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LIFE SUPPORT FOR MANNED PLANETARY MISSIONS.

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CURRENTLY FEASIBLE LIFE SUPPORT SYSTEMS, APPLIED TO MISSIONS OF TIME DURATION NECESSARY TO REACH MARS OR VENUS, THE LAUNCH WEIGHTS WHICH ARE INVOLVED, AND SOME PROBLEM AREAS

Code 2A

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In the near future we will see man orbiting and landing on the moon, and the establishment of an orbital space station. These things being accomplished, and man's ability to live and function effectively in space proven, the next logical step in the exploration of space is the manned orbiting and manned exploration of the planets nearest to Earth, Mars and Venus. The purpose of this article is to show the application of present technology to the problem of the support of man, within these vehicles, for these missions. A number of possible systems for the support of man for long-term missions within the solar system are discussed, in relation to the systems which are currently being developed for manned space stations and other shorter term missions. The trade-off of weight as a function of time for these systems is discussed, together with a summary of the problems relative to man's influence on these systems, as well as the problem areas foreseen for these systems.

The first consideration for systems for manned planetary missions is the effect that the mission length has on these systems. These systems must operate for much longer periods than those currently planned for manned space stations because of the impossibility of providing resupply for these planetary missions.

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As a result, these long-term systems must differ somewhat in operation and construction.

The current state of the art indicates that it is possible to support men in a space environment for periods of time up to 3 months or so without resupply. It is not meant that the hardware required exists today; however, the technology does exist so that, with good engineering design and system integration, it is possible to support men for these time periods with a launch weight expenditure of about 400 pounds per man. These systems include the following processes as shown in figure 1: carbon dioxide removal, oxygen supply, or, if sufficient power is available for these missions, perhaps oxygen reclamation; water recycling to recover water from urine, washing, and humidity control; as well as contaminant control. Not included is the food supply necessary for man.

The systems which are being considered at this point, the 3-month systems, have some inefficiencies or some lack of balance, which must be made up in the form of stores, either carried along with the initial launch vehicle or resupplied at periodic intervals. For example, the water reclamation for these missions will probably not recover water contained in the feces of the occupants; thus some 1/4 pound of water per man per day will be lost for use. For these missions this loss is probably justified since the weight of systems to recover this water would weigh more than the water which is lost for use during these time periods. In a similar fashion, if regenerable carbon dioxide removal systems only are used, then oxygen supplies must be provided in the form of stores. If, on board these vehicles, there is available sufficient power to afford the reclamation of oxygen from the carbon dioxide, there will still be some amount of oxygen storage required, on the basis that there is contained in the expired carbon dioxide somewhat less oxygen than is consumed by the occupants.

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Consider first the concepts which are suitable for these tasks; those systems which are currently being designed for the medium-term mission and which could be utilized for planetary missions if large weights of stores could be carried in the launch vehicle. (A summary of these systems appeared in the September 1962, Astronautics, as a part of a space station issue.)

In figure 2 is shown the weight of the environmental control system at launch per man, including a power penalty of 300 pounds per kilowatt of power required by these systems for their operation. This penalty of 300 pounds per kilowatt appears to be reasonable when using solar cell arrays. (For this use, nuclear power supplies are believed to be too far in the future for application, and fuel cells are not applicable because of their large weight for missions of this duration.) Shown here are the weights of systems used to control the environment within this spacecraft, including oxygen supply, carbon dioxide removal, humidity control, contaminant control, and spares. The weight of these systems is shown as a function of time of use, in days that these systems are to be used. The weights shown are plotted on log-log coordinates to illustrate the importance of these expendable supplies; all of these relationships are simple linear functions of a base weight plus a weight per day of these expendables. The time period of interest for these planetary missions is that portion of the figure from about 200 to perhaps 500 or 600 days (the shaded portion of figure 2), as compared with the time of use for which they were designed, about 100 days. Figure 2 illustrates the fundamental concept that time of use is the most important factor in system weight, a concept demonstrated by the steep slope of the curves (1 and 2) which utilize the most supplies. These systems use one of the following means to achieve this environmental control: (1) cryogenic oxygen supply and molecular sieves to remove carbon dioxide, these sieves being regenerated by exhausting this

carbon dioxide to the vacuum of space; (2) partial reclamation of carbon dioxide, methane being exhausted to space; (3) complete regeneration of all the oxygen contained in the expired carbon dioxide; and (4) photosynthetic reactions.

