SOCIETY OF AUTOMOTIVE ENGINEERS, Inc.
485 LEXINGTON AVENUE
NEW YORK 17, N.Y.

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INTRODUCTION TO LIFE-SUPPORT SYSTEMS FOR EXTRATERRESTRIAL APPLICATION

PREFACE - This report is an introductory treatment of life-support systems for extraterrestrial application and serves to make an initial step in organizing currently available information on the subject. It is designed to illustrate the need for further more detailed treatment of many areas, including:

Requirements for life-support systems
Instrumentation and control in life-support systems
Reliability aspects of life-support systems
Testing of life-support systems

It is intended that SAE Committee SC-9 will continue to develop such areas to the extent required by the industry.

1. PURPOSE - This report was prepared in order to:

   a. Examine the disciplines of sciences and engineering which are involved in design, manufacturing and operation of life-support systems for use in spacecraft.

   b. Indicate the present extent of knowledge.

   c. Recommend areas where additional knowledge is most urgently needed for near future applications.

2. CONCLUSIONS

2.1 For mission durations which will be encountered in the immediate future, it is concluded that there is a definite need for continuous major effort to provide lightweight gravity insensitive (or reduced gravity) equipment systems for the following:

   a. Removal of carbon dioxide and other contaminates from local atmosphere.
   b. Recovery of oxygen from carbon dioxide and/or water.
   c. Potable water recovery from urine and hygienic water.
   d. Waste collection, handling, treatment and personal hygiene.

2.2 For extended mission durations and large multi-manned vehicles, more sophisticated systems will be required for the above areas, and additional problem areas will be encountered. Among these are:

   a. Minimized heat leakage and wall condensation.
   b. Atmosphere stratification in large compartments.
   c. Compartmentation, pressure lock operation, and decompression.
   d. Long-term atmosphere storage.
   e. Integration of multiple subsystems, including space radiators with structure.
   f. Extravehicular and intervehicular operations.

g. Resupply, maintenance, emergency operation, and long-duration system monitoring.

These problem areas will be discussed in future revisions of this information report.

2.3 Additional development is required in all of the hardware areas to improve the ability to provide systems of minimum weight and maximum reliability.

2.4 Life-science requirements are sufficiently complete to guide development of equipment. Application of general engineering, physics, chemistry, etc., and ingenious designs are needed. Better knowledge of the external environment (meteoroids, composition of lunar soil, etc.) is needed for future designs.

Further work is required in the life-sciences area to more adequately define physiological limits and extremes. This is particularly true for multiple stress conditions, pressure-suit conditions, and other conditions unique to space flight.

3. DEFINITIONS

3.1 Life-Support System - A life-support system is commonly defined in the industry as a system which provides elements necessary for maintaining human life and health in a state required for performance of the prescribed mission. In its function, a life support system, depending upon specific design requirements, will provide suitable pressure, temperature and composition of local atmosphere, control carbon dioxide and water vapor, dispose of wastes, and supply food and water. Depending on the length of mission and number of crew members, it may or may not reprocess wastes such as carbon dioxide, water vapor, urine, feces, etc.

Life-support systems may differ widely depending on mission requirements, such as normal operation, escape, emergency, parking, moon landing, etc. In all cases, time of the operation is a very important design factor.

A life-support system is sometimes briefly defined as a system providing atmospheric control, water, food, thermal management, and waste management.

3.2 Life Sciences and Bioastronautics - Life sciences are, collectively, the discipline of sciences concerned with basic information on life, its processes, chemical reactions, requirements, by-products, response to different conditions, etc. Bioastronautics is a term which denotes the spectrum of scientific, technical and engineering research, development and applications related to the support of man and the preservation of his effectiveness in aerospace systems.

3.3 Human Factors - The science of human factors is devoted to determination of human (although it could include other living creatures) machine relations, establishing best shapes, arrangements, physical layouts of work and rest area, etc., in order to obtain best overall performance. Human factors is often considered to be a part of life sciences.

3.4 Application of Definitions - Both life sciences and human factors along with a multitude of other sciences, such as thermodynamics, chemistry, mechanics, etc., supply vital information for the design of the life-support systems as well as many other systems. This comment is made because in some cases confusion exists in using the above definitions.

To repeat: life sciences supply basic information on life, which defines the requirements that must be met by a life-support system.

4. GENERAL REMARKS - In order to evaluate the status of the life-support systems, two areas were surveyed:

a. Availability of design information
b. Status of equipment and systems (hardware)

Required design information encompasses large numbers of different scientific disciplines and it would not be practical to list them all in detail. The list concentrates on areas where there is lack of information to the extent that it may impair satisfactory design of life-support system.

A small number of life-support equipment and systems have been built in the industry. An attempt is made to list most of them and point out their limitations and need for further work.

