AEROSPACE AND UNDERSEA MEDICINE

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GENERAL NEUROLOGY

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Introduction

The nervous system provides the substrate for consciousness and is the principal organ and motivator of behavior. In this master system various mechanisms integrate so as to produce levels of alertness, arousal or drowsing. These internally located and diffusely acting components probably relate very closely with the thermoregulatory systems of the body as a whole and,in conjunction with these and other homeostatic mechanisms,provide for the cerebral metabolism of consciousness. Obviously, one of the several human requirements of prolonged space flight will be imposed by the altered cycles of wakefulness and drowsing or sleeping. Necessarily, the operational requirements of the craft will impose arbitrary schedules of watchfulness, wakefulness and sleeping. This artificial duty cycle may or may not coincide with the natural requirements of the brain. The determination of the most applicable duty cycle is a principal neurological requirement among all the others which aggregate as the medical requirements for manned space flight.

Generally speaking, the nervous system is the organ of communication. Thus in 85% of human brains, verbal communication is represented predominantly on the left side while much of non-verbal communication may be represented on the opposite. Conversely, 5% of persons owe their verbal communication capability mainly to the right hemisphere and the non-verbal to the left. The remaining 10%

probably have left sided verbal communication and are left handed. Handedness, obviously, has some relationship to the cerebral lateralization of communication capability. The majority of persons are right handed and have a predominance of communication capability in the left hemisphere. This probably applies to the 85% just noted. 10% are left handed and also have left predominance for verbal speech, while 5% probably have right predominance and are truly left handed. Just as obviously, motor performance unrelated to handedness and even so related is a contralateral function. That is, left hemisphere generally exercises a major control in right motor functions while the opposite applies to the left motor function. Thus, speaking superficially, one might say that both communication and principal motor tasks have critical lateralization requirements within the nervous system. That is, they are specifically oriented to side. One of the characteristics inherent in weightlessness is disorientation to side, or more generally, disorientation to a rectilinear environment. Could one not ask the question, what effect does weightlessness have on motor competence and, specifically, on the competence of the so-called predominant hand? Also, is there any relationship between the lateralization of speech as predicted in the astronaut and his communication during weightlessness? Thus, would a tape of his operational communication taken in the pre-flight status compare meaningfully to similar tapes taken in flight and post flight status? Spectrographic analysis could be used for this evaluation. It seems likely that right-left disorientation and reduction in communication capability might be critical characteristics of the weightless state which await objective evaluation.

If much of human memory is dependent upon verbal symbolism, then reduction in verbal communication capability might impose a burden on recent memory and this should be tested. Similarly, if primitive memory is spatial rather than verbal thus relating the organism in its infant state to form and space rather than to word and other verbal symbols, does weightlessness disorient this spatial memory? Should memory tests of a simple nature be included in the in flight experimental status list and, of course, controlled by pre- and post flight test?

With these and other questions in mind, the following task list is included for the draft:

1. <u>Communication</u>
   a. Verbal: oral, written
   b. Non-verbal: CW (Morse), semaphore and symbolic
   c. Cerebral dominance and handedness
   d. Auditory
   e. Visual

2. <u>Orientation</u>
   a. Right-left
   b. Form, space, distance
   c. Temporal

3. <u>Memory</u>
   a. Verbal: recent and past
   b. Non-verbal: recent and past

4. <u>Arousal-drowsing cycle</u> (sleep rhythm)
   a. Circadian rhythm
   b. Electroencephalographic evaluation: interhemispheral comparison by spectral power analysis and comparison of hemispheral relationships of sleep patterns
   c. Electrographic and continuous performance testing correlation and continuous performance correlation

5. <u>Temperature regulation</u>
   a. Correlation of body temperature with circadian rhythms
   b. Correlation of body temperature with arousal-drowsing cycle

c. Correlation of skin resistance and GSR with arousal-drowsing cycle
d. Correlation of skin temperature and GSR with alpha frequency determination and EEG

6. <u>Movement</u>

   a. Dexterity and hand power
   b. Extremity powers
   c. Gait

7. <u>Coordination</u>

   a. Rate, range and power
   b. Vestibular functions

8. <u>Sensations</u>

   a. Pain threshold
   b. Touch
   c. Temperature
   d. Pressure
   e. 2-point

SPECIAL SENSES

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Introduction

The importance of man's role in space and in the undersea environment is based in large measure on his flexibility in the face of novel situations, and his ability to respond to a variety of contingencies in an adaptable fashion. Such performance would be impossible for even the most carefully pre-programmed mechanical system. Man's special ability is based in large measure on his information processing capacity. The role of the special senses is of particular importance in this connection. In both the space environment and the underseas environment, vision is probably the most important of the senses, at least in terms of contact with the external environment. The sense of audition in both of these environments is completely dependent upon electronic communication devices for most of its information. The sense of touch will in most instances be attenuated by protective covering. The senses of taste and smell must be taken into account in connection with long missions, but not for their roles in information processing, primarily. Negative inputs must be avoided for these two senses where possible, although such inputs may provide information when equipment is not functioning properly and excessive heat or other causes generate odor. The vestibular sense is of considerable importance and will be dealt with extensively in subsequent lectures. The primary burden of this presentation will be a detailed discussion of the visual sense, followed by a brief consideration of the auditory sense and the vestibular sense.

VISION

The nature of the appropriate physical stimulus an some information as to the mode of exitation of the retinal receptors will be presented. There will be a brief review of retinal and visual physiology accompanied by a discussion of recent information in this area. The range of the physical stimulus over which the visual system functions will be discussed. Problems in light and dark adaptation will be considered and the mechanism which permits the eye to adjust its range of function will be discussed.

The spatial resolution capability of the eye will be examined. The modification of this capability with level of adaptation will be treated. Similarly, the variations in temporal resolution and the temporal resolution capacity of the visual system will be discussed.

One of the most important of visual capabilities, form discrimination, will be discussed in relation to recent findings in the electrophysiology of single cells in various locations in the visual system. Discussion will extend to the specialized coding of single cells for discrimination of form, motion and other aspects of the visual world.

Color vision will be treated briefly as it relates to problems in discrimination and as it is dependent upon the various characteristics of the visual system. Binocular vision will also be treated briefly.

AUDITION

The auditory stimulus and its appropriate range of characteristics will be considered. The anatomy and neurophysiology of the auditory system will be described briefly and comparisons made with the visual system with respect to discrimination, specialized neural systems and the like. The possible function of efferent systems in both audition and vision will be discussed briefly.

