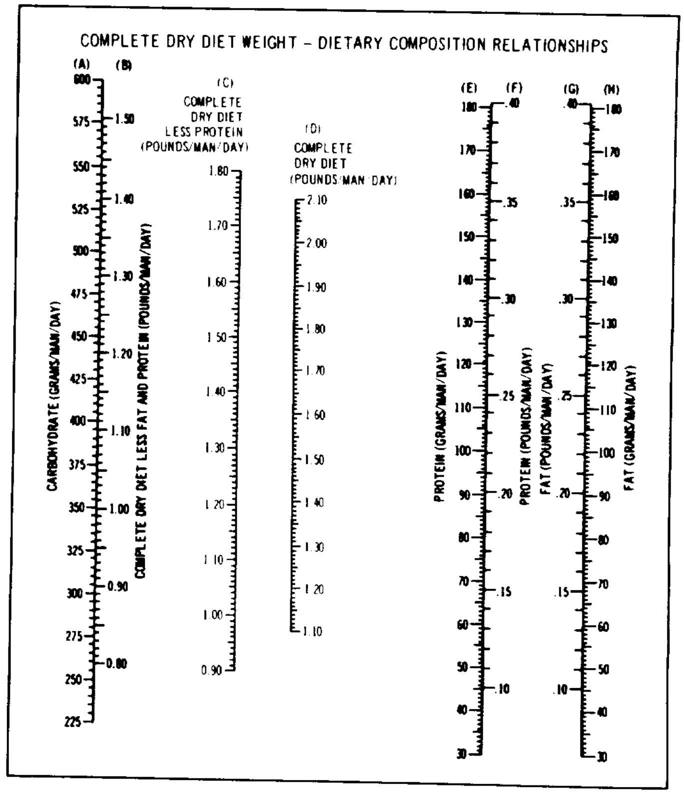
This figure was designed for the primary purpose of determining the complete dry diet weight when the weight ratios of carbohydrate, fat and protein are known. This was made possible by including in Scale B all the ingredients of a complete diet with the exception of the fat and protein. See the footnote at the bottom of this page for the dietary factors included in Scale B.

<u>Problem 1</u> – What is the dry weight of a complete diet which supplies 500g. carbohydrate, 100g. fat and 70g. of protein per day?

<u>Solution</u> – Draw a straight line from the 500 point on Scale A through the 100 point on Scale H. This will intersect Scale C at the 1.55 point. From this point draw a straight line through the 70 point on Scale E. This line will intersect Scale D to give the answer to the problem.

<u>Answer</u> – 1.70 lbs.

Footnote – Scale B represents the sum of the following dietary ingredients, the indicated grams of carbohydrates; 0.20 lbs. of indigestible bulk; 13.26 g. minerals consisting of the following elements. Na – 4.2 g., Cl – 6.50 g., P – 1.26 g., Ca – 0.84 g., K – 0.42 g., S – 10 mg., Mg – 10 mg., Fe – 10 mg., and Zn – 10 mg. Trace quantities of I, Cu, Mn, Co, and Mo would be supplied as additives or contaminants with the other dietary ingredients; and 128.8 mg. of crystalline vitamins consisting of the following: Vitamin C – 77 mg., Vitamin A – 32.3 mg. B-carotene, Vitamin E – 1.5 mg. α-tocopheral, Vitamin D – 1.0 mg. 7-dehydro cholesterol, pantothenic acid – 2.5 mg., 1.5 mg levels of thiamine, riboflavin, and pyridoxine and niacine – 10 mg., and trace (ug) quantities of Vitamin-K, biotin, B_{12} and folic acid.



e.

This figure was designed to determine the oxygen consumption per man per day when the weight ratios of carbohydrate, fat, and protein are known.

<u>EXAMPLES OF USE</u>

Example 1 – What is the oxygen consumption on a 2800 Kcal. diet consisting of 530g. carbohydrate, 44.5g. fat and 70g. protein?

<u>Solution</u> – Draw a straight line from the 530 point on Scale A through the 44.5 point on Scale I. From the intersect formed by this line on Scale C draw a straight line through the 70 point on Scale F. This line will intersect Scale D to give the desired answer in pounds/man/day or Scale E liters/man/day.

Answer – 1.87 pounds or 593 liters

<u>Example 2</u> What is the daily oxygen consumption on a 2800 Kcal diet consisting of 275g cabohydrate, 158g. fat, and 70g. protein?

<u>Solution</u> Draw a straight line from the 275 point on Scale A through the 158 point on Scale I. From the intersect formed by this line on Scale C draw a straight line through the 70 point on Scale F. This line will intersect Scale D to give the desired answer in pounds/man/day or Scale E in liters/man/day.

<u>Answer</u> 1.93 pounds or 613 liters.

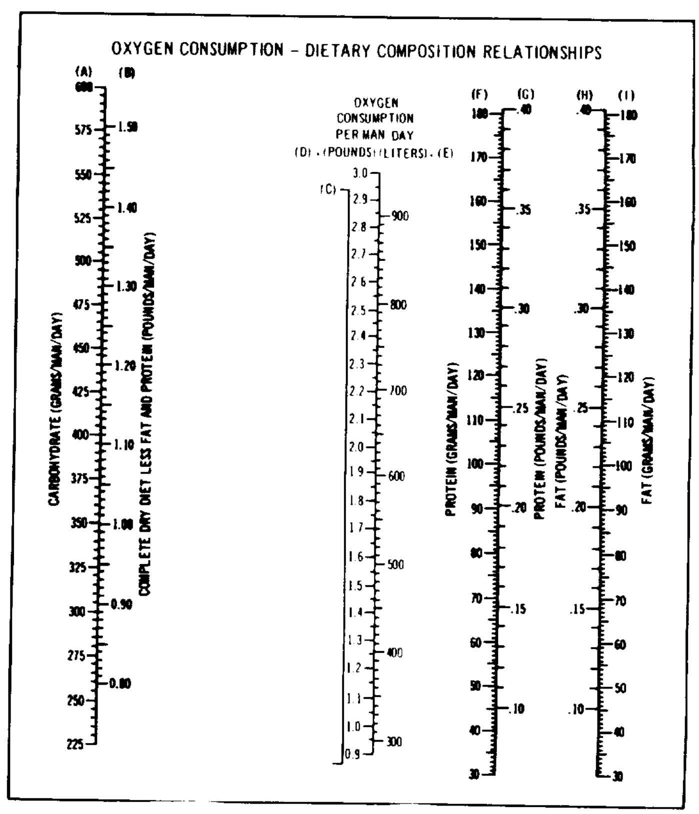


Figure 14-6 (continued)

f.

This figure was designed to determine the carbon dioxide production per man day when the weight ratios of carbohydrate, fat and protein are known.

EXAMPLES OF USE

Example 1 – What is the daily carbon dioxide production on a 2800 Kcal. diet consisting of 530g. of carbohydrate, 44.5g. of fat and 70g. of protein?

Solution – Draw a straight line from the 530 point on Scale A through the 44.5 point on Scale I. From the intersect formed by this line on Scale C draw a straight line through the 70 point on Scale F. This line will intersect Scale D to give the desired answer in pounds man/day Scale E in liters man/day.

Answer – 2.39 pounds or 551 liters

Example 2 – What is the daily carbon dioxide production on a 2800 Kcal. diet consisting of 275g. of carbohydrate, 158g. of fat and 70g. of protein?

Solution – Draw a straight line from the 275 point on Scale A through the 158 point on Scale I. From the intersect formed by this line on Scale C draw a straight line through the 70 point on Scale F. This line will intersect Scale D to give the desired answer in pounds man day or Scale E in liters man day.

Answer – 2.18 pounds or 503 liters

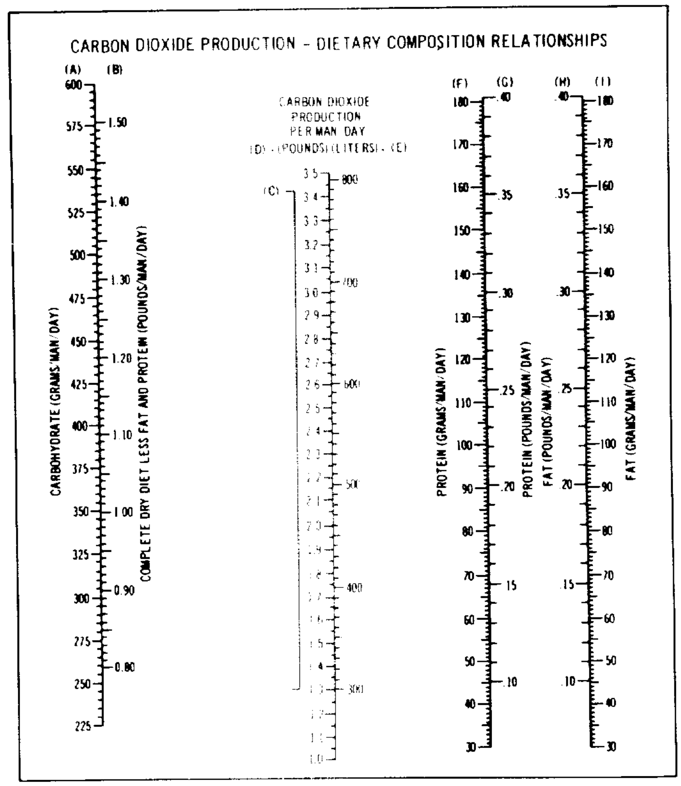
RQ DETERMINATION UTILIZING FIGURES 4 AND 5

What are the RQ values for the diets used in Examples no. 1 and no. 2 in explaining the use of figures 4 and 5?

Solution for Example No. 1 diet – The intersect on Scale E (Figure 5) gave a production of 551 liters of CO_2, the intersect on (Figure 4) showed the consumption of 593 liters of O_2.

$$RQ \quad \frac{\text{liters } CO_2}{\text{liters } O_2} = 0.929; \text{ for Example No. 2 diet:}$$

$$RQ = \frac{503}{613} \quad 0.821$$



g.

This figure was designed to determine the metabolic water production per man per day when the weight ratios of carbohydrate, fat and protein are known.

EXAMPLES OF USE

Example 1 – What is the daily metabolic water production on a 2800 Kcal. diet consisting of [illegible] of carbohydrate, 44.5 g. of fat and 70g. of protein?

Solution – Draw a straight line from the 530 point on Scale A through the 44.5 point on Scale H. From the intersect formed by this line on scale C draw a straight line through the 70 point on Scale E. This line will intersect Scale D to give the desired answer

Answer – 0.81 pounds of metabolic water man day

Example 2 – What is the daily metabolic water production on a 2800 Kcal. diet consisting of [illegible] of carbohydrate, 156g. of fat and 70g. of protein?

Solution – Draw a straight line from the [illegible] point on Scale A through the 156 point on Scale H. From the intersect formed by this line on Scale C draw a straight line through the 70 point on Scale E. This line will intersect Scale D to give the desired answer.