It can be visualized that there are cases in which equipment could be built except for lack of specific design requirements of data, or where design data is available but engineering knowledge is insufficient to design satisfactory equipment. It is also possible to have so little data that no intelligent guess as to a possible design or even need of equipment or a system can be made.

In some other cases the system could be improved somewhat but not to the point that existing systems should be considered inadequate. In the continuous effort to save weight, there is no definite line between completely satisfactory system and one which needs more development.

Length and type of the mission influence to a large extent the detail information needed and the approach to the equipment design. Proper design approaches for shorter missions, for example, may not be satisfactory for longer missions and new principles may have to be applied.

5. DESIGN INFORMATION

5.1 Life Sciences and Human Factors

5.1.1 Information sufficient to design life-support systems for from a few hours to 90-day missions is presently available. Short mission duration flight systems have been built, and longer ones are in the design stage. More accurate design data, if it were available, could reduce to some extent the design conservatism that has been used to take care of uncertainties. The importance of eliminating or reducing conservatism based on imprecise or inadequate design data is particularly important for long mission lengths. In general, the lower cabin pressure, less oxygen, food and water given to man, the lower the overall weight of the system. Also, the higher the cabin temperature, and the higher concentration of carbon dioxide and contaminants, the lower the weight will be. There is a definite need for knowledge of extremes of local environment which can be sustained for long periods and, connected with this, the human energy and matter balances. Since water is the largest weight expendable item required to support life, it is especially important to establish accurate design data as a function of the environment and the mission made, i.e., with the crew in or out of protective garments. The amount of mechanical energy provided by man for operation of equipment during long periods should be established for near zero-g and for .16 g. Also, more definite requirements for the local atmosphere needed to be defined, including the significance of trace contaminants.

Extreme limits for long time emergency conditions are important. Emergency is understood as a condition where normal human functions may be limited, health may be impaired but with large probability of recovery and survival after successful termination of the emergency.

Although the above information is needed and can improve designs, it is felt that for the near future (5 years) lack of additional life sciences information will not impede the progress of evolution of life-support systems.

Food for the original short space flights has been largely of the "snack" variety and was comprised of minimum quantities and minimum variety for obvious reasons. This will not be permissible or desirable for future, longer missions. With the emphasis always on the maximum efficiency of the crew, intensive effort will be justified toward variable, palatable, and nutritious diets.

The effect, if any, of the extended zero-g condition on the required diet is unknown at this time.

5.1.2 On human factors, as with life sciences, there is sufficient information for current and near future designs, although these designs may not be the optimum.

More information on arrangement and design of equipment for servicing and repair and maintenance in weightless condition is needed. It is very important to establish compatibility of man in a space suit with functions to be performed and equipment to be operated. The life-support system is indirectly affected since it has to be integrated with the protective suits as well as with the vehicle design.

5.2 Extraterrestrial Environment

5.2.1 The natural environment has a large influence on the thermal management aspect of the life-support system. Most of the heat rejection is accomplished by radiation into space, and detailed knowledge of the radiant interchange between the spacecraft and its environment is therefore important. Radiator surfaces can be damaged by meteoroid and cosmic dust and by radiation affecting the thermal properties of the radiator surfaces. Knowledge of the physical and chemical properties of the lunar soil is important for advanced system design because of its possible application as a heat sink and as a source of water and oxygen. Although shielding is not a function of the life-support system, but of overall vehicle design, it may affect the life-support system because the use of food, water, wastes for shielding is possible. Knowing the amount and degree of radiation at all times as well as predicting of solar flares is important. Environment in the vicinity of earth and moon is of prime interest; environments around the planets Mars and Venus are becoming of interest.

In conclusion, data on cosmic dust and meteoroids and properties of lunar surface are urgently needed for the near future designs.

5.2.2 Environments induced by the operation of the vehicle may influence the design of the life-support system and should be well defined. Vibration, noise, acceleration, thermal radiation, nuclear radiation, impact of dust and debris, hot gas blasts, etc., can be generated by the vehicle itself and by other vehicles operating nearby. Induced environment is a function of vehicle design and operation, but in many cases its final effect is a result of its combination with the natural environment. If natural environment is well defined, then from definition of vehicle operation the induced environment can be established.

5.3 Thermodynamics and Heat Transfer - Life-support system design involves substantial use of thermodynamics, flow of fluids, heat transfer, etc. Good data are available in most cases; however, more information is needed on boiling and condensing heat transfer in low-g conditions. Also, data on heat transfer properties of different materials are often not sufficiently accurate (see AIR 732). Satisfactory designs of near future systems will not be impeded by the lack of thermodynamics and heat transfer data; however, some design conservatism will be employed to allow for uncertainties in heat transfer properties and mechanisms.