VESTIBULAR SYSTEM

The role of the vestibular system in a three dimensional world and unique differences between the system when suspended in a water environment and when freely floating in a space environment will be considered. Discussion of the vestibular system will be brief and serve merely as an introduction to later detailed presentations on this subject.

VESTIBULAR FUNCTIONS

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The object of this presentation is an attempt to provide a useful grasp of how the vestibular organs serve man under natural circumstances and how this servation may be perverted in artificial force environments. The first portion will deal briefly with the peripheral sensory organs, their central nervous system connections, normal functions, and functional disturbances. The second portion will deal with vestibular problems in weightlessness and artificial gravity.

Part I

The nonacoustic portion of the labyrinth comprises the semicircular canals and otolith organs, collectively termed the "vestibular organs." The six canals, bilaterally paired and oriented approximately in orthogonal planes, are uniquely structured to respond to the inertial accelerations generated by rotary motions of the head. The sensory elements, acting as transducers, convert mechanical to electrical energy, and the impulses are conducted to the central nervous system. They function as integrating accelerometers and subserve or contribute to such useful functions as sensing rotation, tracking and stabilization of the visual image, and maintenance of postural equilibrium.

The four otolith organs, bilaterally paired, consist essentially of curved macular plates with the otolith membrane containing calcium carbonate concretions (s.g. 2.72) resting on the hairlike projections of the sensory cells. Gravity, change of position of the head with respect to gravity, and linear accelerations exert shearing forces that cause the hairs to bend, thus converting mechanical to electrical energy. The tonic sensory input has important modulating influences and contributes to our orientation to the gravitational upright; the phasic input contributes to the maintenance of postural equilibrium and to locomotion.

One means of investigating the importance of the vestibular organs is to study the effects of loss of function through disease or injury in man or destruction of these organs in animals. Loss of vestibular function in birds, fish, and subhuman primates renders them unfit to live in their native habitat. On the other hand, persons who have lost the function of the vestibular organs early in life are not seriously handicapped. The difference here between man and beast lies not so much in the peripheral organs which function similarly as it does in the use of these sensory inputs for body orientation, locomotion, and visual acuity. With primitive man, the hunter and the hunted, the loss of the nonacoustic labyrinth probably posed a very serious affliction. Such loss due to injury, for example, would have been unlikely inasmuch as the vestibular organs are surrounded by strong bone structure. This great protection is made possible by the fact that mechanical linkage to the outer environment is not a requirement for their stimulation by gravity and inertial accelerations.

Under natural conditions, the behavioral responses to which the vestibular system contributes are characterized by automaticity, reliability, and egality among members of a species or subspecies. There is little if any manifestation of "disturbance" in vestibular mechanisms under natural conditions, implying that the incredibly complex integrative mechanisms intercalated between sensory input and motor output have been effected in elegant fashion. Potentially, this "elegance" is of such importance to the organism that it could have evolved only through natural selection and survival of the fittest. This backward look at our evolutionary development is enormously important in appreciating the harmony which characterizes functions subserved by the vestibular organs under physiological conditions and our inherent limitations in maintaining homeostasis when the vestibular organs are stimulated under unnatural conditions.

If it appears that in man there is a disparity between the magnitude of the vestibular system and its servation, this disparity disappears when one considers the potentialities of the vestibular system for causing disturbances. Such disturbances occur during exposure to unusual force environments, and the responses fall into two categories. One category involves the vestibular servation system, and includes such effects as nystagmus, illusions, and motor incoordination. Responses in the second category are in the nature of epiphenomena and are evoked by vestibular activity radiating beyond the servation system to cell assemblies which normally are not subject to vestibular influences. This may result in widespread absurd responses, and the symptomatology of motion sickness falls into this category. The great individual differences in response which are manifest when persons are exposed to unusual force environments are not easily explained, although they have their basis in the fact that nature did not anticipate man's ingenuity in manipulating the gravitoinertial force environment. A highly simplified yet useful model will be used in discussing these two categories of vestibular disturbances.

Part II

Weightlessness. The vestibular organs are affected quite differently in weightlessness. At rest there is "physiological deafferentation" of the otolith apparatus, but there is no corresponding effect on the semicircular canals. Lifting the gravitational stimulus to the otolith receptors would reduce their tonic modulating influence and leave them with a resting discharge which would be gravity independent. With natural movements of the body (head) the transient linear accelerations might or might not constitute an adequate stimulus to the otolith apparatus, and, if adequate, the information would not be useful for orientation to the upright. The semicircular canals, however, would be stimulated by the angular accelerations generated in much the same way as under terrestrial conditions, although there is evidence that the effects of such stimulation may be different, due, in all likelihood, to the reduction in otolithic input.

In orbital flight, some Russian cosmonauts described symptoms which their scientists believe had their genesis in the vestibular organs and in nonvestibular proprioceptive systems normally stimulated by gravity. These symptoms were either characteristic of motion sickness or a type of disorientation consisting of a feeling of being upside down with reference to the spacecraft. The reports of American manned space flight experiments indicate that none of our astronauts experienced illusions or symptoms of motion sickness until the Apollo series of space flights when motion sickness became a problem.

Experiments conducted in the weightless phase of parabolic flight have shown that the great majority of experimental subjects manifested a changed susceptibility to motion sickness when exposed to Coriolis accelerations as compared to similar experiments conducted under terrestrial conditions; susceptibility was lowered in some and raised in others. In the absence of rotation some subjects, asymptomatic while secured in their seats with head fixed, experienced motion sickness while making standardized head motions.

Artificial gravity. The generation of artificial gravity by causing a spacecraft to rotate would result in certain advantages and disadvantages. From the biomedical standpoint, the benefits would come under such headings as habitability and general fitness. The disadvantages are due to functional disturbances resulting from Coriolis accelerations produced by the astronaut's movements in the rotating spacecraft and will be discussed under two headings, motion sickness and ataxia. Rotating rooms have been used to simulate conditions in a rotating spacecraft, and the experimental findings have good validity, especially when important differences between the two conditions are taken into account. Indeed, the use of rotating rooms has led to the study of motion sickness under controlled laboratory conditions, and the findings have theoretical as well as practical significance. Emphasis will be given to studies demonstrating the prevention of motion sickness by means of standardized adaptation schedules.

Although the vestibular organs are of primary significance in causing motion sickness in a rotating vehicle, they play a far smaller role in connection with postural equilibrium and locomotion. Evidence will be presented demonstrating this uncoupling between motion sickness and ataxia. Inability to simulate subgravity levels constitutes a major handicap in using rotating rooms as simulators for purposes of studying postural equilibrium and locomotion. It is safe to predict that astronauts exposed for the first time in rotating spacecraft will go far better prepared to cope with motion sickness than ataxia, although the latter constitutes a far less important problem.