Answer – 0.77 pounds of metabolic water man day

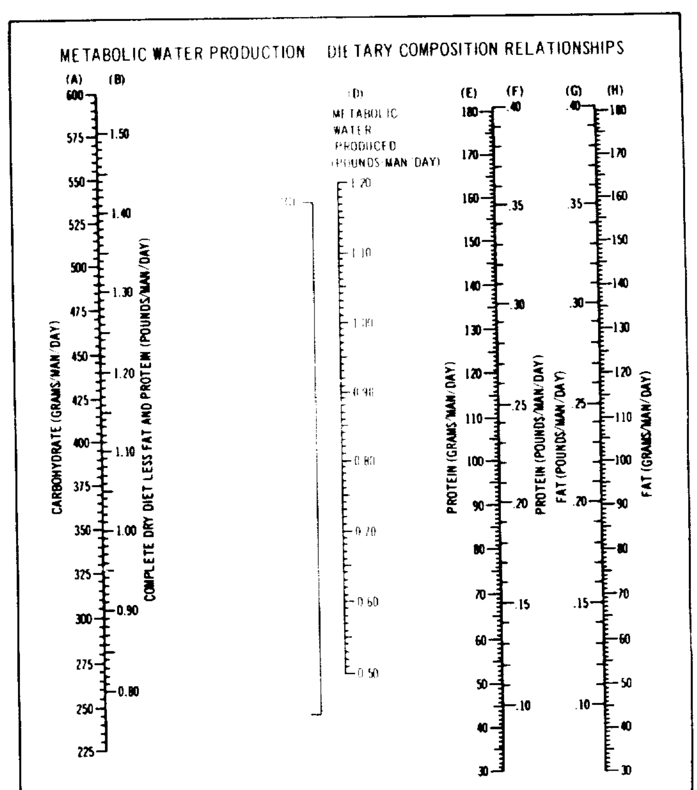


Figure 14-6 (continued)

h.

This figure was designed to determine the relative volume in cubic inches of a complete dry diet when the weight ratios of carbohydrate, fat and protein are known.

EXAMPLES OF USE

Example 1 What is the daily volume of 2800 Kcal. diet consisting of 530g. of carbohydrate, 44.5g. of fat and 70g. of protein?

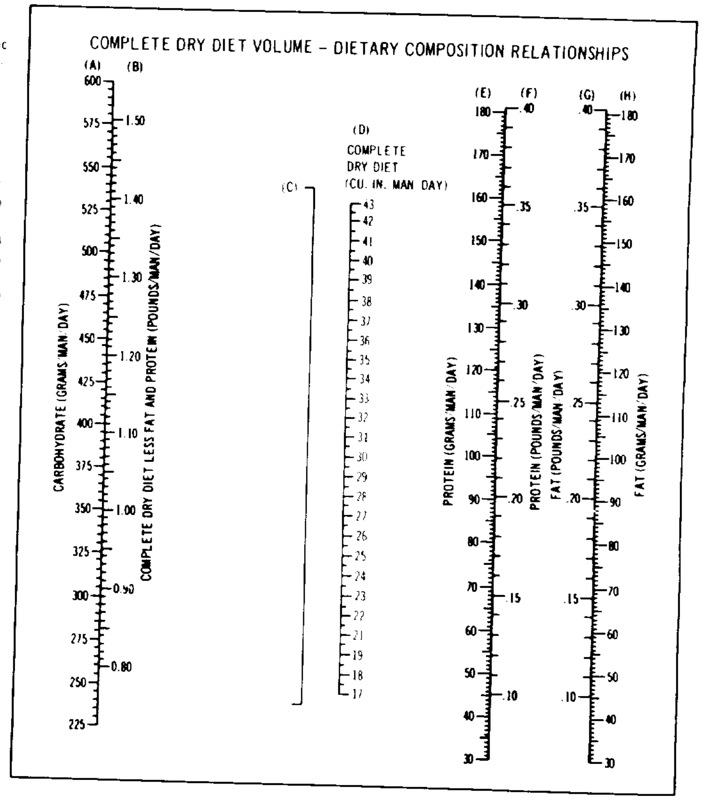
Solution -- Draw a straight line from the 530 point on Scale A through the 44.5 point on Scale H. From the intersect formed by this line on Scale C draw a straight line through the 70 point on Scale F. This line will intersect Scale D to give the desired answer.

Answer 30.6 cu. in. man day.

Example 2 What is the daily volume of a 2800 Kcal. diet consisting of 275g. of carbohydrate, 158g. of fat and 70g. of protein?

Solution Draw a straight line from the 275 point on Scale A through the 158 point on Scale H. From the intersect formed by this line on Scale C draw a straight line through the 70 point on Scale F. This line will intersect Scale D to give the desired answer.

Answer - 28.5 cu. in. man day.



i.

This figure was designed to determine the relative density-volume factor, as compared to water, of a complete dry diet when the weight ratios of carbohydrate, fat and protein are known. This density - volume factor divided by the weight of the diet in pounds and multiplied by 62.43 (pounds weight of cubic foot of water) will give the weight per cu. ft. of the diet.

EXAMPLES OF USE

Example 1 - What is the weight in pounds cu.ft. of a 2800 Kcal. diet sonsisting of 530g of carbohydrate, 44.5g. of fat and 70g. of protein?

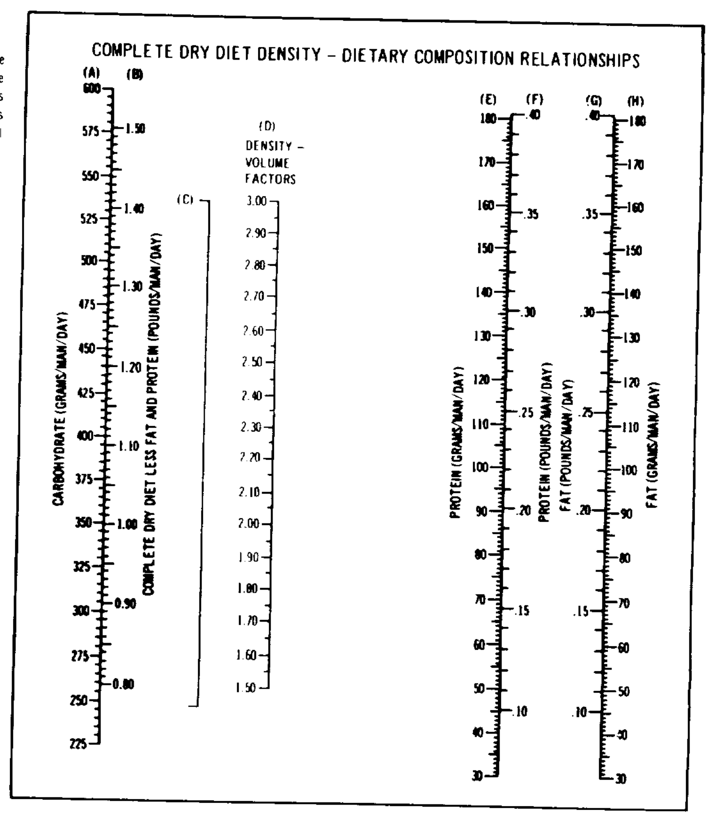
Solution From Figure 4 the weight of a complete dry diet with this composition is found to be 1.64 pounds. Draw a straight line from 530 point on Scale A (Figure 9) through the 44.5 point on Scale H. From the intersect formed by this line on Scale C draw a straight line through 70 point on Scale E. This line will intersect Scale D to give the desired Density - Volume Factor which in this case is equal to 2.46.

Calculations – $\frac{2.46}{1.64} \cdot 62.43 = 93.5$ pounds cu. ft.

Example 2 - What is the weight in pounds cu.ft. of a 2800 Kcal. diet consisting of 275g. of carbohydrate, 158g. of fat and 70g. of protein?

Solution - Using the same manipulations as described in Example I, the following values are obtained: diet weight equals 1.34 pounds and the Density - Volume Factor equals 1.84.

Calculations - $\frac{1.84}{1.34} \times 62.43 = 85.6$ pounds cu. ft.



Operational Considerations of Packing and Dispensing of Foods

The space environment presents several constraints on the design of space food and feeding systems. These are summarized in Tables 12-7a and 12-7b. These foods should be available to crews in a shirt-sleeve environment and in pressure suits during the appropriate phases of the mission. Several types of dispensing devices have been designed (11, 26, 63, 77, 87, 98). Snack items should be readily available (11).

The packaging form must conform to the storage space available (72). It must resist the physical factors of the environment. Crumbling, spilling, and leaking must be kept to a minimum because of the danger of floating particles in the weightless environment (7). In general, the packaging must be operative under the following environmental conditions:

- Temperature range: $0^{o}F$ to $150^{o}F$
- Humidity: up to 90 or 100 percent
- Vacuum: as low as 10^{-4} mm Hg
- Acceleration: up to 10 g

Other factors to consider are: level of chronic vibration; nature of the ambient gas; duration of storage; pH, fat content, microbiology, light sensitivity and consistency of the food, type and level of trace contaminants in the atmosphere, and maximum radiation background.

Figure 14-7

Biological Engineering and Operational Constraints in Space Feeding Systems

(After Heidelbaugh[34])

a. Sources of Constraints on Feeding Systems

Biological constraints	Engineering constraints	Operational constraints
Food safety limits	Temperature tolerance	Rehydration time
Acceptability limits	Weight limitation	Handling
Gastroenterologic limits	Volume limitation	Food heating and cooling
Nutritional limits	Water for rehydration	Food residue stabilization
Dietetics	Pressure	Vehicle interface
	Relative humidity	
	Acceleration	
	Vibration	

b. Typical Engineering Constraints on Feeding Systems

Constraint	Specification requirements		
	Zero-g feeder-pack*	Meal-pack**	Feeding systems†
Temperature tolerance	0 to 80 F. (−17.8 to 26.7 C.) for 36 hr.	0 to 90 F. (−17.8 to 32.2 C.) for 90 days and 130 F. (54.5 C.) for 3 hr.	0 to 90 F. (−17.8 to 32.2 C.) for 90 days and 130 F. (54.5 C.) for 3 hr.
Weight limitation	Conform to feeding system	Conform to feeding system	1.9 lb./man/day
Volume limitation	Conform to feeding system	Conform to feeding system	225 cu. in./man/day
Water for rehydration	USPHS potable standards	Not applicable	Not applicable
Pressure	29 to 1 x 10^{-4} mm. Hg	289 to 29 mm. Hg	289 to 29 mm. Hg
Relative humidity	0 to 100% for 36 hr.	0 to 100% for 90 days	0 to 100% for 90 days
Acceleration	Not applicable	1 to 7.25 g in 325 sec.	1 to 7.25 g in 325 sec.
Vibration	Not applicable	5 to 2,000 c.p.s.	5 to 2,000 c.p.s.

*One portion of food vacuum packaged in a zero-g feeding package. **Selected zero-g feeder-packs assembled into a meal unit and vacuum packaged in an overwrap. †Configuration of meal-packs designed to satisfy pilot and flight requirements. C.P.S. = cycles per second.

Figure 14-7 (continued)

c. Microbial Requirements for Foods in Space Feeding Systems*

Category	Required limit
Total aerobic plate count	Not greater than 10,000/Gm.
Total coliform count	Not greater than 10/Gm.
Fecal coliform count	Negative in 0.5 Gm.
Fecal streptococci count	Not greater than 20/Gm.
Coagulase-positive staphylococci	Negative in 0.5 Gm.
Salmonellae	Negative in 5 Gm.

* When examined by the methods suggested by El Bisi (22).

Packaging must have the following functional characteristics:

- Package proportion: ease of handling and use.
- Water of reconstitution: provide for the package to accept water directly from a probe without contaminating the probe and to hold the water and contents without spillage after removal of the probe
- Kneading: provide for kneading of the enclosed contents without spillage and with adequate visibility.
- Food delivery to mouth: provide means on the package for direct transfer of food (or beverage) from package to mouth without loss of contents; provide for neck of package to close after initial opening and between moments of ingestion to prevent loss of contents; provide for delivery to closed pressurized helmet.
- Storage: integration with storage modules and waste disposal
- Package stabilization: provide a means for physical attachment to a surface or to clothing.