These systems are not charged with the thermal control or with the supplies to make up for vehicle leakage; however, all these systems have been charged with the amount of oxygen which is required to balance the cycle. The steep slopes associated with the lighter weight systems reflect their need for added supplies; and the greater base weights and flatter slopes are associated with those components which recover more of the waste products. Again, all these systems are penalized at a rate of 300 pounds per kilowatt of power used in their operation. The large base weight associated with the photosynthetic reaction demonstrates the large volumes of water media currently needed to support the algae and the large surface areas or power penalties needed to illuminate them.

In a similar manner, figure 3 shows the weight as a function of time of mission for water management systems, including the reclamation of water from urine, washing, and from humidity control and the weight of the waste management system. These systems are charged with the water lost for use which is contained in the feces as well as any water lost for use in the reclamation process. In this figure are shown two processes for the reclamation of waste liquid: (1) the compression-distillation process, which achieves its purification by passing the waste liquid through a vapor phase and then condensing the vapor to potable water and (2) a process operating on the electrodialysis principle, which achieves the purification of the waste liquid by transferring the unwanted ions through a membrane as a result of the application of an electrical potential. Both of these systems presently require some pretreatment or post-treatment of the water. Also shown in this figure as dashed curves are two theoretical systems which, in

addition, are capable of reclaiming for use the 1/4 pound per man per day of water contained in the feces and which have an overall estimated efficiency of reclamation of all waste liquid of 96 and 99.5 percent, respectively. Efficiency in this case, is output quantity divided by input quantity. It can be seen from these theoretical curves that better efficiencies than are now available are required for these planetary missions, from a standpoint of vehicle launch weight.

The weights which are given in the preceding paragraphs (and shown on these two figures) are not to be taken as firm, fixed numbers. Improvements in these systems can and will alter the picture considerably. Breakthroughs, better design, more efficient systems, and better systems integration can result in a decreased launch weight by reducing the basic weight of this hardware or, perhaps more important in the case of the long-term mission, improvements in the efficiencies will reduce the need for expendables and thereby reduce the weight which must be carried along on these missions, this decrease appearing as a decreased slope on these curves.

Thus far, these figures have shown the weight of systems which were designed for 3-month missions applied to missions of duration necessary to reach the nearest planets; these longer missions require that the launch weight be increased to approximately 860 pounds per man for the environmental control and the water management systems combined or to a weight more than double the weight necessary to support men for a 3-month mission. Furthermore, the weights shown have not included the weight penalties necessary to provide food for the occupants of these vehicles. None of these systems shown, with the possible exception of the photosynthetic system, is capable of providing food for these men. It becomes necessary then, to provide food as an expendable, at the least possible cost in vehicle launch weight. For these applications the use of freeze-dehydrated food is

probably most economical; this food has about 90 percent of the water removed from it before packaging and results in a weight reduction of about 50 percent. (For use, this food is mixed with water from the water management system and consumed.) The cost, in terms of vehicle launch weight for this food $\left(1\frac{1}{2}\right.$ pounds per man per day$\left.\right)$ for a 500-day mission, for example, would amount to some 750 pounds per man. (The present state of the art as regards the possibility of providing some or all of this food from a photosynthetic system is not particularly promising and will not be considered here.) This food, when mixed with water and eaten, is utilized by the body to provide energy and to maintain life. This utilization involves the oxidation of the food with the oxygen that is breathed.

Table I shows the approximate water and oxygen balance of a man in a closed environment. By using the best approximations that are available, the table shows that man consumes about 2.00 pounds per day of oxygen in breathing and exhales about 2.25 pounds of carbon dioxide. The oxygen in this carbon dioxide amounts to some 32/44th of this 2.25 pounds or about 1.64 pounds per day, some 0.36 pound per day less than was consumed. On the other hand, the excess of water produced by man, by his metabolic process, amounts to some 0.70 pound per day, this water containing some 0.62 pound per day of oxygen. Reducing this 0.62 gain by the 0.36-pound shortage in the carbon dioxide results in an excess of some 0.26 pound of oxygen per man per day, which is in the form of water, weighing some 0.29 pound. Thus, if nearly all the water in the wastes of the body were reclaimed - that is, the water contained in the feces reclaimed as well as that in the urine, in the wash water, and from the humidity control system, not only would oxygen make-up for the oxygen reclamation system be unnecessary but also some small inefficiencies in the water management system could be afforded. The