VESTIBULAR MODELS

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I. General vestibular considerations

  A. Vestibular inputs

    1. Angular acceleration

    2. Specific force $(\bar{g}-a)$

  B. Vestibular outputs

    1. Nystagmus

    2. Perceived rate, orientation

    3. Manual control commands

    4. Postural reflex

  C. Anatomy

II. Semicircular canals as overdamped angular accelerometers

  A. Torsion pendulum model

  B. Acceleration impulse response, cupulograms

  C. Limitations of the second order model

  D. Acceleration step response

  E. Frequency response

  F. Threshold

III. Otoliths as linear accelerometers

  A. Structure

  B. Nonlinear model

  C. Frequency response

  D. Thresholds

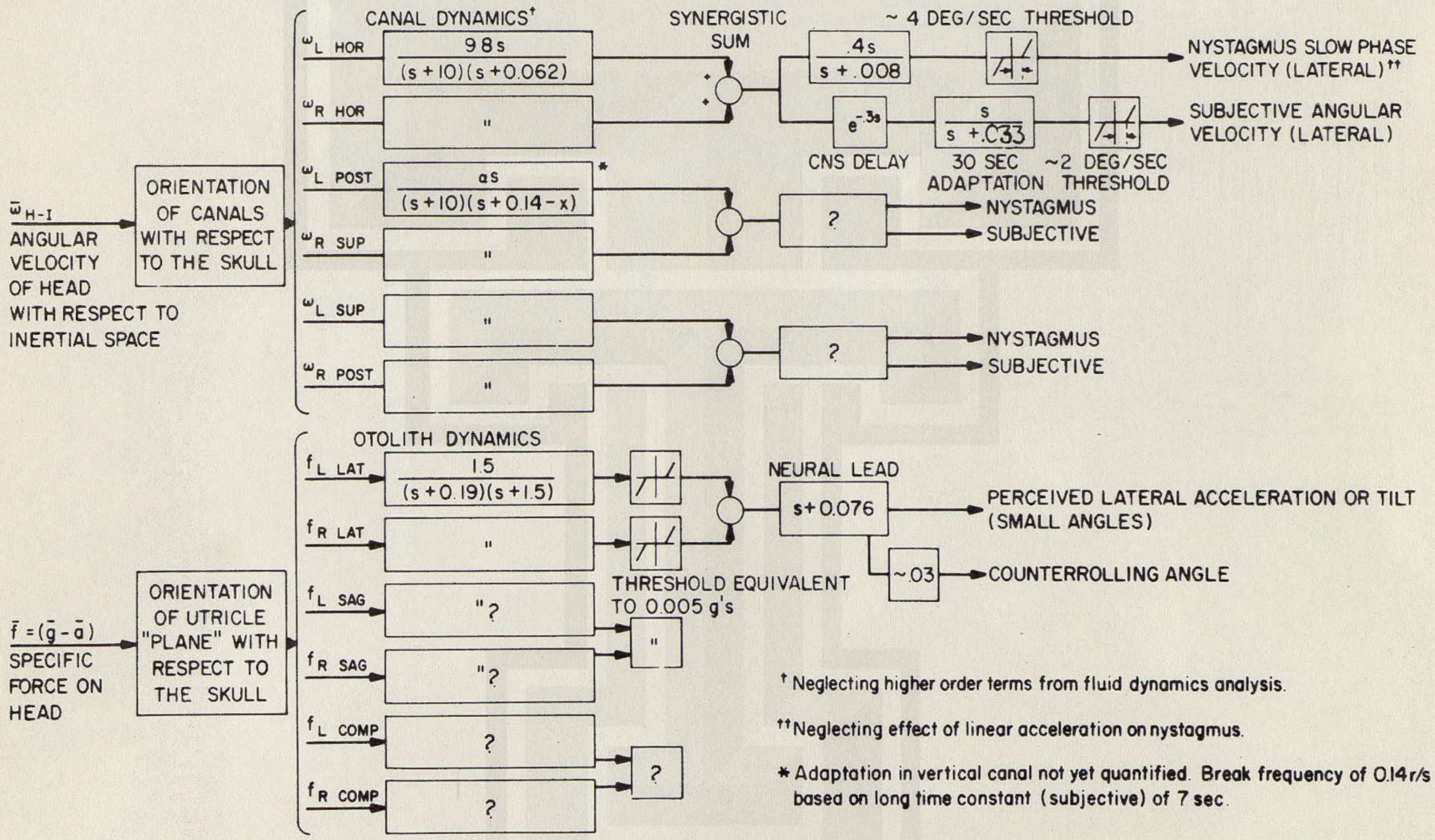
IV. Cross-coupling of linear and angular sensors

A. L-nystagmus

B. Barbecue spit

C. Roller pump model

V. Summary Biocybernetic Model



SUMMARY DIAGRAM, BIOCYBERNETIC MODEL OF THE VESTIBULAR SYSTEM

(from L. R. Young, "The Current Status of Vestibular Models," <u>Automatica</u>, Vol. 5, Pergamon Press, Great Britain, in press)

MAN-MACHINE INTEGRATION

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M.I.T.

A. General Remarks

1. Paradigms - old and new
2. Mathematical models - borrowed from engineering and for engineering purposes
   a. "continuous filter" models - example: manual control
   b. "probablistic matrix" models - example: information processing
   c. "accumulate evidence and decide" models - example: signal detection
3. Common sense design and design from experience
4. Simulations
   a. ethological approach
   b. formal experimental design

B. Apollo Guidance and Navigation System

1. A man - computer - sensor - display - other men system
2. Early part-task simulations
   a. airplanes and simple optics to study orbital landmark tracking
   b. analog computers in zero g parabolas to study star tracking and tethering
3. Hybrid simulations
   a. display and control integration
   b. procedures verification
   c. astronaut training
4. How driving a modern spacecraft differs from driving an airplane or motorcar

C. Human supervised computer - manipulator

1. Early hardware developments

2. Early gee-whiz robots

3. Transmission delay problems for tele-puppet continuous control in space

4. Supervisory control

    a. communications interface - analogic and symbolic commands

    b. inside - computer models of outside task

    c. how people like to control things - natural language and preview

T.B. Sheridan
10 August 1969

References on Man-Machine Integration

1. Chapanis, Alphonse; Man-Machine Engineering; Behavioral Science in Industry Series; Wadsworth Publishing Company, Belmont, Calif.; 1965. A qualitative and elementary introduction to design of displays and controls. Paperback.