The material considerations for packing are:

- Impart no toxicity to food
- Stability in temperature ranges stated
- Low permeability to water vapor and gases
- Ability to withstand Mullen burst of 40 psi
- Flexibility
- Puncture-resistance (from granular type foods) on kneading
- Minimum evaporation rates in vacuum
- Radiation-resistance within anticipated cabin module exposures
- No cracking at low temperature
- No peeling at high temperature
- Sealability
- Transparency

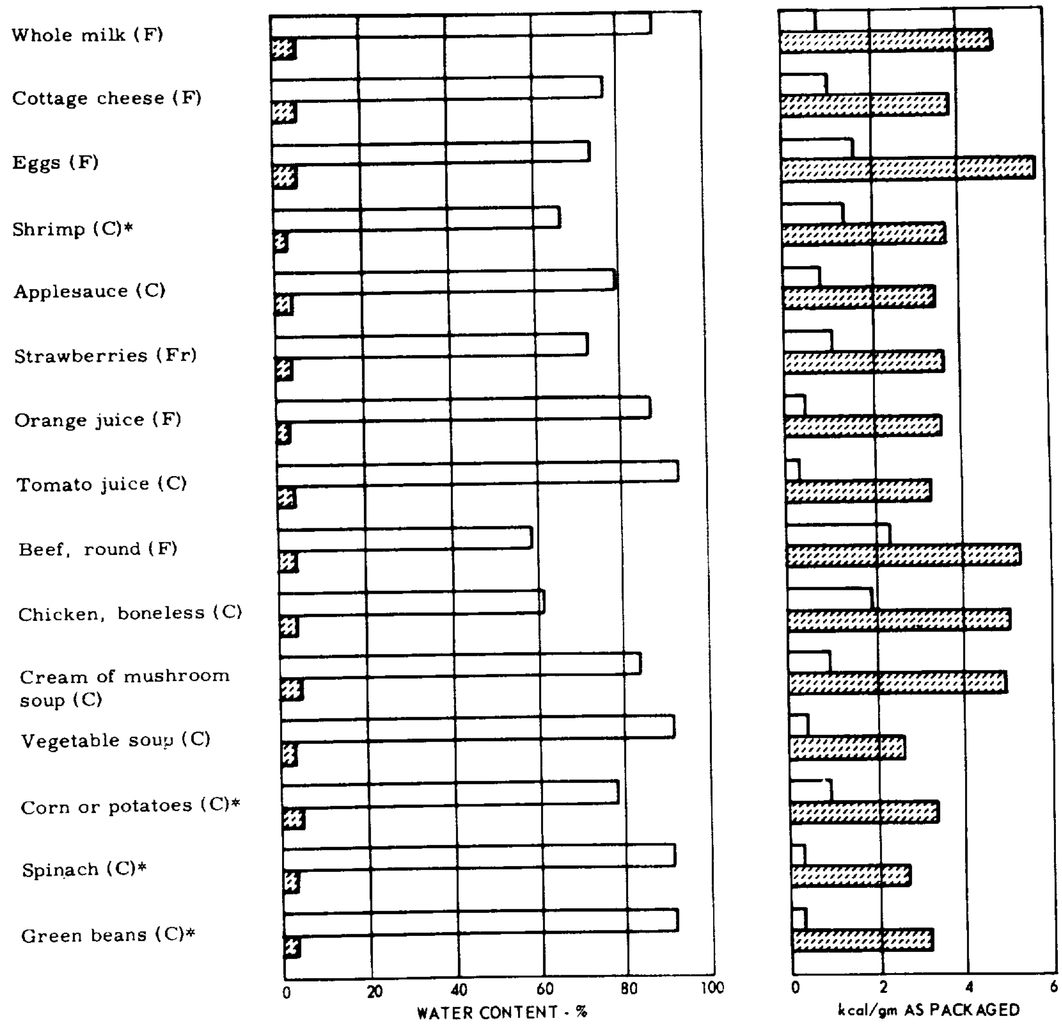
The following discussion illustrates several solutions to the weight, power, and secondary constraints imposed by the space environment. Foods of high density can reduce considerably the weight penalty of the nutrition subsystem. The density of foods may be increased by dehydration and compression (53, 100). The effect of dehydrating food is seen in Figure 14-8a in terms of percent of water content attainable and kcal/gm as packaged (96). These are for standard, commercially available, food items.

Density of dehydrated foods may be increased by reducing interstices to a minimum in the food and between packages. This reduction can be

Figure 14-8

Weight Penalties of Foods and Feeding Systems

a. Water Content and Weight of Fresh and Dehydrated Foods



*Data based on drained solids.

(F) Fresh, (C) Canned, (FR) Frozen Food

Dehydrated Food

(After U.S. Department of Agriculture [96])

Figure 14-8 (continued)

b. Weight, Volume, and Power for Several Types of Feeding Systems (See text)

Feeding System	Food		Environmental Conditions	Equipment			
	Weight	Volume		Type	Weight	Volume	Power
	(lb)	(ft³)			(lb)	(ft³)	(kilowatt hrs/day)
Minimal Acceptability: Foods compressed, freeze dehydrated, and limited in variety; no food service equipment available; temperature of water for food reconstitution 80-90°F.	1.0	0.06	Weightlessness	Water Storage Unit	1.5	0.4	0.01
Moderate Acceptability: A moderate variety of pre-cooked dehydrated foods, instant beverages, and bite-size pieces; approximately half the water at 40°F ± 5°, the remaining half at 180°F ± 10°; food service equipment limited to a water cooler and heater.	1.7	0.13	Weightlessness	Water Heater	5.0	0.6	0.30
				Thermo-Electric Water Cooler	5.5	0.7	0.45
High Level of Acceptability: A moderate variety of pre-cooked dehydrated foods, instant beverages, bite-size solids, and one pre-cooked frozen meal per day; approximately 4/5 of the water requirement for food preparation, the remaining 1/5 contained in frozen foods.	2.5	0.15	Partial Gravity	Water Heater	5.0	0.6	0.30
				Thermo-Electric Water Cooler	5.5	0.7	0.45
				Thermo-Electric Freezer	158	12.0 capacity	15.00
				Oven	10.0	0.9	1.00

(After Brehm[18])

accomplished by compression of foods into block forms that may approach the average molecular density of the products (53, 100). However, such a procedure reduces a normal chunk food to a homogeneous paste upon rehydration. Furthermore, rehydration rate is reduced in compressed foods, especially by the constraint of only cold water available (11). (See below Table 14-10c). Several approaches to the problem of retaining the particulate character of the foods are to avoid excessive compression; to avoid freeze-dried foods whenever possible in favor of foods dried by conventional methods; or to shape the foods into blocks within their packages by vacuum-molding.

Caloric density of foods may be increased, independent of physical density, by exchanging low calorie carbohydrates (4 kcal/g) for high calorie fats (9 kcal/g). However, nutritional requirements and palatability are factors that limit the quantity of fat to about 50 percent of the caloric intake. This should be kept in mind when interpreting Figures 14-5 and 14-6.

Table 14-8b represents weight, volume, and power estimates for several types of feeding systems. Food values cited are for one man for one day. A standard value has been assumed for the daily water supply: 2500 cc/man. It is assumed that the crew size will be two to four men and that mission durations will extend from two weeks to two months. Food weight and volume values include weight of food, dispensers, and packaging. The equipment data are based on state of the art designs. Values for weight, power, and volume of all equipment, except the freezer, will meet the needs of space missions of indefinite duration, provided only two crew members eat at one time. Freezer weight, volume and power data are based on food supplies for a four man crew, 60 day mission and are not applicable to early Apollo mission

Prototype Space Diets and Organoleptic Preferences

Early in the Apollo program an attempt was made to improve on the palatibility of the Gemini diet by establishing astronaut preference for space-type food. The diet presented here as a prototype was designed using the general nutritional principles outlined above (11). This particular diet will probably not see operational use in Apollo because it was not designed specifically with the time-temperature criteria for stability in mind (8). A modified Gemini diet is under study for operational use in Apollo (see below). The Stanford Research Institute Study is being presented because it represents a detailed compositional and hedonic study (with astronaut preferences) of a diet which could be modified for extended space use. The data elucidates some of the problems which future designers of space diets should consider.

The approximate composition of items developed for this diet is listed in Table 14-9. The formulated items were analyzed by the Association of Official Agricultural Chemists (AOAC) methods. Standard and uniform products were computed from USDA Handbook No. 8 (59). (Addresses of food sources are available on p. 133 of Reference (11). Evaluation of acceptability of these items in several menu forms is available (10, 11).

The general food preference of astronauts and other test subjects for the types of food presented in Table 14-9a are seen in Table 14-9b. The variability in evaluation by non-astronaut subjects of the items in prototype diet of Figure 14-9a is seen in Table 14-9c. The data were obtained in open laboratory conditions with no attempt at cabin or work simulation. The cycling pattern of the diet as well as monotony and fatigue factors involved over a 14-day feeding period must be considered (80, 83). More detailed data are available for three different menu cycles of these foods with some variation in presentation of different items. The types of snacks suggested for prototype space diets are seen in Table 14-10a. Table 14-10c evaluates the rehydration characteristics of these snacks. Subjective evaluation of these snacks under open laboratory conditions is seen in Table 14-10b. Details regarding the unsatisfactory nature of some of the snacks are available (11). It is clear that a larger sampling of opinion is required for definitive evaluation of the suitability of these dietary components in space diets of long duration.

Other precooked, dehydrated, compressed and liquid diets have also been evaluated for long periods in space-cabin simulators (21, 37, 41, 44, 45, 46, 51, 56, 73, 82, 86, 88, 99). These references cover both preparation and study of the diets.