decision as to what efficiency is required will depend on the weight trade-offs for these systems including the vehicle leakage. It should be emphasized again, however, that these numbers are variable and depend on man, his environment, work load, diet, and so forth. The magnitude of these numbers, on an average, for people who may be making such space trips is not well defined here on earth, to say nothing about the variations which may exist in a zero or partial gravitational field. The fundamental principle, however, is valid, that man produces more water, or oxygen in this water, than he consumes, this surplus coming from the food that is eaten. With a completely closed system such as the photosynthetic system, this is not true, for this surplus is only existent when food is stored, not produced, by the system.

By applying this 0.70 pound of surplus water, which is obtained by a water management system which is about 99.5-percent efficient, to the make-up of the oxygen reclamation system, the launch weight of the vehicle can be significantly reduced. In figure 4 the total weight of both the environmental control and the water management systems is shown as a dashed curve (curve 2). Shown also, for reference, is the best of the near-future state-of-the-art systems which are now in the research and development state (curve 1). None of these weight penalties include the expendables for make-up of leakage and for thermal control, since these depend heavily on vehicle structure, vehicle atmospheric pressure, and duration of the mission. In addition, these curves do not reflect the weight of stores for food. Shown also, is the current estimate for the weight penalty for the 3-month missions. The near-future curve does not intersect this point, since this curve was generated by systems which are optimum for the longer time period. Even so, this figure shows that by optimizing the water reclamation system and applying these reclamation products to the make-up of the environmental control

system, substantial savings in launch weights can be had; the crossover point occurring at something less than 200 days.

Curve 2 on figure 4 represents the weight of the combined environmental control and water management systems at launch, necessary to support man for the time periods shown, these time periods enabling manned missions to the nearest of the planets. If the weights of the following are added to this curve (as derived from the particular vehicle configuration) thermal control systems, atmospheric gas storage to maintain vehicle pressure due to gas loss from leakage, and a supply of food, probably in the form of freeze-dehydrated food, a final curve representing the total launch weight for the life support system would be obtained.

For these missions, special attention must be given to a number of systems, aside from the problem of providing the necessary overall reliability and maintenance capability; most notable of these is the contaminant sensing and control system. This problem does not occur in the short-term, high leak-rate vehicles such as Mercury. With the low leak rate necessary for economy of launch weight, the problem of contamination of the vehicle atmosphere by materials outgassing and by the occupants themselves presents a serious problem. Atmospheric filters or subsystems which selectively oxidize or remove these contaminants must be developed, together with a sensor capable of both the identification and measuring of the concentration of all of the possible contaminants which may be harmful to the occupants. This area requires special attention, not because of the weight penalty associated with these systems, but because too little is presently known about the possible contaminants which men and materials will inject into this atmosphere and how man will react to these contaminants. Further, there is the problem of the design and production of a sensor which will be capable of both the

determination of the identification and concentration of all of the contaminants which may possibly occur over these time periods. This instrument must, in addition, be constructed as a "flight instrument," that is, it must be small, lightweight, have low power consumption, and be able to survive and function during the periods of the acceleration and vibration within the launch vehicle.

In summary then, some of the possible systems that are within the near future state of the art for the support of man for long-term missions to other planets within the solar system have been discussed. Outlined briefly are those systems necessary to sustain life and some details as to the weight and characteristics of these systems and of man in these systems.

Certain problem areas which are apparent when these systems are considered and which must be solved well in advance of any attempt to accomplish these missions are as follows: First, and certainly most obvious, is the problem of producing these life support systems, together with their instrumentation and controls which must function with the required reliability and economy to permit these missions. This problem lies not so much with the theory of operation, but rather with the design, construction, and evaluation of these systems.

Second is the problem area of man within this environment. Much more must be known about man in order to design and build these systems. For example, the solution to the contaminant control problem could, without much doubt, be solved readily if there existed with certainty the knowledge of what contaminants these materials and man are going to inject into this atmosphere, and, of equal or perhaps more importance, what maximum allowable concentrations of these contaminants man can tolerate for these time periods without suffering a degradation of performance.