2. Edwards, Elwyn; Information Transmission; Chapman & Hall Ltd., London; 1964. A handy reference for quantitative information models as applied to humans. Paperback.

3. Edwards, Ward and Amos Tversky; Decision Making; Penguin Books Ltd., Middlesex, England; 1967. A Fine Collection of classical papers on the subject. Paperback.

4. Raiffa, Howard; Decision Analysis, Introductory Lectures on Choices Under Uncertainty; Addison-Wesley; 1968. A first class set of introductory lectures in decision analysis. Paperback.

5. Green, David M. and John A. Swets; Signal Detection Theory and Psychophysics; John Wiley and Sons; 1966. A sophisticated, very readable text on the quantitative aspects of psychophysics. Hardcover.

6. Fogel, Lawrence J.; Biotechnology: Concepts and Applications; Prentice-Hall Space Technology Series, Englewood Cliffs, N.J.; 1963. A good scissors and paste job. Hardcover.

7. Teleoperators and Human Augmentation; NASA SP-5047; Washington, D.C.; December 1967. A readable compendium of work done in the last twenty years. Paperback.

8. Teleoperator Controls; NASA SP-5070; Washington, C.C.; December 1968. Same as above, with special emphasis on controls. Paperback.

9. Kelley, Charles R.; Manual and Automatic Control; John Wiley & Sons; 1968. A qualitative discussion of manual control. Hardcover.

RESPIRATORY PHYSIOLOGY

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I. Introduction: Respiratory and circulatory systems compensate for long diffusion paths in larger animals with an external and internal exchanger. Rate of diffusion of gases proportional to chemical activity or partial pressure, not concentration.

II. Composition of inspired gas. Difficulties of verifying slight detrimental effects in near-normal ranges.

A. O_2: Human body adapts remarkably to wide range of ambient Po_2. There are definite upper and lower limits.

B. CO_2: An upper limit, to which body shows some adaptation, but no lower limit.

C. Inert gases: Toxic or narcotic, effects at high pressures; aeroembolism from dissolved gases; inert gas required in alveoli to prevent atalectasis.

III. Respiratory function of the lungs

A. Mechanics: bellows action

1. Normal: diaphragm, pleura; lung volumes; airway resistance, compliance
2. Effects in changes in gravity
3. Effects of increased pressure

B. Distribution of inspired gas in relation to capillary blood

1. An important problem; common dysfunction in disease
2. Respiratory dead space; wasted ventilation; non-uniform alveolar ventilation/alveolar capillary blood flow
3. Regulation of alveolar ventilation/capillary blood flow
4. Effect increased and decreased gravity on distribution

C. Circulation: (covered in other lectures)

1. Pulmonary circulation: low pressure; depends on ambient, alveolar and pleural pressure
2. O_2 carried as hemoglobin ligand: CO_2 as bicarbonate
3. Hydrostatic pressure within lung limits maximal gravitational force that can be tolerated.

IV. Control of respiration

A. Arterial P_{CO_2} and pH on medullary respiratory centers
B. Arterial P_{O_2} on chemoreceptors
C. Cerebrospinal fluid pH and P_{CO_2}
D. Reflexes and sensation from whole body
E. Temperature
F. Higher centers in central nervous system

V. Self cleansing action of lung

A. Cough
B. Mucus sheet: moved by cilia

General References

The Lung, J. H. Comroe, Jr., R. E. Forster, A. B. DuBois, W. A. Briscoe, and E. Carlsen, Year Book, 1962.

"Physiology in the Space Environment," Vol. II, *Respiration*, NAS-NRC Publication 1485 B, Washington, 1967.

CARDIOVASCULAR FUNCTION

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The Normal Circulation

The heart and blood vessels are organized into a complex functional unit that provides blood to the various parts of the body. Each functional aspect of this system is controlled by feedback type mechanisms and the entire system organized to meet the varying demands for blood in different tissues of the body. By and large, the body is able to meet these demands, although at times there may be transient inadequacies. The organizational pattern could be broken down as follows:

1) The control of blood flow to the capillaries depending upon local needs, determined primarily by chemical factors but supplemented by nervous impulses. This part of the system is dependent upon adequate perfusion pressure (blood pressure). The capillaries are where the real business of the circulation goes on.

2) A mechanism for maintaining an adequate arterial blood pressure. The carotid sinus and other reflex arcs are involved in maintenance of a reasonable level of control although there is considerable minute-to-minute variation.

3) The cardiac output or, in other words, the amount of blood pumped by the heart is adjusted to meet the total needs of the body for that particular moment. In the main, this is adjusted to meet metabolic requirements. For instance, it is

increased under the stress of exercise, but other factors such as heat loss and emotions may play a strong influencing role. The characteristic of the normal circulation is a flexibility in the level of blood circulation dependent upon body needs.

Faulty Integration of the Normal Circulation

Under a variety of circumstances the normal circulation will fail to operate in a properly integrated fashion. Examples of this are as follows:

1) Syncopy (fainting) is a failure of integration of the circulation. There are many causes of fainting; some associated with cardiovascular disease, but the common variety of fainting is of the type described here. It occurs in normal individuals under stressful, usually emotionally charged circumstances. The loss of consciousness is related to inadequate arterial pressure to push blood upward to the brain, and hence the faint is more apt to occur in the upright position. There are various other symptoms that may occur at the time related to an extensive discharge of nervous reflexes in a disorganized fashion.

2) The circulation may become somewhat disturbed by emotional influences, the rapid heart beat and power occuring with emotionally charged situations is a good example. The cardiac output under these circumstances may be markedly increased and there may also be changes in arterial pressure. The person may become aware of his heart beat (palpitation) and he may feel anxious or some other change in feeling state.

3) Under special stressful circumstances, other abnormalities of the circulation may occur. For instance, under the

stress of human centrifuge fainting of a different sort than that described above may occur. It too is characterized by sudden loss of consciousness. Under conditions of increased atmospheric pressure and then release, air embolus (bends) may also occur. In summary, circulatory integration may become faulty in the normal individual under stressful circumstances of various sorts extending from relatively minor emotional impacts to serious and profound stresses such as gravitational force and increased ambient pressure of the atmosphere.

Failure of the Circulation Due to Disease

Causes

Many types of factors may couse cardiovascular disease. The principle ones are arterialsclerosis, rheumatic fever, high blood pressure and a variety of diseases that influence the myocardium. Despite the variation in causes, the impact of these diseases may be classified in a few general catagories.