Figure 14-9

Composition and Astronaut Preferences for Components of a Prototype Space Diet

(After Calloway et al[11])

a. Approximate Composition of a Prototype Space Diet

Food Item	Source[1]	Quantity (g per 100 g)[2] Moisture	Ash	Nitrogen	Crude Fat	Crude Fiber	Carbohydrate (by difference)
Almonds, blanched	White's	(4.7)	(3.0)	(2.98)	(54.1)	(2.7)	(16.9)
Applesauce	Vacu Dry	(2.0)	(1.8)	(0.29)	(tr)	(4.9)	(89.4)
Apple mincemeat pudding (a)	SRI Formula	19.6	2.7	0.48	18.8	2.2	53.7
Apple mincemeat pudding (b)	SRI Formula	(5.0)	(3.2)	(0.57)	(22.3)	(2.6)	(63.3)
Apricots	Mariani	30.6	2.5	0.55	0.3	2.3	60.9
Bacon bar	Wilson	15.9	8.1	6.08	35.9	0.5	1.6
Beaten biscuit	Merritt's	3.8	2.4	1.30	17.0	0.9	68.4
Beef with potatoes and gravy	SRI Formula	3.0	6.3	6.00	7.1	0.8	45.3
Beef with spaghetti and tomato sauce (b)	SRI Formula	2.3	6.7	4.46	19.3	1.0	42.8
Beef sticks	Bob Ostrow	12.6	6.0	4.50	48.8	1.0	3.5
Bread pudding	SRI Formula	2.0	2.6	0.79	17.8	1.2	71.4
Brownies	Langendorf	7.6	1.0	0.81	21.7	1.2	63.5
"Buttered" cinnamon roll	SRI Formula	(12.3)	(0.9)	(1.03)	(20.2)	(0.9)	(59.5)
"Buttered" rye	Wedemeyer	37.2	2.3	1.70	tr	0.6	50.2
Candy-coated chocolate	Boldemann	1.0	2.7	0.96	18.2	1.1	71.0
Caramels	Calliard and Bowser	(7.0)	(1.0)	(0.46)	(11.6)	(0)	(77.5)
Cashews	Circus	(3.6)	(2.7)	(2.96)	(48.2)	(1.3)	(25.7)
Cereal with apples in sauce	SRI Formula	1.3	2.1	1.07	17.9	1.4	71.2
Chicken with potatoes and gravy (b)	SRI Formula	3.5	6.1	4.16	18.7	1.1	44.6
Chicken salad	SRI Formula	2.0	2.8	4.74	26.8	1.2	37.6
Chicken soup	SRI Formula	1.2	6.7	7.38	29.9	0.3	15.8
Chili con carne with crackers	SRI Formula	3.6	6.6	4.26	21.2	1.1	40.9
Chocolate bar	Hershey	(1.1)	(1.7)	(0.96)	(33.5)	(0.5)	(55.2)
Chocolate with almonds bar	Hershey	(0.6)	(1.8)	(1.28)	(38.6)	(0.6)	(49.4)
Cinnamon roll	Svenhard	13.3	1.0	1.12	13.6	0.9	64.5
Coffee	Freeze Dry	(2.6)	(9.7)	(2.80)	(tr)	(tr)	(35.0)
Cocoa (a)	SRI Formula	1.4	4.4	2.75	1.9	1.3	73.8
Cocoa (b)	SRI Formula	(2.3)	(4.1)	(2.51)	(6.8)	(1.0)	(70.1)
Coconut macaroons	Archway	8.8	1.0	0.67	16.5	2.9	66.6
Crab Newburg with toast	SRI Formula	2.0	4.9	7.41	37.1	0.3	9.4
Cream, synthetic	Carnation	(5.8)	(3.2)	(1.50)	(27.5)	(0)	(54.1)
Crisp cereal with peaches	SRI Formula	2.7	2.2	0.74	26.8	0.6	63.1
Custard with fruit	SRI Formula	1.6	3.1	1.76	1.8	1.6	80.9
Fish wafers	Freeze Dry	1.1	5.9	9.28	18.9	0.3	15.8
Fruit cake	Cross & Blackwell	(18.1)	(2.1)	(0.77)	(15.3)	(0.6)	(59.1)
Grape drink	Wyler	(0.1)	(0.4)	(0.02)	(0.2)	(0.2)	(99.0)
Grapefruit drink	General Foods	(0.1)	(0.4)	(0.02)	(0.2)	(0.2)	(99.0)
Grapefruit juice	SRI Formula	(0.8)	(2.3)	(0.61)	(0.8)	(0.3)	(92.0)
Ham chunks	Freeze Dry	0.4	7.3	5.58	35.0	0.2	22.2
Ham in mustard sauce	SRI Formula	1.2	4.6	3.15	50.7	0.2	23.6
Honey nut roll	Istanbul Bakery	10.8	1.4	1.29	29.3	2.3	48.2
Lemon drink	Wyler	0.1	0.4	0.02	0.2	0.2	99.0
Lemon-apricot pudding (a)	SRI Formula	1.8	4.8	1.40	0.5	0.5	83.6
Lemon-apricot pudding (b)	SRI Formula	(3.1)	(4.3)	(1.43)	(9.2)	(3.4)	(74.0)
Margarine, anhydrous	Coldbrook	0.4	0.1	0.01	99.1	0	0
Mints	Norcal	(1.0)	(0)	(0)	(0)	(0)	(99.0)
Orange drink	General Foods	(0.1)	(0.4)	(0.02)	(0.2)	(0.2)	(99.0)
Orange juice	Plant Industries	(1.0)	(3.4)	(0.8)	(1.7)	(0.8)	(88.1)
Pea soup with bacon	SRI Formula	4.4	9.5	5.15	29.2	0.56	24.1
Pea soup	Vacu Dry	3.6	9.3	4.99	10.0	1.5	44.4
Petit fours	Continental	3.6	1.0	2.37	31.2	0.9	48.5
Pineapple juice	Patterson	1.5	2.0	0.55	0.2	0.1	92.8
Potato soup	SRI Formula	2.2	4.6	0.68	32.9	1.3	54.6
Potatoes with bacon	SRI Formula	11.0	5.1	3.04	31.5	1.3	32.1
Potatoes with "butter"	SRI Formula	2.5	4.6	0.68	37.8	0.9	49.9
Pumpernickel	Juillard Fancy Foods	26.9	1.1	1.04	0.8	1.4	63.9
Salami	Gallo	21.9	5.8	4.37	37.4	0.2	7.4
Seafood with noodles Orientale	SRI Formula	2.0	4.2	5.98	36.7	0.9	18.8
Spanish rice	SRI Formula	0.6	3.9	2.29	36.8	1.0	43.4
Starch jelly candy	Charm	(11.7)	(0.1)	(tr)	(0.7)	(0)	(87.4)
Swedish meatballs	SRI Formula	1.6	4.1	3.57	42.1	0.6	29.3
Tea	Lipton	(3.8)	(6.1)	(5.0)	(tr)	(0.1)	(80.0)
Tomato soup	SRI Formula	2.2	5.0	1.17	38.5	1.9	45.1
Wheat bits with raisins	SRI Formula	4.9	2.2	0.76	14.4	1.0	72.8
Yams with bacon and apples	SRI Formula	5.2	5.3	2.53	14.5	1.6	57.6

[1] Manufacturer of conventional items or SRI-developed formula

[2] Values in parentheses are from USDA Handbook No. 8; others are by analysis.

Table 14-9 (continued)

b. Mean Food Preference Scores of Astronauts and of Other Test Subjects. Ratings are based on same hedonic scale as Table c.

Item	Rating	
	Astronauts[1]	Other Test Subjects[2]
Almonds	5.3	5.1
Apples	5.6	5.1
Apricots	6.0	3.9
Asparagus	5.3	4.2
Bacon	5.6	5.7
Bananas	5.3	5.2
Beef	6.0	5.6
Butterscotch flavor	5.1	3.9
Candy	5.1	4.4
Carrots	4.9	4.7
Celery	5.5	5.3
Cereal, cold	5.0	4.2
Cereal, hot	5.0	5.5
Chicken	5.1	3.9
Cheese	4.9	5.1
Chocolate flavor	5.9	5.3
Coconut	4.5	4.4
Codfish	3.8	1.5
Coffee	4.8	4.7
Crab	5.8	3.5
Dates	5.4	3.0
Eggs	5.4	5.6
Fish	4.9	3.7
Grapefruit	5.5	5.0
Ham	5.3	5.0
Jelly, jam	5.1	4.5
Lemons	5.3	4.8
Liver	4.8	3.5
Lobster	5.9	4.1
Luncheon meat	4.4	4.9
Onions	5.1	5.1
Oranges	5.8	5.2
Peaches	5.9	5.3
Peanuts	5.4	5.1
Peas	4.5	5.0
Pineapple	5.5	4.4
Potatoes	4.9	5.1
Pudding	4.3	3.9
Raisins	5.3	4.2
Rice	5.1	4.3
Sausage	5.5	5.2
Shrimp	5.8	4.5
Squash	4.4	2.3
Strawberries	5.8	5.7
Sweet potatoes	4.5	3.8
Tea	5.3	5.0
Tomatoes	5.9	4.8
Turkey	5.1	4.9
Vanilla flavor	5.5	4.8
Yams	5.0	2.6

[1] Armstrong, Glenn, Grissom, McDivitt, Schirra, Slayton, Stafford, and Young

[2] Eleven subjects tested prior to habitability studies.

Table 14-9 (continued)

c. Mean Evaluations Scores[1] Assigned to Meal Items of a Prototype Space Diet by Subjects in Habitability Study

Item	Rating[2]	
Main Dish		
Seafood with noodles Orientale	6.0	
Beef with spaghetti	5.3	(5.6)[3]
Chili con carne	5.0	
Crab Newburg	4.7	
Chicken with potatoes and gravy	4.5	
Chicken salad	4.0	(3.0)
Potatoes with "butter"	3.8	
Swedish meatballs	3.5	
Ham with mustard sauce	2.6	
Beef with potatoes and gravy		(2.6)
Soup		
Chicken		(4.0)
Potato	3.7	
Tomato	3.0	
Beverage		
Orange juice	6.0	(6.0)
Cocoa	5.6	(5.6)
Lemon drink	5.4	(5.6)
Grape drink	5.3	
Tea	5.2	
Coffee	5.0	(3.3)
Grapefuit juice	5.0	
Pineapple juice		(3.7)
Dessert		
Custard with fruit	5.0	
Apple mincemeat pudding	4.8	
Lemon pudding	4.8	
Bread pudding	4.5	
Breakfast		
Crisp cereal with peaches	5.2	
Cereal with apples	5.0	(3.6)
Wheat bits with raisins	4.8	
Potatoes with bacon	4.8	
Yams with bacon and apples		(3.3)
Snacks		
Chocolate with almonds bar	6.0	(6.0)
Chocolate bar		(6.0)
Cashews	5.3	
Coconut macaroons	5.3	
Mints	5.3	(5.0)
Cinnamon roll	5.0	
Beef sticks	5.0	
Petit fours	5.0	
Fruit cake	5.0	
Brownies	4.8	
Bacon bar	4.6	
Honey nut roll	4.4	
Apricots	4.0	(4.6)
"Buttered" rye	4.0	(2.3)
Ham chunks	3.8	
Caramels	3.7	
Starch jelly candy	3.7	(5.7)
Fish wafers	2.6	
Rye with salami		(2.6)

1. Numerical values were assigned based on a hedonic scale, with 6 as "Like very much" and 0 as "Dislike very much".
2. Each value represents the average of 3 to 6 judgements.
3. Ratings in parentheses were assigned in a previous experiment.