Finally, there is the problem of what numbers can be expected in terms of pounds per day per man, with respect to oxygen uptake, carbon dioxide output, water production, and nutritional balance. All these factors must be considered within a zero or partial g environment, within reasonably confined quarters, and for these time periods. The solution to these problems can probably only be obtained by experiment with man in such vehicles as space stations for these time periods.

Figure 1 - Life support system for medium duration mission.

Figure 2 - Environmental control system.

Figure 3 - Water management system.

Figure 4 - Oxygen and water balance.

Figure 5 - Combined environmental control and water management systems.

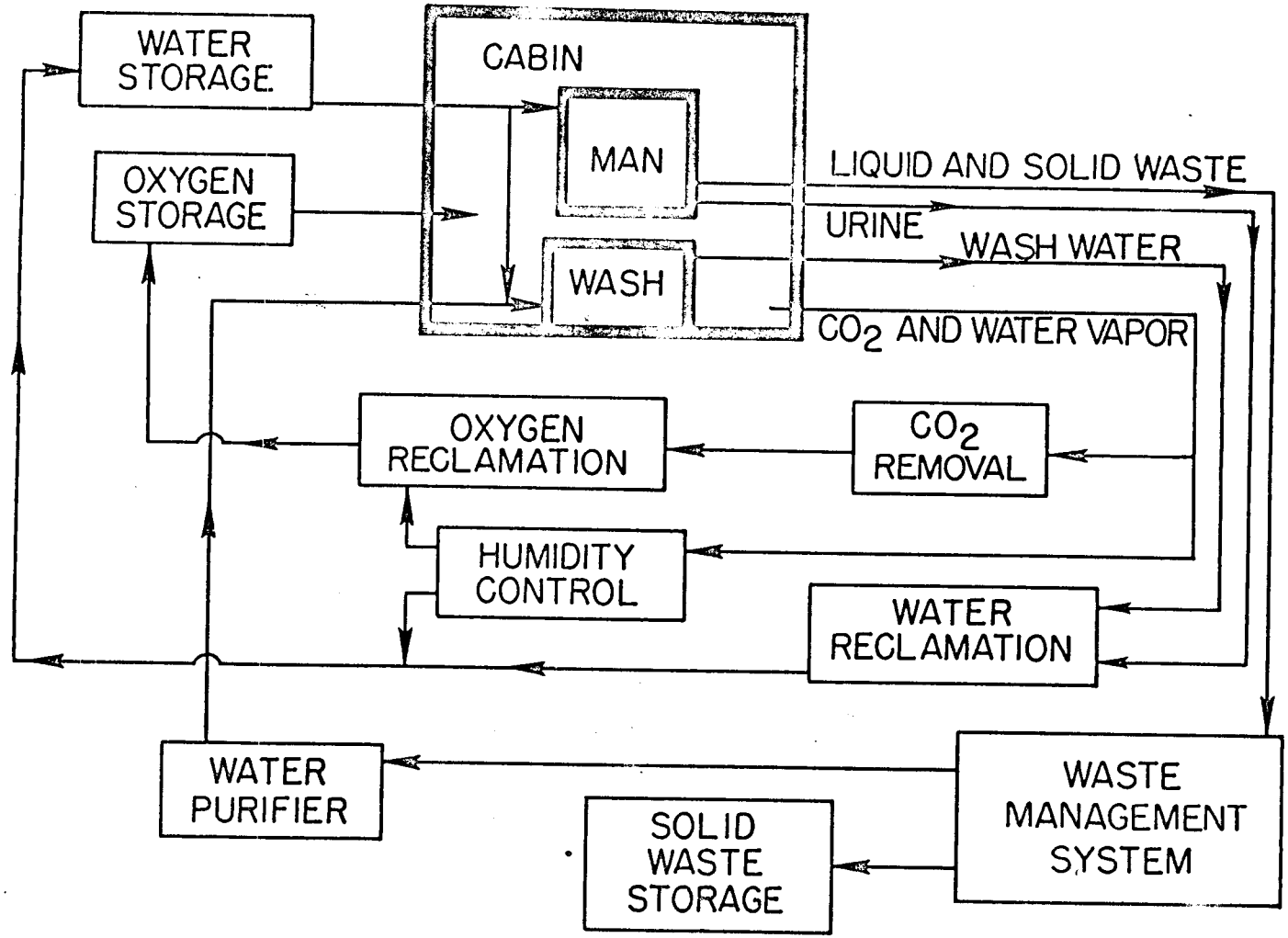

Figure 1

POPMA