Types of Disturbances

Heart Failure

When heart disease involves the heart and interferes with its function as a pump, the situation described as heart failure occurs. This represents a relatively moderate but important and usually prolonged limitation of the function of the heart as a pump. The manifestations experienced by the patient are not directly attributable to the diminished blood flow but result from secondary phenomena that occur and are described under the general heading of congestive heart failure. They are mainly respiratory symptoms with shortness of breath, as a predominant one and those due to increased extracellular fluid content of the body (edema).

Shock

Shock occurs with more serious and acute disturbances of the functions of the heart but may have other causes such as trauma. Shock due to heart disease is predominantly due to acute inadequacy of the heart as a pump and occurs in such situations as myocardial infarction.

Vascular disease with diminished blood flow may occur in various diseases affecting specific parts of the body. Most prominent is coronary artery disease with diminished blood flow to the heart muscle itself. This results in either transient attacks of pain (angina pectoris) or in death of the heart muscle in the area involved (coronary occlusion, myocardial infarction, heart attack). If the cerebral vessels are involved it may lead to cerebral dysfunction or to gross neurologic defect with paralysis of one half of the body, (stroke). Involvement of the blood vessels serving the extremities may also lead to pain on motion and in the more severe situations to necrosis and death of the peripheral tissues, requiring amputation.

Other forms of vascular disease such as bacterial infection exist, but the catagories indicated above are the most prominent ones.

ELECTROCARDIOGRAPHY

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I. Introduction

- A. Electrophysiology of the myocardial cell
- B. Volume conductions and dipole concepts
- C. Anatomical Determinants of ventricular depolarization

II. The Normal Electrocardiogram

- A. Technique of obtaining
- B. Nomenclature
- C. Criteria of normalcy
  - 1. QRS, ST, and T contour and heading
  - 2. Rhythm

III. The ECG as a Medical Monitor

- A. Value
- B. Inherent problems
- C. Importance of a validated system
  - 1. Conventional 12-lead
  - 2. Frank-triaxial

IV. Factors Which Alter the Normal ECG

- A. Posture
- B. Exercise
- C. Heat and cold
- D. Emotion, e.g., startle
- E. Gravitational forces
- F. Drugs
- G. Electromagnetic forces

V. The Arrhythmias

A. Benign or functional

B. Secondary to organic heart disease

VI. Conduction Defects, Intraventricular

A. LBBB

1. Mechanism

2. Recognition

3. Significance

B. RBBB

1. Mechanism

2. Recognition

3. Significance

a. Congenital

b. Acquired

VII. Coronary Artery Disease

A. Incidence

B. Life history

C. Coronary artery disease vs coronary heart disease

1. Limitations of the ECG

D. The acute coronary incident

1. Electrophysiology

2. ECG manifestations

3. Sequelae

VIII. Coronary Heart Disease Without Recognized Infarction

A. Small unidentified infarcts

B. Ischemic heart disease; infarct

1. Angina Pectoris

2. Exercise ECG

3. Conduction disturbances

4. Differential ECG diagonals

IX. Other Acute Cardiac Myopathies

A. Pericarditis

B. Trauma

C. Acute cor pulmonal

X. Summary

A. Evident value of ECG as a monitor

B. Importance of triaxial system

PO4 - Sl. less > Ca in body
In all tissues
80% in Bone
20% in ms Nerve etc.

Diet - Meat & Eggs - Hi Protein Diet
Functions - Energy & Enzyme Systems
Bone & teeth

Mg - Not studied as much
Bone, ms, soft
Meat = ppl source
M. irritability
Activates enzyme systems
(many)

Fe - Hemoglobin - Bl. cells, liver
Liver, meats, eggs
Hb primary function
- also Cu & Co

I2 - Dietary - Thyroid chemical
specifically
Sea food

S - Meth = ppl function
Food in body organs
& in Tyrosine with N in
body muscle
- Ratio of S:N in
urine & ratio of
N2 determination in
N2 losses

CALCIUM METABOLISM AND MINERAL BALANCE

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National Institutes of Health, Bethesda, Maryland

I. Definition of minerals (Ca, Mg, P). (Cu Mn Zn Co Se & other trace elements also)

A. Abundance in the body. 1-1.5 Kg Ca (Ave. 1.2 Kg) - 2% of Body Wt. - 99% in Skel.
B. Sources in diet. Bl. level 9-11 mg%. 60% ionized 40% protein-bound
Milk, Green Veg., Shellfish, Beans, & Eggs

II. Physiological considerations.

A. Functions in relation to skeleton (1. Primary), muscle and circulation-coagulation (Essential). (Permissible range [illegible] small for these functions)
B. The concept of balance--intake versus output (several routes of excretion).
C. Quantitative aspects of normal intake and output.
D. Internal movements of calcium metabolism (diagram) and concept of turnover.
E. Interrelationships with acid-base balance.

III. Mineral metabolism in disease - brief consideration of the major changes in the minerals in certain disorders of bone, particularly osteoporosis and fracture, as background for potential hazards of space flight.

IV. Ground-based studies relevant to space flight.

A. Studies of immobilized bed rest in normal subjects as nearest simulation to weightlessness, with particular detail on the Cornell study of 1944-46.

1. Changes in calcium and nitrogen balance.
2. Changes in urine relative to threat of urinary tract stone formation.
3. Correlation with other measurements.
4. Findings in other bed rest studies and water immersion.

B. Calcium balance changes in paralytic polio.
C. Effects of slow oscillation, polio versus normal bed rest, significance for protective measures.
D. Studies of other situations bearing on space flight (altitude).

V. Metabolic study in space flight--the Gemini VII study.

A. Problems of procedure in unusual environment.
B. Problems of control--dietary, presence of many stresses.
C. Major findings - calcium, phosphorus, hormones.
D. Significance of findings and necessity for additional observations.

Normal Ca Intake = 500-800 mg per d.

- for higher in growing boys
- whole cow's Milk – 1 qt @ 1100 mg
- 35% Ca taken in absorbed
- remainder in stool
- Also some endogenous fecal Ca c̄ bile – = ± 150 mg per d.

∴ Dietary intake 800 mg – Fecal output = 650 (500 + 150)

- Urine 50–200 mg/24 hrs – up to 200 mg per d. [illegible] considered O.K.

- Skin – up to 210 mg per d. in sweat but only c̄ severe & profuse sweating.

- Usually ambulatory conditions = under 30 mg per d.