Table 14-10

Evaluation of Snacks in a Prototype Space Diet

(After Calloway et al[11])

a. Snacks Prepared for a Prototype Space Diet

Item	Description	Supplier	Weight (g)	Treatment
Almonds	Blanched, whole	White's	50	None
Apricots	Dried halves	Mariani	29	None
Bacon	Compressed	Wilson	53	Crumbled and recompressed
Bacon bar	Compressed	Wilson	85	None
Beef sticks	Dried	Bob Ostrow	56	None
Beaten biscuit	Rounds, 3/4-inch diam	Merritt's	15	None
Brownies	Cakes, top-frosted	Langendorf	78	None
"Buttered" cinnamon roll	Squares, 3/4-inch Anhydrous margarine	Svenhard Coldbrook	85 7	Cinnamon roll compressed; coated with anhydrous margarine
"Buttered" pumpernickel	Rounds, 1 1/2-inch diam Anhydrous margarine	Juillard Fancy Foods Coldbrook	40 8	Rounds spread with anhydrous margarine
"Buttered" pumpernickel with sausage	Rounds, 1 1/2-inch diam Anhydrous margarine Sliced salami	Juillard Fancy Foods Coldbrook Gallo	40 24 8	Salami sandwiched between 2 slices spread with anhydrous margarine
"Buttered" rye	Squares, 3/4-inch, "Vollkornbrot" Anhydrous margarine	Wedemeyer Coldbrook	100 20	Squares spread with anhydrous margarine
Candy-coated chocolate	Rounds, 9/16-inch diam	Boldemann	60	None
Caramels	Bars, 2-inch x 1/2-inch	Caillard and Bowser	55	None
Cashews	Roasted	Circus	57	None
Chocolate	Bar	Hershey	57	None
Chocolate with almonds	Bar	Hershey	57	None
Cinnamon roll	Sliced	Svenhard	57	None
Coconut macaroons	Pieces, 1 1/2-inch x 3/4-inch	Archway	80	None
Fish cakes	Rounds, freeze-dried	Freeze Dry	45	Packaged under N_2
Fruit cake	Bar	Cross & Blackwell	57	None
Ham chunks	Squares 3/4-inch freeze-dried	Freeze Dry	28	Packaged under N_2
Honey nut roll	Pieces	Istanbul Bakery	57	None
Mints	Rounds	Norcal	30	None
Petit fours	Coated square cakes	Continental	60	None
Starch jelly candy	Pieces, 1 1/2-inch x 3/4-inch	Charm	76	None

Table 14-10 (continued)

b. Results of Subjective Evaluation of Snack Items in a Prototype Space Diet After Storage Tests

(Two weeks at 100^{o}F; 90% relative humidity; vacuum 10^{-1} mm)

Item	Rating			Comments
	Acceptable	Improvement Needed	Unacceptable	
Candy mints	x			
Dried apricots	x			
Beef sticks	x			
Candy-coated chocolate	x			
Toffee fingers	x			
Beaten biscuits	x			
Almonds, blanched unsalted	x			
Peanuts, bland coating	x			
Caramels	x			
Macaroons	x			
Starch jelly candy		x		Eliminate sugar coating
Fruit cake		x		Coating necessary to avoid crumbling
Rye bread with butter		x		Coating necessary to avoid crumbling
Bacon bar	x			
Candy-coated almonds			x	Coating crumbles
Cashews		x		Eliminate salt
Brownies			x	Crumbles and melts
Chocolate (high melting point)			x	Melts
Ham chunks			x	Excessive crumbling
Fish wafers			x	Excessive crumbling
Petit fours			x	Melts
Honey nut roll			x	Crumbles; too sticky
Cinnamon roll		x		Coating necessary to avoid crumbling

Table 14-10 (continued)

c. Rehydration of Prototype Dehydrated Space Foods in Cold Water (80°F)

Item	Rating after 2 minutes			
	Good	Fair	Poor	Comments
Applesauce[1]	x			
Potatoes with bacon		x		
Crab Newburg with toast	x			
Bread pudding	x			
Crisp cereal with peaches[1]	x			
Ham in mustard sauce			x	
Apple mincemeat pudding	x			
Wheat bits with raisins[1]	x			
Beef with spaghetti and tomatoes	x			Noodles still crisp
Cereal with apples in sauce	x			
Chicken salad		x		Slight starchy taste
Lemon pudding[1]	x			
Swedish meatballs			x	Meat "crunchy"
Chili con carne with crackers	x			
Custard with fruit	x			
Chicken with potatoes and gravy	x			Flavor not as good
Seafood with noodles Orientale	x			
Pea soup			x	
Tomato soup			x	
Potato soup			x	
Spanish rice	x			
Cocoa	x			Must be vigorously shaken
Coffee	x			
Orange juice[1]	x			
Grapefruit juice[1]	x			
Lemon drink[1]	x			
Grape drink[1]	x			
Potatoes with "butter"			x	

[1]Normally rehydrated with cold water.

Apollo foods are currently of two types - nominal and contingency (45, 46). Table 14-11 covers the nutrient composition and Table 14-12 the meal and cycle form of the Apollo nominal mission diet. Table 14-13a covers the nutrient composition of semisolid and rod form of the contingency diet. The semisolid foods can be made up in foil packs or in tube form, the latter eaten by being squeezed through an aluminum toothpaste tube. Tubed foods are squeezed through an aperture in the helmet of a space suit. The rod form are in long spaghetti cylinders, 13 feet of which supply the normal daily requirement per man. The rod food is forced by a plunger through an aluminum tube screwed into an aperture in the helmet. In a recent study, four human male subjects participated in a 90-day experiment consisting of 60-day and 30-day confinement periods with a 5-day break between. The subjects were confined either to the controlled activity facility or the chamber of the Life Support Systems Evaluator at the Aerospace Medical Research Laboratories, Wright-Patterson AFB (45). In the chamber, they were in 50% oxygen-50% nitrogen at 382 ±2.6 mm Hg, wearing pressure suits unpressurized and pressurized at 3.7 psi. The subjects ate a fresh food diet, An Apollo nominal diet, or an Apollo contingency diet that provided 2200, 2500, and 900 kcal/day, respectively. The rod form of the contingency diet was the more accept-

Table 14-11

Nutrient Composition of Test Apollo Nominal Mission Diet

(After Katchman et al[45])

Constituent	Units	Cycle I	Cycle II	Cycle III	Cycle IV
Weight	g	544.50	543.10	541.20	545.45
Water	g	16.1	16.3	10.4	15.0
Calories	cal	2622	2650	2601	2637
Protein	g	102.9	112.7	109.7	107.1
Fat	g	118.8	125.6	111.5	122.5
Carbohydrate	g	287.2	269.5	289.9	290.3
Fiber	g	4.31	3.62	6.65	4.32
Ash	g	19.7	19.4	19.6	20.6
Calcium	mg	993	531	866	810
Phosphorus	mg	1618	1443	1381	1751
Iron	mg	11.4	10.6	9.7	11.1
Sodium	mg	4025	7076	4513	4833
Potassium	mg	2474	2411	2059	2208
Magnesium	mg	267.0	251.0	220.5	255.4
Chloride as NaCl	g	10.34	10.13	11.19	11.79

Analysis of the Apollo nominal mission diet was supplied by the Food Division, U. S. Army Natick Laboratories, Natick, Massachusetts.

Table 14-12

Menu of Test Metabolic Diets for Apollo Mission

(After Katchman et al[45])

Meal A	Meal B	Meal C	Meal D
		Fresh food diet	
Canadian bacon Bread and butter Applesauce Gingerbread Chocolate milk	Roast beef sandwich Sliced peaches Peanut butter cookies (3) Grapefruit Tang	Sliced turkey Dinner rolls (2) Apricot halves Pound cake Milk	Ham and cheese sandwich Red cherries Brownie Orange Tang
		Apollo nominal mission diet	
Cycle I			
Toasted oat cereal Sausage bites Toasted bread cubes Orange drink	Beef and gravy Corn bar Date fruitcake Toasted bread cubes Tea and sugar	Pea soup Salmon salad Cinnamon toast Fruit cocktail Orange drink	Chicken sandwich Chocolate pudding Peanut cubes Orange-grapefruit drink
Cycle II			
Apricot cereal cubes Canadian bacon and applesauce Toasted bread cubes Cocoa	Beef bites Potato salad Pineapple fruitcake Orange drink	Beef sandwich Chicken salad Peach bar Banana pudding	Potato soup Chicken and gravy Toasted bread cubes Peanut cubes Tea and sugar
Cycle III			
Sugar coated flakes Sausage patties Cinnamon toast Orange-grapefruit drink	Tuna salad Cheese sandwich Apricot pudding Orange drink	Beef pot roast Pea bar Toasted bread cubes Pineapple cubes Tea and sugar	Crab bites Cinnamon toast Applesauce Brownie Grapefruit drink
Cycle IV			
Strawberry cereal cubes Bacon squares Beef sandwich Orange drink	Corn chowder Beef sandwich Chocolate pudding Gingerbread	Shrimp cocktail Chicken and vegetables Toasted bread cubes Butterscotch pudding Orange-grapefruit drink	Beef and vegetables Spaghetti and meat sauce Cinnamon toast Apricot cubes Tea and sugar

Table 14-13

Nutrient and Chemical Composition of Test Contingency Diet for Apollo Mission *

(After Katchman et al[45])

a.

Constituent	Units	Semisolid	Rods
Energy per unit	kcal	475.0	485.0
Weight per unit	g	140.0	110.0
Energy per gram of diet	kcal	3.4	4.4
Carbohydrate	g	65.3	72.1
Protein	g	11.9	10.0
Fat	g	18.5	17.5
Water (by difference)	g	44.0	10.0
Thiamine	mg	2.0	**
Niacin	mg	10.0	**
Vitamin B_6	mg	0.8	**
Riboflavin	mg	2.0	**
Calcium pantothenic acid	mg	3.0	**

* Analysis of the contingency diet was supplied by the Food Division, U.S. Army Natick Laboratories, Natick, Massachusetts.

** Vitamins are presumed to be present in the rod food in the same amounts as in the semisolid food.

Table 14-13 (continued)

b.

Constituents /24 hr	Units	Foil pack (A)	Rods (B)**	Tube pack (C)	Rods (D)
Dry solids	g	202	196	221	191
Water	g	78	36	116	23
Protein	g	22	28	25	26
Fat	g	38	38	34	36
Carbohydrate (by difference)	g	137	127	159	127
Fiber	g	2	1	1	1
Ash	g	3	3	4	1
Calcium	mg	615	540	510	540
Phosphorus	mg	615	147	570	170
Sodium	mg	285	730	240	120
Potassium	mg	730	258	680	300
Chloride	mg	417	1620	480	370
Magnesium	mg	105	49	74	47

* Analyzed by Wisconsin Alumni Research Foundation, Madison, Wisconsin.

** 2.0 g of sodium chloride added.

able from an organoleptic standpoint. Table 14-14a covers the acceptability ratings of the diets. The tube form was more easily handled from a functional standpoint, although the formulation of the tube food as well as the tube itself needs to be improved to make it operationally more effective than at present. The subjects lost about 500 g/day of body weight while on the contingency diet of which about 50% is estimated to be water. About 40 g/day of body weight was lost because of protein catabolism but no ketone bodies were found in the urine. Blood levels of sodium, potassium, phosphorus, chloride, calcium, and magnesium were maintained in the normal range of clinical values. Physiologic measurements all were in the normal range of clinical values. However, the 17-hydroxycorticoids of the urine decreased to low normal and below normal ranges of clinical values. Three of the four subjects completed a simulated Apollo emergency mission wearing a pressure suit pressurized at 3.7 psi and on a 900-calorie contingency diet. There were no adverse effects upon their health and no evidence that their capacity to function in a normal manner was in any way impaired. Water consumed varied from 700 to 2000 ml/day. Table 14-14b covers the waste management associated with the diets.

Rehydration of Foods

Hot water for rehydration of space foods and the preparation of hot meals represents an important power requirement for the command module during a mission. Since power consumption is a direct function of water temperature above ambient temperature, criteria to aid in the determination of minimum temperature requirements for the rehydration of hot meals are necessary. Operations in the Apollo LEM, for example, require that foods be rehydrated with cold water. Table 14-10c represents rating of prototype space foods after 2 minutes of rehydration in cold water at 80°F.

The subjective nature of palatability as it relates to food temperature is a complex subject that may best be solved by the astronauts themselves. However, a panel composed of a laboratory staff placed the lower temperature of acceptability of semisolid hot foods at 105°F, soup at 115°F, and coffee or tea at 120°F (11). In establishing the water temperature requirements for initiating the hydration of specific foods so that these minimal temperatures are attained, the following data are required:

- cooling rate of food and water mixtures
- temperature drop from mixing food and water without heat loss (at time zero)
- time required for consumption of food

Solution of appropriate cooling-rate equations indicates that the initial water temperature required to have semisolid foods at 110°F ten minutes after rehydration in ambient temperatures of 70°F is 146°F. Under similar conditions, the water temperature required to have coffee at 120°F five minutes after hydration is 145°F. Therefore, maximum initial temperature of hydration water for most foods can be set at 145°F without effects on palatability.