5.4 Chemistry and Physics - Certain functions of life-support systems, such as carbon dioxide adsorption and absorption, oxygen regeneration, water recovery from urine, etc., are designed around known chemical reactions, physical processes, or both. There is a large amount of general knowledge of applicable reactions and physical processes, but since many of them had no practical use in the past, there is a lack of sufficiently detailed information.

One exception is in water recovery from salt and brackish water which is somewhat similar to water recovery from urine. Here substantial studies have been made, and chemistry and physics of numerous processes are known. Many of them are currently under investigation for commercial applications and some may eventually be useable in space.

For near future designs better knowledge of existing reactions and processes and possible new discoveries are definitely needed. Lightweight carbon dioxide, oxygen and water management systems are important for longer time missions. Present methods with weight proportional to time impose large penalties as the time of operation is extended. Need for water recovery was temporarily de-emphasized for medium time missions, because the use of fuel cells for non-propulsive power was supplying sufficient water as a by-product. This may not be the case in longer missions. Better understanding of the physics and chemistry of carbon adsorption and absorption, oxygen regeneration and water recovery are urgently needed. These include chemistry of superoxides, Sabatier reactions, electrodialysis, osmosis, adsorbants, molecular sieves and similar devices, membranes, etc. Biochemistry and photochemical reactions have a long-range potential; processes based on growing algae are of interest, as they may be useful in the distant future.

5.5 General Engineering - In the design of life-support systems, as in any other complicated engineering designs, many inputs are required which can be classified as general engineering and scientific knowledge. Specific benefit to life-support systems can be obtained from: advancement of methods of gas analyses which can be adapted to lightweight and gravity insensitive equipment; advancement of lightweight compact quiet fans, compressors and pumps; lightweight leakproof valves exposed to vacuum and connected with seals, etc., which will not deteriorate in vacuum atmosphere.

6. EQUIPMENT AND SYSTEMS

6.1 Methods and Management of Local Environment - For the purpose of this discussion, pressure, temperature and composition controls are listed separately. In actual systems these functions are often integrated.

6.1.1 Pressure - In single gas systems, oxygen used for pressurization also supplies breathing needs. In two gas systems, control is needed to adjust the supply of oxygen and inert gas at different rates, since both are lost by leakage but only one is used in the metabolic processes. The simplest storage of these materials is in the gaseous form at high pressure (as was done in project Mercury). Larger amounts of gas can be stored more economically in liquefied form. Conventional liquefied gas insulated containers are satisfactory when gravity exists (moon, rotating space station). For low-g condition, gases are stored in supercritical conditions at cryogenic temperatures. The storage of two-phase, subcritical cryogenic fluids for zero gravity application is currently under development and appears promising. Chemical storage will have appeal for some missions. The closed gas regeneration systems of various types may be used for the longer missions in the future. Storage methods are well developed (although not all have been tested in low-g condition), and no serious problems are anticipated. However, further efforts must be made to obtain an approach to more efficient zero gravity storage.

6.1.2 Temperature - Heat can be transferred to outside walls through the vehicle structure and can be disposed by radiation to space. Space radiators can be used with intermediate heat transfer fluid loops. Expendable heat sinks, such as boiling water, are feasible and, also, heat can be disposed of to cold fluids which are used in the vehicle for other purposes. (For example, cryogenic hydrogen which is needed for a secondary power unit.) All these methods seem to be well developed and laboratory hardware has been designed and built for all of them (in some cases they have been tested in actual operation.) Lack of accurate design data mentioned before, that is, boiling heat transfer coefficient under low-g condition and damage to radiators by meteoroids or radiation, leads to overly conservative designs. Sublimation heat transfer equipment will require additional development.

6.1.3 Composition - So far, only rather primitive methods of absorbing carbon dioxide chemically and control of contaminants by filtering through activated carbon have been used and designed for the near future. Since the amount of chemical is proportional to the carbon dioxide absorbed (time and number of occupants) longer missions lead to large weights. A lightweight, reliable system is needed which should have weight basically independent of mission time. Such systems can use regenerative absorbants, change of state of gas, or similar approaches. Extensive laboratory work with systems using molecular sieves has been done and some flight equipment has been built; however, no tests in actual flights have been performed.

Considerable weight saving can be made on the amount of stored oxygen if part of the oxygen can be recovered from carbon dioxide. This is especially important for longer missions. Extensive laboratory work has been done in this field with laboratory equipment built and operated. However, work has not progressed far enough to have flyable experimental equipment. For very long periods, algae systems based on photochemical reactions on living matter have been considered, and numerous laboratory tests were made. However, it cannot be expected that these systems will be applicable in the near future. Many contaminants which cannot be filtered by activated carbon can be oxidized in the presence of catalysts. This process is in-