I – O Studies

I	O
800	520 } Fecal
	150 }
	30 – Sweat
	100 – Urine
	800 = 0 Bal.
	if 700 = +100 mg Bal.

Bone is Living Tissue

As bone ages H_2O is withdrawn c̄ X tal lattice

Concept of MISCIBLE POOL of CALCIUM

6–10 ~~mg~~ Gm/Kilo = rate of movement of Ca to & from [illegible] per day

Ca as buffer

Alk or acidosis influences rate of Ca turnover (bone resorption) & Ca absorption as well.

During 1st 30 yrs of life & skel. growth – rate c̄ bed [illegible] of neg. to probably very fast then slows. After age 30 5–10% (15–30 mg/day) & decrease in bone mass – rate prob. declines in later years.

Ovariect – Osteoporosis more common 25–30% of ♀ over age 50

5–10 or 15 Million people in USA

(Cancellous bone = a reservoir for Ca)

Space Flt – projected changes

Balance Studies

Background – Classic study (Deitrick, Whedon, & Shorr)

GEMINI VII Study

Wrap up – Studies to be continued in Space Flt

Problems – During these should be resolved.

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for G. D. Whedon - Calcium Metabolism and Mineral Balance

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BIOCHEMISTRY IN A WEIGHTLESS ENVIRONMENT

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REVIEW OF STRESSES – SPAMAG LIST – POINT – LITTLE KNOWN BIOCHEMICALLY AT THIS TIME + CAN'T DIVORCE BIOCHEM. c PHYSIOL.

I. Problem Areas for Consideration in Weightlessness

1. Cardiovascular system
2. Liver & kidney function
3. Muscle activity
4. Endocrine function
5. Electrolyte balance
6. Calcium balance
7. Radiation injury
8. Acid base balance
9. Environmental variations

Electrophoresis
LDH ISOZYMES
PROTEINS
Alb
Glob
Immunoglobulins
Lipoproteins

Sp-Ion Electrodes
Ionized Ca
Na & K – Beckman
Benet of
Switzerland
[illegible].

HCO_3^-

II. Metabolic Variables Relating to Problem Areas

1. Electrolyte variations
2. Protein changes
3. Enzyme activity
4. Red and white blood cell integrity
5. Steroid variations
6. Calcium mobilization and increased excretion
7. Carbohydrate utilization – Rotating room – Glucose Utilization to go c Normal 2%/min. to 10%/min. – suggest any type of motion sickness inducing environment. Diet prepared also switched c protein to fat predom.
8. Lipid utilization
9. Trace metal requirements
   Cr III Reqs. Normally 20-40 ppb.
10. Vitamin requirements

Deficiencies can be demonstrated in 30 days in equilibrium lab.

Took 21 days to in very good lab. to demonstrate

Mo also vital
Ni MB ENZ.
for protein
Synthesis – of
nucleic
acids.

Possibility of ~~use~~ of PAROTID secretions

Tube
Atomic Abs.
or also
Gas Chromatograph

III. Monitoring of Metabolic Variables

1. Liver and kidney function tests
2. Electrophoretic determination for protein variations
3. Determination of electrolytes for electrolyte balance
4. Determination of carbohydrate and lipids
5. Determination of hormone activities
6. Measurement of enzyme and isoenzyme activities
7. Trace metal measurements
8. Hematological parameters
9. Determination of vitamin levels

IV. Instrumentation Involved - Present in Terrestrial Laboratory

1. Conventional instruments and apparatus
    a. Spectrophotometric equipment
    b. Electroanalytical equipment
    c. Volume measurement equipment
    d. Paper strip procedures
2. Reagent preparations and standards

V. Instrumentation for Weightless Laboratory

1. Requirements for weightless laboratory
2. Problems of conventional equipment
3. Development requirements

HEMATOLOGY

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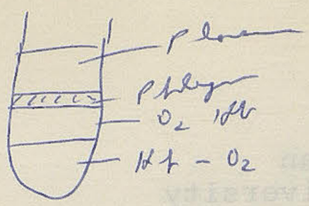
Another name for the hemopoetic system is "the erythron" which is composed of bone marrow, peripheral blood and in some animals or in certain diseases includes the spleen, liver and lymph nodes. The cells of this system are erythrocytes, leukocytes, and platelets. Although these cells, the plasma and the blood vessels have intimate physical relations and interactions in health and disease, the primary functions of each of the blood cells differ greatly. The prime function of the red cells is gas transport, of the leukocyte is protection from foreign agents (physical, cellular and microbial) and of the platelet is hemostasis.

Examinations by a variety of methods of the morphology, biophysics and biochemistry of these cells provide a large body of information concerning the genesis of many diseases. The diagnostician uses the quantitative and qualitative abnormalities of hemopoetic cells as indicators of the presence of disease. Measurements of cell volumes, masses and kinetics are made with the use of multiple technics and the results expressed in different fashions. The following table gives the more commonly used normal human values

TISSUE	CONCENTRATION CONVENTIONAL EXPRESSION Cells/mm^3	VOLUME ml/Kg	PER PERSON APPROXIMATE ML ~ 70 Kg
WHOLE BLOOD	---	70	4900
PLASMA	---	40	2800
RED CELLS +	5×10^6	30*	2100
WHITE CELLS *	5×10^3	0.06	~10
PLATELETS	5×10^5	.20	~20

Hx



- Choleric
- Phlegmatic
- Sanguine
- Melancholic

Greek Interpretation

Blood

Volume – Ml/Kg per wt. In 70 Kg man

Whole Blood 70 4900

plasma 40 2800

RBC's 30 2100

WBC's .06 ~10

platelets .2 ~30

RBC life span 120 d

~~removed~~ @ 1% / day

Destroyed " " "

Cr^{51} → Best method we have but [illegible]

Won't detect ↓ in RBC ~~B~~ life span down to 70 days

DI ISO PROPYL FLURO PHOSPHATE = DFP

DFP^{31} used

\+ Hematocrit = 43%

* Refers to all leukocytes

White cells are estimated at 2 x volume of red cell

Platelets are estimated at 1/10 volume of a red cell

Cell volumes are measured by labelled cell dilution methods which utilize morphologic, antigenic or isotopic labels. The use of methods for cell volume determination and of rates of formation of cells allow estimates of the circulation times of cells, the pattern of destruction of the cells and the rates of renewal of the cell masses. These are shown in the following table.