Table 14-14

Organoleptic and Waste Management Evaluation of Nominal and Contingency Apollo Diets (See text for description)

(After Katchman et al[45])

a. Organoleptic Evaluation of Different Forms of Nominal and Contingency Apollo Diets

	Apollo nominal mission diet					
	cycle I	cycle II	cycle III	cycle IV	cycle I	
Chamber ANM (A)	5.6	6.4	6.5	5.8	6.5	
CAF - Chamber ANM (B)	5.6	5.9	6.2	6.2	6.3	
	5.7	5.7	6.1	5.9	6.5	
CAF - Chamber ANM (B)	6.5	6.8	6.0	6.0	6.2	
Test period and condition	**Contingency diet**					**Average per 5-day test period**
	day 1	day 2	day 3	day 4	day 5	
CAF Foil pack (A)	1.9	2.4	2.6	2.6	2.0	2.3 ± 0.4
CAF Rods (B)	3.9	4.2	4.1	4.0	3.2	
Chamber Rods (B)	4.2	5.8	5.8	6.0	5.0	
Tube pack (C)	6.0	5.0	4.8	4.3	4.3	

A, B, and C refer to specific versions of diets tested.

CAF = Controlled Activity Facility

Chamber = Life Support Systems Simulator (50% N_2 - 50% O_2 at 382 mm Hg).

Numbers are averages of 4 subjects on a 9 point hedonic scale.

Table 14-14 (continued)

b. Waste Management Nominal Mission and Contingency Diets in Apollo

	Fresh food	Apollo nominal mission food	Contingency food
	Intake, g/24 hr		
Dietary solids	512	568	202
Dietary water	1167	20	89
Ad libitum water	1400 ± 417	2000 ± 182	1500 ± 311
Metabolic water	314	357	134*
	3400	2900	1900
	Excretion, g/24 hr		
Urine	1300 ± 590	1300 ± 580	1100 ± 465
Feces	65 ± 17	86 ± 2.5	32 ± 12
Insensible water	1500 ± 274	1000 ± 68	600 ± 189*
	2900	2400	1700

* Does not include water of metabolism from body stores.

Current Packaging Materials

The operational requirements for food packaging and dispensing have been covered above. Material requirements for use in packaging of space food should ideally meet the criteria posed above. The most stringent requirements are high strength and excellent barrier against penetration by oxygen and water vapor. Tables 14-15, 14-16, and 14-17 represent the physical properties of candidate materials. More detailed analysis of properties of materials in Tables 14-16 and 14-17 are available (11).

Of the single-film materials, fluorohalocarbons such as Aclar have the best water vapor barriers and polyvinylidine chlorides (Saran), the lowest oxygen permeability. Polyethylene is quite permeable to oxygen but is most sealable by heat. All are stable and flexible within the temperature and atmospheric ranges specified. All have good tensile and tearing strength and are puncture resistant. The latter is important because some foods have sharp particles and evacuation of the package required to reduce bloating upon decompression creates high concentrated stresses in the film material. To obtain the best all-around physical properties, various thicknesses of several different film materials are usually laminated together by either extrusion or adhesion. Approximate properties can be estimated by adding the separate properties of each part of the laminate. Actual properties can be obtained only by testing each complete laminate, as the techniques of each converter will cause variances.

Preliminary testing of laminates suggests that the most useful laminate would probably consist of the following individual films (11): Aclar; polypropylene with a Saran coat or Mylar with a Saran coat; and polyethylene (medium density) or Surlyn A (a modified polyethylene).

Metal foil laminates form ideal barriers but are susceptible to damage under folding and kneading, and evacuation. They are also opaque and do not allow visualization of the food during kneading in rehydration. They appear especially useful in package overwraps for grouping daily diets for each man. The most promising foil laminates are (11);

May Industries/Reynolds Aluminum. 2-mil laminate

Mylar	.0005
Aluminum Foil	.0004
Rislan (Nylon 11)	.001

Dow Chemical Co. 3.7-mil laminate

Polypropylene
Aluminum foil
Polyethylene
} individual thicknesses not known

Minnesota Mining and Manufacturing Co.

25A20 2.5-mil laminate
45AX88 4.5-mil laminate

Metallized aluminum
Mylar
Polyethylene
} individual thicknesses not known

Table 14-15

Plastic Films for Food Packaging (1 mil thick)

(Adapted by Finkelstein[25] from data of Modern Plastics Encyclopedia[65], Allied Chemical[1], and Clauser[12])

Characteristics	Polytrifluorochloro ethylene (Aclar 33-C)	Polyester (Mylar)	Polyamide (Nylon)	Polyethylene, low density (Marlex)	Vinylidene chloride (Saran)	Polyvinyl chloride (Pliovic)
Weight (in^2/lb)	13,000	20,000	24,000	30,000	16,000-23,000	20,000-23,000
Tensile strength* (lb/in of width)	5-6	23-40	9	1.3-2.5	8-20	1.4-5.6
Elongation* (%)	35	35-100	orients	200-800	20-140	150-500
Burst strength; Mullen Test** (points)	35	45-60	-	-	23-35	20
Tear strength; Elmendorf Test*** (grams)	200-350	10-27	-	100-300	10-100	60-1400
Moisture vapor transmission rate (gm mil/day, 100 in^2, atm)	0.4 (at 100°F)	24 (at 103°F)	300-320 (at 100°F)	7-15 (at 77°F)	3 (at 100°F)	70-170 (at 100°F)
Permeability to oxygen cc(STP)mil/day, 100 in^2, atm.	7 (at 75°F)	1.1 (at 70°F and 0% RH)	2.6 (at 73°F and 0% RH)	750	1.0 (at 73°F)	625

*Tensile strength and elongation: American Society of Testing Materials D-882, Procedure 3.
**Mullen Test: American Society of Testing Materials D-774.
***Elmendorf Test: Figures represent pull to continue tear after starting.
Note: The names Aclar, Mylar, Marlex, Saran, and Pliovic are registered trademarks.

Table 14-16

Water Vapor and Oxygen Transmission for Single Films

Film	Operating Temperature (°F)	Water Vapor (per mil thickness) g/100 sq in./24 hr at 100°F and 95% RH	Oxygen (per mil thickness) cc/100 sq in./24 hr/atm
Aclar	-420° to 370°	0.015	6-8
Mylar	-80° to 300°	1.8	3-5
Nylon 6	-100° to 300°	36	8
Polyethylene (med. dens.)	-60° to 200°	0.5-5.0	250-400
Saran 7	0 to 250°	0.2-0.3	0.9-1.0
Surlyn A	-160° to 160°	1.5	500

(After Calloway et al[11])

Table 14-17

Permeability Data on Laminated Materials

Laminate	Water Vapor g/100 sq in./24 hr at 95% RH	Oxygen cc/100 sq in./24 hr/atm
Milprint, M-Mylar/Polyethylene	0.3-0.5	0.55-0.7
3M 25A6 Mylar/Polyethylene	0.4	7
3M 45A27 Mylar/Polyethylene	0.2	3
RAP-7700 Aclar/Mylar/Polyethylene	0.03-0.04	2.3

(After Calloway et al[11])

Prototype food storage and dispensing bags for Apollo have been designed under the packaging criteria presented above (11). A prototype rehydrating system is also available.

Starvation and Performance Capacity

In the rare situation where lack of food and water and not lack of oxygen stores limit survival, the effect of starvation on performance must be considered. The lack of water has been covered in Water (No. 15).

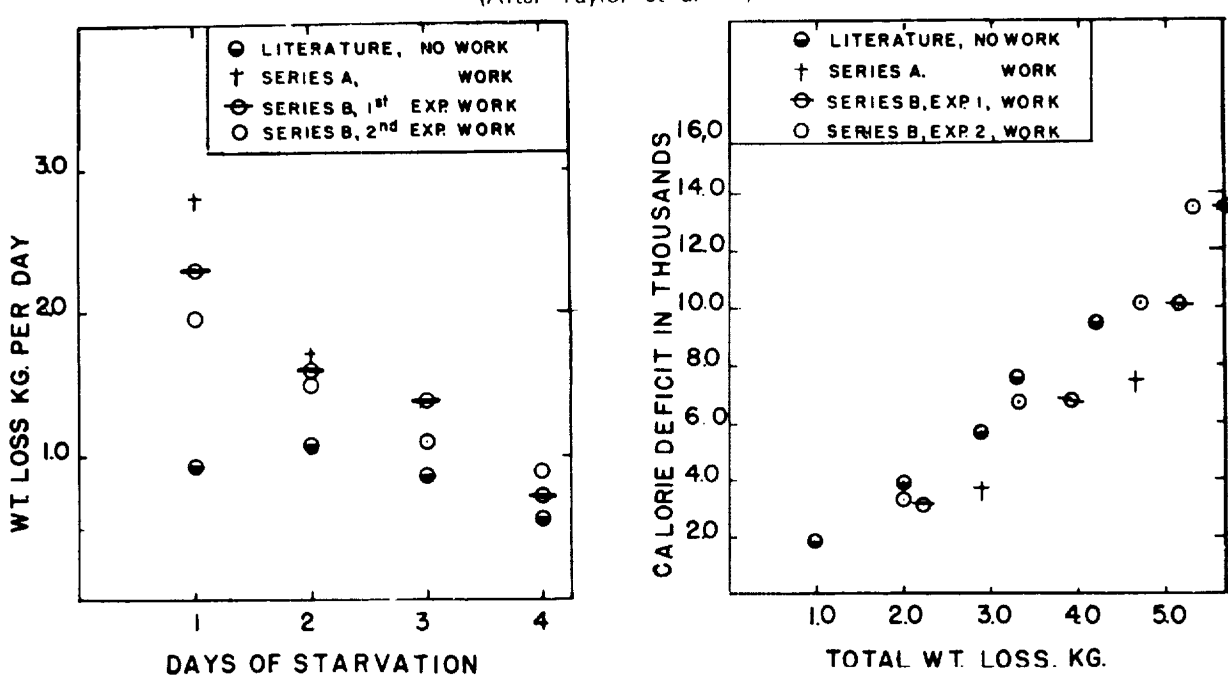
It is clear that the decline in human performance during starvation is a critical factor in a survival situation. Both acute and chronic starvation affect the physical and mental ability of the subject to extricate himself from his environment and also affect his psychological set. Anxiety is a major factor to be considered. The design of optimum survival rations has already been mentioned above. The response of humans to starvation has also received much study (15, 17, 49, 54, 91, 97, 101). The effects of acute starvation accompanied by hard work on the well-being and performance of man are of special interest and importance in certain emergency situations.

The results of the two most extensive studies to date on acute starvation will be presented to define the problem (15, 17, 91). Because of the uniqueness and importance of these data in space emergencies, they will be covered in detail.

Figure 14-18

Comparison of Weight Losses and Calorie Deficit Per Day in Young Men Who Were Starving With and Without Work

(After Taylor et al[91])



a. Daily Weight Loss Data

The data on men starving without work were drawn from the literature (See original paper for literature sources and text for details.)

b. Calorie Deficit Per Kg of Weight Loss

Weight losses and calorie deficits were calculated from the morning of the first day of fasting to the morning of the last day or fasting.