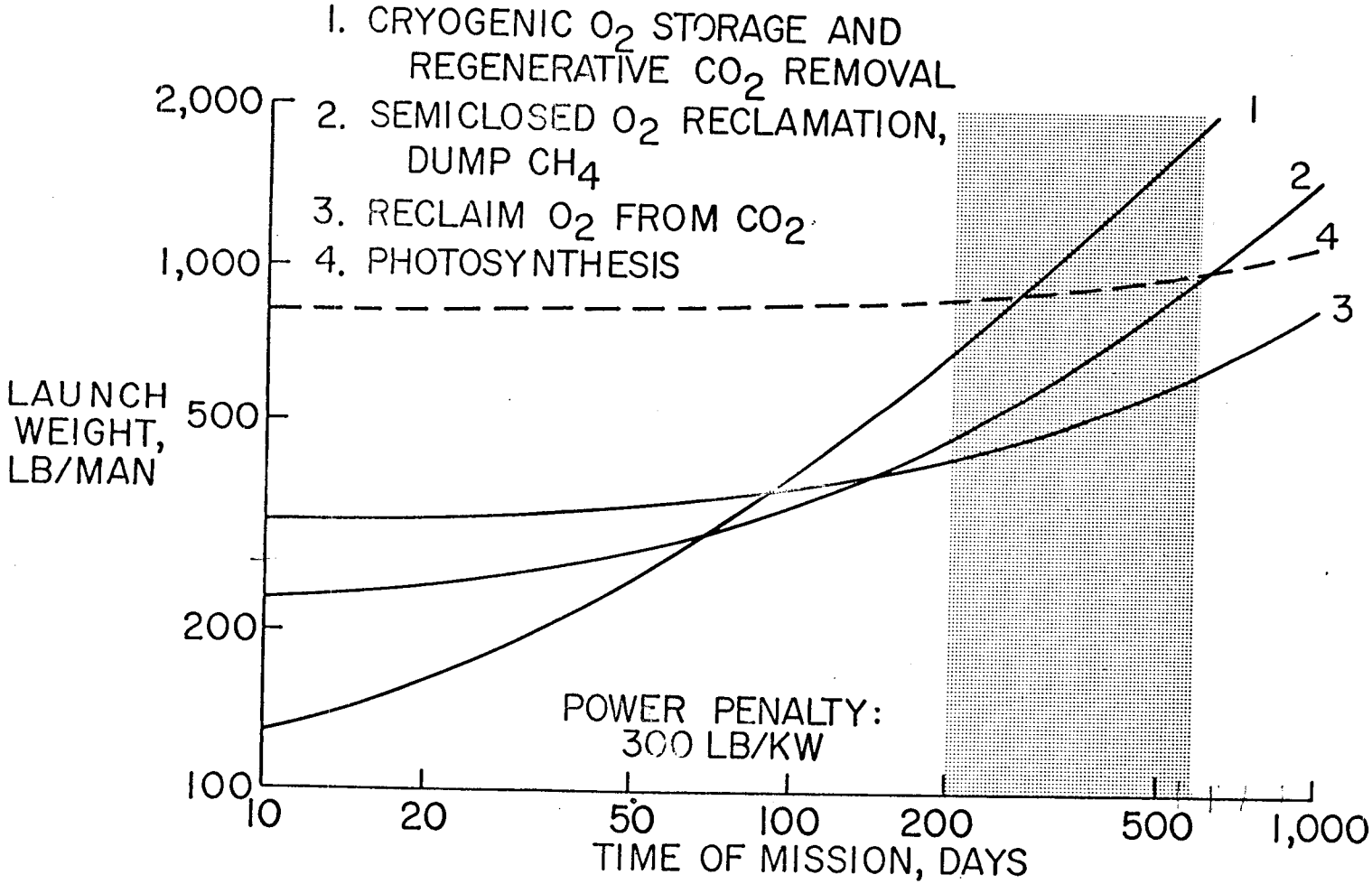

Figure 2

POPMA

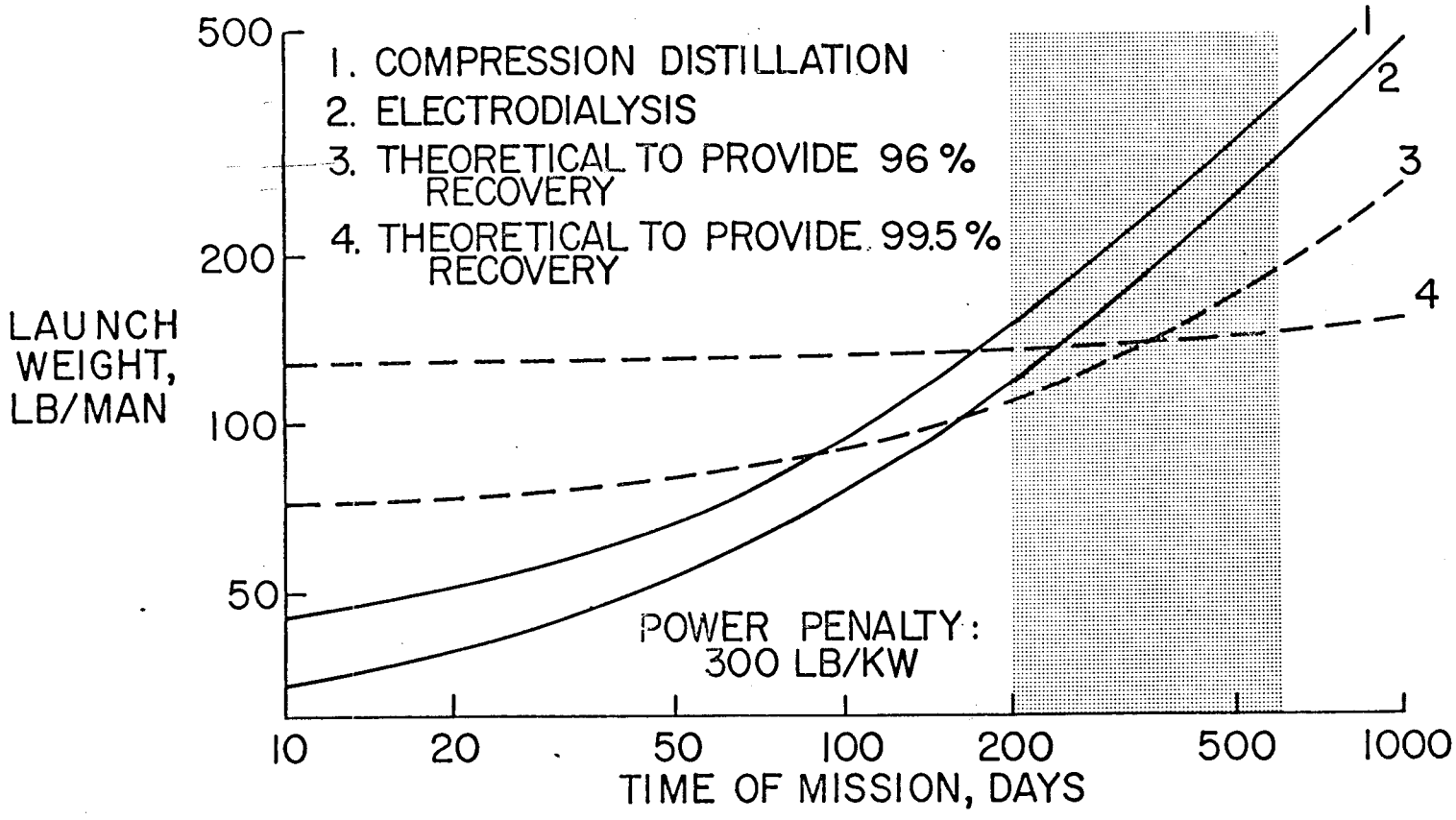

Figure 3

POPMA

INPUTS, LB/MAN-DAY		OUTPUTS, LB/MAN-DAY	
FOOD & DRINK	4.80	URINE	3.05
METABOLIC WATER	0.70	FECES	0.25
		EVAPORATION	2.20
TOTAL	5.50	TOTAL	5.50
O_2	2.00	CO_2	2.25
		(1.64 OF O_2)	

SHORTAGE:

2.00 OF O_2 CONSUMED

-1.64 OF O_2 IN CO_2 EXHALED

0.36 LB/MAN-DAY SHORTAGE OF O_2 FROM RECLAMATION SYSTEM

GAIN:

0.62 LB/MAN-DAY OF O_2 CONTAINED IN 0.70 LB/MAN-DAY OF METABOLIC H_2O

NET GAIN:

0.62 OF O_2 GAIN

-0.36 OF O_2 LOSS IN RECLAMATION OF CO_2

0.26 LB/MAN-DAY OF OXYGEN, OR 0.29 LB/MAN-DAY OF WATER

Figure 4 POPMA

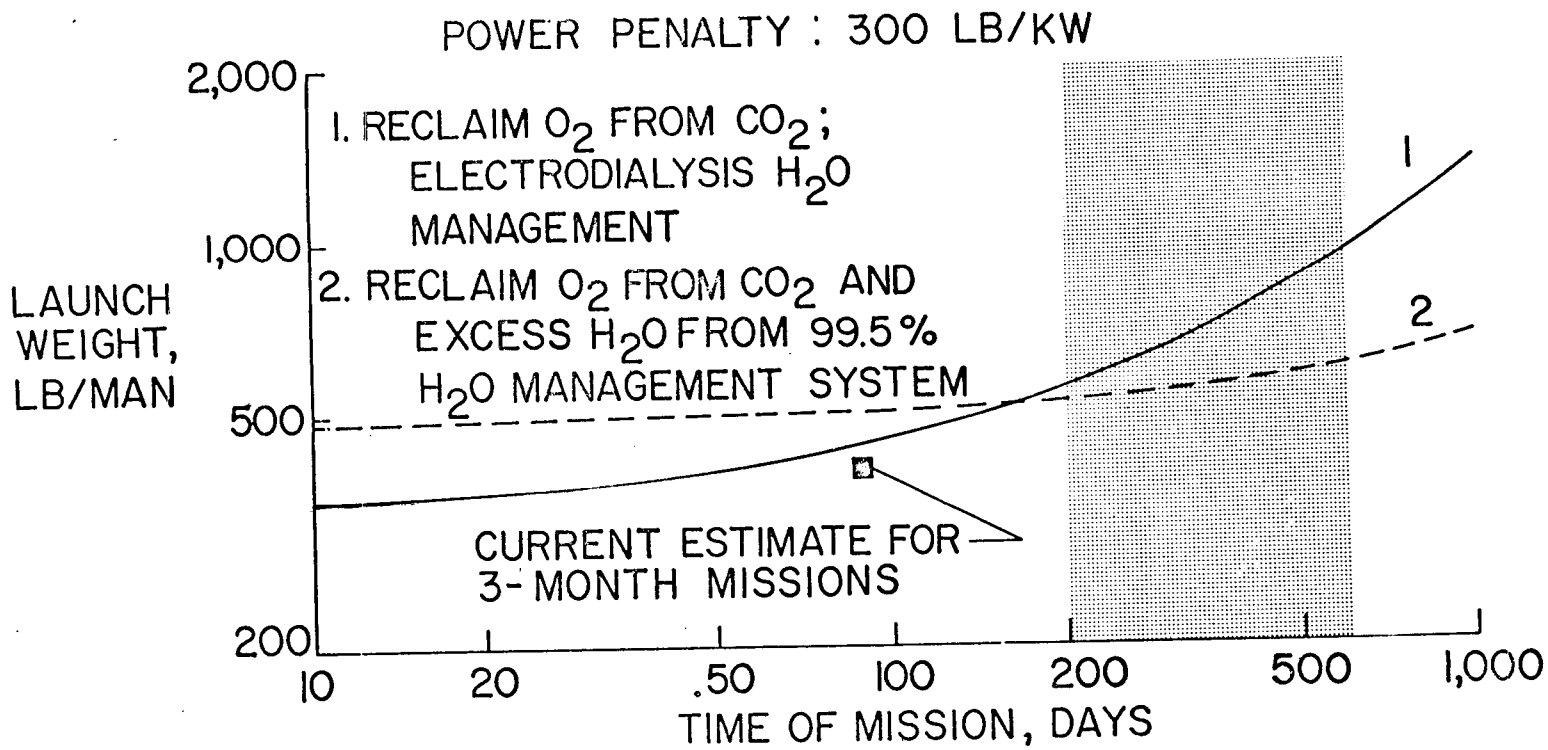

Figure 5

POPMA