Cell	Label	Type of Disappearance	$T_{\frac{1}{2}}$	Generated per second & destroyed
Erythrocyte	DFP^{31}	Finite - ±1%/day	50d	1.0×10^6
Leukocytes	DFP^{31}	Random	$7\frac{1}{2}$ hr.	$.5 \times 10^6$
Platelets	DFP^{31}	Random	5d	1.0×10^6

The blood generative tissues have a reserve capability to produce more cells than are ordinarily needed. Estimates of the red cell reserve capacity indicate a two to five fold capability. Estimates of leukocyte and platelet reserve capabilities are less accurately estimated, but undoubtedly exist. Rates of blood cell formation and destruction are affected by a variety of disease processes which includes infection, inflammation, neoplasia, and specific organ diseases, such as chronic hepatic or renal disease.

While abnormalities of all of the formed elements may be present in some diseases, a decreased red cell concentration (anemia) is most common. An increase in leukocytes (leukocytosis) and a decrease in platelets (thrombocytopenia) are the next most common abnormalities.

Thus, quantitative abnormalities of blood cells give clues as to the presence and type of disease. Additionally, there are primary hematologic diseases which include hyperplasias, hypoplasias and neoplasias of the blood cells and are exemplified by the diseases such as polycythemia vera, the leukemias, and the lymphomas.

The regulation of production and destruction of each of the blood cells is provided by entirely different means. Time does not permit discussion of all of the regulatory mechanisms for blood cells. Perhaps the major abnormality of blood cells in the space program has been that of the erythrocyte.

Red cell production is regulated, in all probability, by several factors. The most persuasive of these seems to be tissue oxygen tension. Increased oxygen tensions cause a lesser rate, and decreased oxygen tensions an increased rate of cell production. The mechanism by which the degree of oxygen tension elicits a change in rate of production of red cell is not completely known, but involves the elaboration of a polypeptide termed erythropoetin or erythropoetin-stimulating factor (ESF) (EP). This substance is synthesized in a number of different places and has its effect on undifferentiated or stem cells. Other substances than erythropoetin, are also regulatory of red cell production, such as hormones.

Red cell destruction normally takes place in a regular, finite fashion, wherein each cell matures in the marrow, undergoes denucleation to form a reticulated cell (reticulocyte), and thereafter becomes the mature, non-nucleated, non-reticulated cell. This mature cell is endowed with the capability for circulation in the blood for every

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Sickle cell → rigid (abnormal)
→ changes shape if O_2 low & →
more normal & O_2 normal or high & vice versa
← Hb ligating c̄ O_2
If rigid can't slide thru 3μ capillary
If goes ↓ O_2 c̄ Normal O_2 (depolymerizing)
& further ↓ for all a[illegible] normal back
Finally → crenellated
Repeated sequence membrane
dependent on repetitive
cell membrane
- not reliably
means.

RETICULOCYTE

near 110 days and then is removed. Current thought suggests that physical wear and tear with loss of units of cell membrane by a process termed "fragmentation" is an important process in the aging or senescence of the normal cell.

Cells may be prematurely removed from the circulation (hemolysis) for many different reasons. Physical damage to cells may take place by virtue of an increase in trauma, such as imposed in a turbulent blood stream, in aortic stenosis, or in the presence of valvular prosthesis or because of hypotonic lysis such as may occur when intravenous water infusions are made. Immune lysis wherein the combination of antigen and antibody of the cell surface causes a rupture in the cell membrane may occur in disease. Congenital or acquired abnormalities of the lipid composition of the cell membrane (abeta lipoproteinemia or lipid peroxidation by oxidative agents including high oxygen tension) may be present. Abnormalities of bioenergetic mechanisms responsible for the maintenance of normal intracellular-extracellular electrolytic differences and for the reduction of sulfhydryl containing substances in the cell membrane, (G-6-PDH deficiency) or leads to hemolysis. Mutant hemoglobins as in sickle cell or hemoglobin C disease cause hemolysis by an imposition of cell rigidity and lack of deformability. The presence of each or almost all of the above examples of premature lysis of the cell can be shown to result in qualitative morphologic abnormalities.

The abnormalities which might be expected in an underwater program or in a space capsule environment are those of the altered environment. When problems of dietary, water and hygienic control are excluded, the factors are 1) change in gas pressure, 2) changes in gaseous concentration, 3) weightlessness, 4) changes in time or timelessness, 5) restrictions or alterations in degree of physical activity, 6) thermal exposure, 7) the imposed acceleration and decelleration forces. Greater

Old cell
Smaller
More [illegible]
Less H_2O
" " Lipid
" " Enzymatic Systems (located in Membrane)

Becomes Osmotically Damaged
K out, Na in
Bursts

$2\alpha + 2\beta$ polypeptide chains in normal Hb
Valine subst. for Glutamic Acid
Polymerized chain of Hb. molecules
→ Fibrils & distorts cell - [illegible]

Lawton & Welch
21 days BR chamber 5 psi 100% O_2
- ↓ RBC production - not $\bar{s}$ BR

Peroxidation of RBC membrane lipids by hi O_2 shown in mice, BUT NEVER BEFORE IN HUMANS - I have no doubt that it has been shown in Gemini

availability of data on the human and more recent months and years of the effects of these factors singly or in combination on red cell production and destruction have been provided by the manned space flights. The better hematologic data was acquired in the Apollo series. There was data of the Gemini 4, 5 and 7 flights which were respectively of 4, 8 and 14 days which indicated a decrease of approximately 10-20% in the red cell mass. This loss had no correlation with the duration of flight and was not seemingly associated with degradation and ability for physical and physiologic performance.

These observations had, however, two important implications. First, that longer periods of space flight might be associated with greater DECREASE OF red cell mass and thereby with physical incapacity or secondly that abnormalities of red cells could be used or were indicators of more widespread cell damage and may have predicted a similar abnormality in non-hematologic cells. It was deemed that the cause of this anemia most likely was related to the hyperoxia. The second candidate for cause of the anemia was weightlessness and restricted physical activity. The results of ground level chamber studies designed to determine the effects of red cell rate of formation and destruction on hypokinesia and hyperoxia have been made. The data suggests that horizontal bedrest and physical inactivity results in a decreased rate of red cell formation and that this may be further aggravated by a modest degree of hyperoxia. In these experiments there was no evidence that accelerated rates of destruction of cells had occurred. At the present time studies are being done which seek a possibility that hyperoxia preconditions red cells and that centrifugal forces imposed upon astronauts during reentry may in combination cause accelerated destruction of cells. Studies of increased temperature and vibration on cells have been relatively few. Some more recent studies show that experimental fever or induced hyperthemia causes an accelerated rate of destruction of red cells. The mechanism by which the hyperthermia induces hemolysis is at present unknown.