Five-Day Starvation with Exercise

Figure 14-18 presents the weight loss and caloric deficit of the men in the first study. The body weight losses of eight men who had merely starved for five days at rest in several different studies were compared with men who worked. Water was given ad libitum. Four men were subjects for a 2.5-day fast (Series A) and twelve men for a 5-day fast (Series B). The average total caloric deficit in Series A was estimated to be approximately 9,000 while in Series B it was approximately 16,000 Cal. The mean weight loss in the first series was 4.5 kg. (6.7 percent) and that in the second 5.5 kg. (7.8 percent). The men walked at 3.5 m.p.h. on a 10 percent grade (an average expenditure of 550 Cal. per hour) for 4 hours each day in Series A and for 3 hours daily in Series B. In addition, one maximal performance test (running at 7 m.p.h. on a grade for 3 to 5 minutes) was carried out each day.

The 2.5-day fast with hard work resulted in 6.8 percent body weight loss while the 4.5-day fast produced an 8 percent loss in body weight. The daily loss of weight in both conditions is seen in Figure 14-18. It will be noted that on the first day the men performing work lost 2 to 2.5 times as much weight as the men who were not performing special work tasks. But by the fourth day, this ratio had decreased to 1.2 to 1.4.

Aerobic work of this type was carried on with few signs of loss of fitness during the first day. On the morning of the second day, work pulse rates were increased by 10 to 15 beats per minute, work ventilation was increased, and the blood sugar during work decreased 25 mg. per 100 ml. Only a small increase in work pulse rate (5 beats per minute) was noted during the remainder of the fasting period. The men were able to complete their walking assignments in all cases except for one individual who was forced to stop walking on the fourth day because of nausea and gastric distress. All the men complained of fatigue, sore muscles, and weakness of increasing intensity as the experiment progressed. Nausea and occasional vomiting were common complaints, particularly after the bouts of anaerobic work. Pain in the side frequently accompanied exhausting work.

Mechanical efficiency of grade walking decreased from 19.0 to 17.8 percent. This decline was paralleled by a decrease in the nonprotein respiratory quotient and an increase in the relative amount of fat metabolized during work. The ability to perform exhausting "anaerobic" work was definitely impaired after the first day of starvation. On the second day of starvation the score of the Harvard Fitness Test was decreased to 70 percent of the control value and on the fourth day the score had dropped to 40 percent. It would appear that alteration of neither circulatory nor respiratory function was important in the decreased performance of the Harvard Fitness Test, but that decreased efficiency of muscular work and the development of pain and other distress were involved. The oxidative energy available during anaerobic work was well maintained as shown by the fact that there was no change in the maximal oxygen intake per kilogram of body weight during the fourth of the 5-day fast. The physiological response to a fixed anaerobic task showed no deterioration at the end of the first day as measured by the blood lactate concentration. However, there was a definite increase in blood lactate concentration and in the 10-minute oxygen debt on the fifth day of the fast.

Strength was not affected while measures of speed and coordination showed some decline during the starvation period. This loss of speed and coordination appeared to be dependent on the blood sugar concentration and could be reversed easily with the administration of 100 gm. of sugar (49). Deterioration in the psychomotor area followed the same general pattern of maintenance of good performance on the first day with definite deterioration on the morning of the secon(Table 14-21 (acute starvation) compares performance with that found in another semistarvation experiment. Recovery of performance was studied after 4 and after 5 days of refeeding. At this time the body weight had returned to the control (pre-fast) values. On the fourth day the ability to perform anaerobic work was found to be completely recovered. On the fifth day, the pulse rate during the walk was 4 beats less than that of the control period. The 10-minute oxygen debt and the blood lactate concentration 12 minutes after a fixed task of anaerobic work had returned to normal levels. The maximal oxygen intake was 2 percent less than the control value and there was a small amount of overventilation present during both work and recovery. It is concluded that the physical deterioration associated with the loss of 40 to 50 gm. of nitrogen under these conditions is repaired within 3 to 5 days of refeeding.

For twelve young men the 4.5-day fast with hard work resulted in an 18 percent decrease in plasma volume and an 8 percent loss in extracellular volum measured by the thiocyanate space. This loss of fluid accounted for 27 percent of the total body weight loss of 5.5 kg. During refeeding after the 4.5-day fast, the initial body weight was recovered in 3 to 5 days of refeeding. The plasma volume and thiocyanate space were 12 to 8 percent, respectively, above the control values. The increases in these spaces accounted for 30 percent of the weight gain during the first four days of recovery. Dysorthostasia may result from this factor.

At the end of 3.5 days of starvation with hard work, one man showed unequivocal jaundice, the liver function tests demonstrated definite malfunction of the liver. The mean 1-minute serum bilirubin of ten men increased from 0.11 mg. per 100 cc. before starvation to 1.27 mg. at the end, and the total bilirubin rose from 0.76 to 1.96 mg. per 100 cc. The 4-hour urobilinogen excretion increased from 1.13 to 2.96 mg. All liver function tests had returned to normal by the third day of recovery. Observations on four men who starved and worked for 2.5 days showed that: (a) nitrogen loss was not affected by the additional caloric expenditure required by the physical work; (b) acetone excretion in significant amounts began on the first day of starvation; (c) resting blood sugar fell 15 mg. per 100 cc. blood by the morning of the second day; and (d) the resting respiratory quotient was depressed to 0.71 on the morning of the second day. Although acetone excretion in significant quantities begins earlier in starvation with work, the quantities excreted per unit of calorie deficit were not different in the two conditions.

Ten Day Starvation

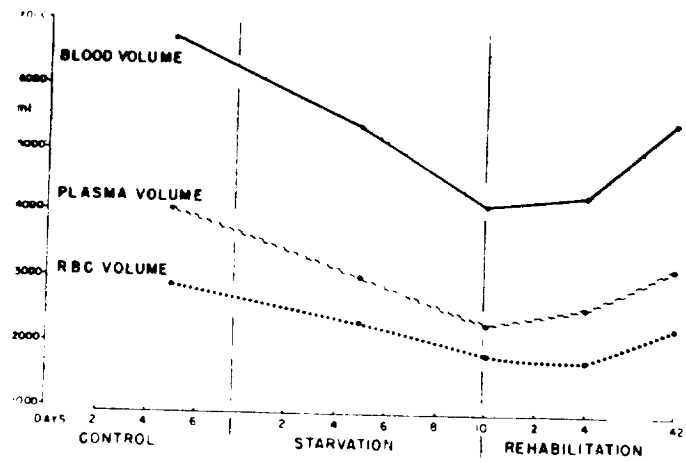
The second study extended starvation to ten days with fluid given ad libitum (15, 17). Body weight decreased progressively for the six male subjects averaging 1.44 kg on day one and 0.35 kg on day 10. Total weight loss averaged 7.27 kg or 9.5%. Fluid balance (sensible and insensible loss) averaged 1.2 kg/man on day 1 and 0.36 kg on day 10. Figure 14-19a represents the loss in blood plasma, and r.b.c. volume during starvation recovery. Figure 14-19b repre-

Figure 14-19

Blood and Metabolic Changes During 10 Days of Starvation with Water Ad Libitum

(After Consolazio et al[15])

a. Blood Plasma and Red Cell Volume



b. Daily Mineral Excretion in Urine,[a] Average/Man Per Day

Phase	Sodium, g	Potassium, g	Calcium, mg	Magnesium, mg	Chloride, mEq
Control	2.99	2.12	125	93.4	92.3
Starvation					
Day 1	2.32	2.10	104	69.9	84.8
2	1.84	1.54	141	111.6	38.2
3	1.77	1.58	107	170.0	12.1
4	1.98	1.77	156	150.5	11.8
5	1.95	1.50	166	94.2	9.0
6	1.98	1.59	157	114.4	12.1
7	1.87	1.56	151	75.2	10.0
8	1.78	1.30	126	68.9	9.4
9	1.67	1.21	104	67.0	7.5
10	1.56	1.12	67	37.6	6.8
Rehabilitation					
Day 1	2.00	1.44	117	45.4	23.6
2	3.33	2.06	175	40.9	72.5
3	4.12	2.31	193	37.7	97.2

[a] Values are means of 6 men.

c. Blood Electrolyte Changes,[a] mEq/liter

Phase	Calcium	Magnesium	Sodium	Potassium
Control	4.8 ± 0.3	1.63 ± 0.10	147.7 ± 3.4	5.6 ± 0.4
Starvation				
Day 1	4.7 ± 0.4	1.83[a] ± 0.14	147.7 ± 5.7	6.1[a] ± 0.2
5	4.5 ± 0.1	1.90 ± 0.36	142.4[a] ± 3.9	4.6[a] ± 0.5
10	4.5 ± 0.1	1.80[a] ± 0.00	142.1[a] ± 1.8	4.5[a] ± 0.4
Rehabilitation				
Day 4	4.3[a] ± 0.2	1.75[a] ± 0.05	142.1[a] ± 1.4	4.6[a] ± 0.2
16	4.3[a] ± 0.1	1.75[a] ± 0.05	143.6 ± 3.3	4.3[a] ± 0.5
24	4.9 ± 0.3	1.85[a] + 0.10	155.4 ± 8.0	5.3 ± 0.6
40	4.7 ± 0.3	1.70[a] ± 0.06	147.0 ± 4.5	5.1[a] ± 0.1

Values are means ± SD.
[a] Significantly different from control values.

sents the mineral excretion and Figure 14-19c the changes in blood electrolytes Large excretion of urinary nitrogen reflected protein catabolism. Other metabolic findings are detailed in References (15) and (17). Abnormal EKG's were noted in all subjects (17) and one subject had an abnormal EEG.

At the end of 10 days, the men were in poor condition mentally and physically with weakness and apathy noted. There was frequent lapse of memory, slowness in answering questions, and mental retardation. Muscle cramps were noted, probably due to intramuscular sodium deficiency (miner's cramps). Performance data are noted in Figure 14-20. The curves of Figure 14-20a show that oxygen uptakes and RQ are significantly altered during fasting. In Figure 14-20b submaximal treadmill work $\dot{V}_E$ BTPS and $\dot{V}_{O2}$ weight are shown to be decreased during both starvation and rehabilitation, probably indicating a training effect. The decrease in maximum aerobic capacity in Figure 14-20c during fasting was not statistically significant. Other maximal work measurements such as $\dot{V}_E$ BTPS pulse rates, and kg-meters of work per minute were altered in such a way during the rehabilitation period as well as during starvation as to indicate a training effect. Oxygen equivalents in liter of air ventilated per liter oxygen absorbed (STPD) decreased during starvation although the changes were not statistically significant. Oxygen pulses decreased slightly during fasting and oxygen debt after maximal performance decreased significantly from 5.3 to about 3 liters after 4 days of fasting and remained reduced during 4 days of rehabilitation. This suggests defective anaerobic metabolism. Other respiratory functions were not significantly changed.

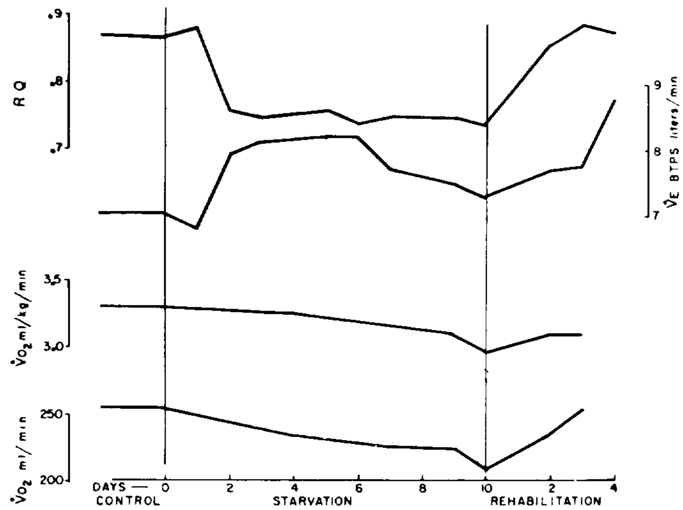
It should be noted that in one other 5-day acute starvation study, an average decrease of 31.6% in aerobic work capacity was reported (54). In the 4, 5, and 10-day studies reported above, there were no real differences in maximum aerobic capacity between control and fasting periods when the data were reported on a ml/min/kg basis. Anaerobic work was definitely impaired in both studies. The physiological basis for degradation of physical work performance during acute starvation is now under study (31, 60).

It appears that the rate of development and the degree of acidosis and dehydration attained are important contributing factors to the loss of fitness. This is especially important in arctic survival where the cold induces a diuresis and this, in turn, increases salt loss, dehydration and acidosis which reaches a peak at the end of three days (76). Orthostatic intolerance will probably increase with dehydration (see zero gravity environment, No. 7, page 7-116). It should be considered that the diuresis of early weightlessness may make an astronaut more sensitive to the dehydration and acidosis of starvation, especially if cold stress is present and vice versa. The additivity of these dehydrative stresses requires further study.

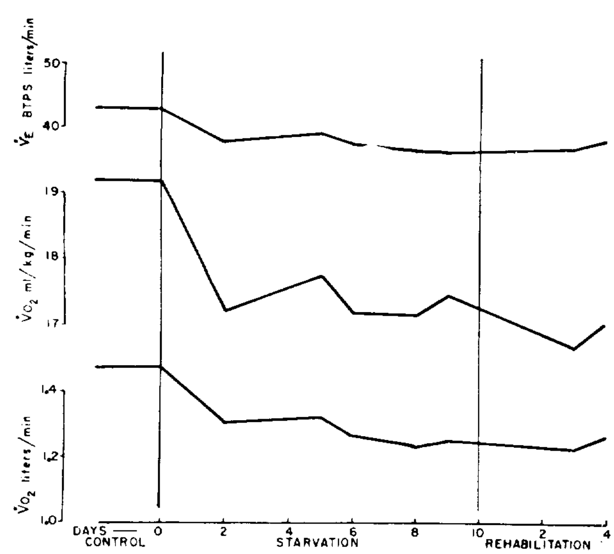
Current studies are focused on the relative effect of 400 Gm carbohydrate versus carbohydrate plus mineral supplement on the ketosis of acute starvation (52). Mineral supplementation with carbohydrate appears better since it reduces the great loss in body water and maintains a better mineral balance. Ketosis is ameliorated but negative nitrogen balance is only slightly improved, if at all. An optimum emergency ration of carbohydrate and minerals is needed for operations where acute starvation is a major hazard (45).

Figure 14-20

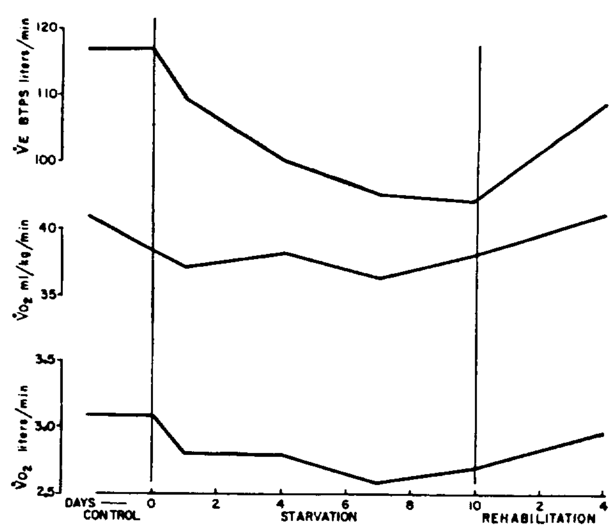
Exercise Performance During 10 Days of Starvation with Water Ad Libitum
(See text)
(After Consolazio et al[15])



a. Basal Metabolic Rate Measurements



b. Submaximal Work Measurements
(Note training effect)



c. Maximal Work Measurements
(Differences not significant)

Semistarvation

Degradation of performance after acute total starvation must be contrasted with the effects of a loss of 24 percent of the body weight and 430 gm of nitrogen as a result of six months of semistarvation (Figure 14-21) (49). During semistarvation there was a 41% increase in plasma volume and a 43% increase in extracellular fluid volume. The semistarved individual performs grade walking with no increase in the work pulse rate but finds that sustained performance of this type is difficult because of muscular weakness. Measurements of static strength show a marked deterioration. The semistarved individual's capacity for anaerobic work is markedly reduced (70 percent as measured by Harvard Fitness Test). The maximal oxygen intake per kilogram of body weight falls 25 percent and the ability to produce lactic acid during anaerobic work was definitely deficient. This deterioration in performance produced by semistarvation was not easily reversed. It takes up to 20 weeks of intensive refeeding for measures of fitness such as the maximal oxygen intake and the Harvard Fitness Test to return to normal.

The sub-tables of Table 14-21 compare the degradation in psychomotor performance after several different stresses with that following acute, total- and chronic semistarvation. The experimental conditions can be summarized as follows:

1. Semistarvation. The food intake was decreased from 3,500 cal. per day to 1,570 cal. per day for a period of 24 weeks. The stress resulted in a decline of body weight from 69.4 kg. to 52.6 kg (49).

2. Acute starvation with hard work. The men ate no food (water ad libitum) and walked on the motor-driven treadmill for four hours daily with interposed rest periods. These conditions resulted in a caloric deficit of from 3,500 to 4,000 cal. a day. (See Figure 14-18).

3. Hard physical work. The experimental regimen involved an abrupt increase in the amount of aerobic work. This was accomplished by increasing the assigned treadmill work from one hour a day at 3.5 m.p.h. on a 10 percent grade to six hours a day for two days and four hours a day for the third day. One-half hour of rest was allowed between work periods. This increased the approximate daily energy expenditure from 3,500 to 5,800 cal.

4. Heat Stress. Unacclimatized subjects were placed in experimental rooms with temperatures maintained at 115° to 120° F during the day time and 90°F at night, with a low humidity (25 percent). Work consisting of seven 10-minute periods of walking on a motor-driven treadmill at 7.5 percent grade and 3.5 m.p.h. alternated with 10-minute rest periods, was carried out on each half day of the experiment. Water was allowed ad libitum.

5. Lack of sleep. The stress consisted of a sleep deprivation of 62 hours. The physical activity was kept at the accustomed moderate level.

Figure 14-21

Comparative Effects of Acute Starvation, Chronic Semistarvation, and Several Other Stresses on Performance

(After Brozek and Taylor[6])

a. Handgrip Dynamometer, Kg

(S. D. = 8.3, based on N = 34.)

Stress	N	Mean change	F-test	D. R.†
Semistarvation	32	−16.4	214.95**	−1.98
Acute starvation	12	+ 0.5	0.26	+0.06
Hard work	10	− 2.8	36.00**	−0.34
Heat	12	− 2.7	18.53**	−0.33
Lack of sleep	12	+ 0.2	0.05	+0.02

b. Back-Pull Dynamometer, Kg

(S. D. = 27.8, based on N = 29.)

Stress	N	Mean change	F-test	D. R.
Semistarvation	29	−49.7	179.32**	−1.79
Acute starvation	12	− 7.2	3.97	−0.26
Hard work	9	−12.2	16.21**	−0.44
Heat	11	−15.3	12.69**	−0.55
Lack of sleep	10	− 7.1	7.68*	−0.26

c. Two-Plate Tapping, Number of Taps Per 10 Seconds

(S. D. = 5.4, based on N = 34.)

Stress	N	Mean change	F-test	D. R.
Semistarvation ξ	32	− 3.3	34.10**	−0.61
Acute starvation	12	−10.3	28.04**	−1.91
Hard work	10	− 1.7	5.41*	−0.31
Heat	11	− 1.7	1.61	−0.31
Lack of sleep	12	− 1.0	4.34	−0.19

ξ Paper-and-Pencil version of the test

d. Speed of Hand and Arm Movements, Number of Times a Ball Is Passed Through a Vertical Pipe in 1 Minute

(S. D. = 5.9, based on N = 34.)

Stress	N	Mean change	F-test	D. R.
Semistarvation ξ	32	− 3.9	31.49**	−0.66
Acute starvation	12	−11.0	16.78**	− 1.86
Hard work	10	− 5.2	16.49**	−0.88
Heat	11	− 4.3	4.15	−0.73
Lack of sleep	12	− 3.5	7.19*	−0.59

ξ Performed standing, not on the treadmill

* Change significant at the 5 percent level.

** Change significant at the 1 percent level

† Displacement Ratio (DR) $= \dfrac{M_C - M_E}{SD}$

where M_C = control mean

M_E = experimental mean

SD = estimate of the standard deviation of the control population

+ = "improvement", − = "deterioration"

Figure 14-21 (continued)

e. Complex Reaction Time, in 1/100 Second

(S. D. = 3.6, based on N = 34.)

Stress	N	Mean change	F-test	D. R.
Semistarvation	32	+ 3.2	26.59**	-0.92
Acute starvation	12	+ 9.0	19.80**	-2.50
Hard work	10	+ 2.1	11.37**	-0.58
Heat	11	+ 3.1	7.57*	-0.86
Lack of sleep	12	+ 1.4	5.65*	-0.39

f. Pattern Tracing, Number of Error Contacts

(S. D. = 13.3, based on N = 34.)

Stress	N	Mean change	F-test	D. R.
Semistarvation	32	+ 20.6	130.42**	-1.55
Acute starvation	12	+ 9.8	17.12**	-0.73
Hard work	10	+ 7.6	8.93*	-0.57
Heat	11	+ 6.4	3.76	-0.48
Lack of sleep	12	+ 0.1	0.00	0.00

g. Pattern Tracing, Length of Error Contacts in 1/4 Second

(S. D. = 7.5, based on N = 34.)

Stress	N	Mean change	F-test	D. R.
Semistarvation	32	+ 6.1	68.29**	-0.81
Acute starvation	12	+ 8.5	31.48**	-1.13
Hard work	10	+ 3.7	4.28	-0.49
Heat	11	+ 5.6	7.18*	-0.75
Lack of sleep	12	+ 4.0	9.69**	-0.53

The psychomotor tests were given daily in all the short-term stresses. For the present purposes only the maximal changes will be given. These changes represent the terminal period of the stress, the important exception being the heat stress in which the maximal changes occurred on the evening of the first day. In the semistarvation experiment the data were obtained in the last two weeks of the 24-week period of reduced food intake. The standard deviations SD and number of subjects in control N are recorded. Dynanometer grip studies in the 10-day starvation study noted above were significantly less than the control only on the 9th day of the study (54).

Following prolonged starvation, realimentation with high caloric diets constitutes a severe cardiovascular, gastrointestinal and general stress which can endanger life (39, 40, 76, 97, 101). This is most pronounced with diets of high carbohydrate. An increase in pulse rate and blood pressure is seen which may lead to heart failure. Realimentation must, therefore, be slow with broths of low carbohydrate content. This approach is recommended after retrieval of chronically starved crewmen in space operations.

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