In summary, the hematologic abnormalities suffered by persons exposed to our space capsule environment and as well to underwater explorations have been few. The data available suggests that any alterations in the rate of red cell production and destruction is related to physical inactivity and to the degree of hyperoxia which was present. All alterations of red cells, white cells, and platelets which have been observed singly or repetitively have reverted to normal following the return to normal earth environment.

MICROBIAL CONTROL

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For a number of years, we have witnessed a continuous demand for more precise control over the microbial elements in occupied environments. While some procedures have required increased environmental controls to prevent escape of pathogenic microorganisms, others aim at the exclusion of contaminants from a process or system. Occasionally, personnel and product protection are needed simultaneously.

The most significant advances toward solving these control problems include: (1) the development design standards for the construction of containment-type laboratory buildings, (2) the development and classification of primary microbiological barriers for environmental control in the smallest practical work area, (3) the development of gaseous decontaminating and sterilizing agents, (4) the utilization of laminar air flow devices in rooms and cabinets for environmental control, (5) the development and continual improvement in microbial filters, and (6) the development of improved devices and procedures for the assessment of contamination levels in air, on surfaces, and within materials.

Ref.
NASA - Clean Room
Standard 209 A

3. Decontaminating Agents

4. Microbial Barriers

Barriers: Classified by

Purpose - Product or personnel

Type - Room or Cabinet

Degree of Protection - Absolute or Partial

Recent Revol. - Whole new industry - LAMINAR FLOW

Hepple Filter?

90'/min

Sounds like Knee

Designed 1st ~ 1961 - Used first by Space

Biomed Appl. many started - Now find - surgery, clean rooms, raising of drugs, isolation rooms, etc

Studies on Laminar Air Flow

Can't clean up - sterilize - but can & does maintain that present

Microbial Lab. Safety

- Much done past 20 years
- Involved Design & Equipment & Techniques
- Pub. "Schemes of Indicators of Risk" - Dr. Donald Wheedham

Factors: Present Work
Dose
Individual Procedures
Source of Contam
Reg. Agencies and of Hazard
Tot. of Info re known X infection
= Systematic Approach which leads → Advancement

Facility Design Concept

Air Locks - Dan Barriers
Buf contain Liquid Effluent
Change Rooms & Showers
Effective Communications & Traffic
Ventilated Cabinets
Laminar Flow Devices

RMERF ISOLAT. FACIL.

LRL NSCA Inst.

Guidance of ICBC - Bact, Sp., & Quarantine Practices OK and dry.

85 K ft^2

S/c, Spls, & Crew Containment

Spls until taken 60-90 days - restraint where possible = "Lot" (M-?)

These advances and concepts developed from them have been utilized recently for the design of a Lunar Receiving Laboratory and for laboratories for research with infectious disease agents and oncogenic viruses. Likewise, these advances have made possible tremendous improvements in the manufacture, packaging, and sterility testing of pharmaceutical products and disposable medical devices.

TOXICOLOGY

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I. Introduction

A. Concept of acceptable contaminant levels

1. Industrial

2. Spacecraft or community

B. Comparison of spacecraft environment to earthbound community

1. Sources of contamination — Anything not normally present

Irritation is often incentive for investigation & control.

a. Community

b. Spacecraft

2. Contaminant removal

a. Leak to space

b. Disposal

II. Statement of Problem

A. Evaluation and comparison of contamination problem in closed system

1. Earthbound community

2. Submarine

3. Spacecraft

B. Need for threshold limit

1. Community

2. Artificial ecology

C Definition of "response"

1. Single response

2. Multiple responses

D. Relationship of contration to response

E. Relationship of time to response

F. Environmental factors affecting responses

1. Thermal

2. Gaseous

G. Establishment of threshold limits

1. Level of "no response"

2. Level of acceptable response

3. Level of unacceptable response

H. Biochemical and physiological factors affecting response

1. Site of action

2. Metabolic inhibitors or accelerators

3. Detoxication mechanisms

4. Pathways of metabolism

I. Reversibility of response

J. Summation of interrelationships

K. Control

1. Input

2. Specific contaminants

3. Potential problems

III. Conclusion: Spacecraft vs. Community Ecotoxicologies

SPACE RADIATION AND MAGNETIC FIELD ENVIRONMENTS

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Three different kinds of radiation fields have to be considered if radiation hazards to man in space are to be analyzed: trapped protons and electrons in the radiation belt, solar particle beams after large flares, and galactic radiation. The bulk of the particle flux in all three fields consist of protons with energies from fractions of one Mev to the multibillion e-volt level. As charged particles, protons are subjected to the deflecting influence of magnetic fields in space. This interaction is the determining factor for the fluxes and energy spectra of all three types of radiation fields.

In the satellite era, direct observations with space probes have greatly changed the older concepts of the magnetic field environment in space. The classical theory held that, since the sun moves through clouds of interstellar hydrogen gas, the neutral hydrogen must fall toward the sun. On its way to the surface of the sun it is ionized by solar ultraviolet and thus constitutes a dilute, highly conducting plasma with its innermost part forming the solar corona. We know today that exactly the opposite is true. The sun actually emits hydrogen plasma against the gravitational force into interplanetary space. The accompanying magnetic fields determine the propagation of charged particles in interplanetary space and confine the Earth's dipole field to a limited region with a diameter of not more than about 40 Earth radii in the equatorial plane. In this cavity, conditions for stable particle trapping exist and flux levels can build up to values at which tissue dose rates well in excess of 10 rads/hour would develop in a human target even within a large vehicle with heavy inherent shielding.

Because of an unexplained eccentricity of the Earth's dipole field, the lowest fringes of the inner radiation belt dip down to different minimum altitudes above sea level at different longitudes. The region of closest approach is in the Southern hemisphere at about 30° West and is called the South Atlantic Anomaly. In that region, radiation levels from trapped protons substantially exceed the galactic level down to the lowest satellite altitudes. On mission Gemini IV, a highest dose rate of 100 millirads/hour was measured inside the spacecraft on central passes through the Anomaly.

Much higher radiation levels can occur in solar particle beams emitted from large flares. Operationally, from the standpoint of assuring radiation safety for the astronauts, the main problem is flare prediction. Statistical evaluation of the flare events of solar cycle 19 (1955-1965) indicates that the probability of encountering a major flare, for instance, on an 8-day lunar mission is very low even during the maximum of the 11-year solar cycle. Complicating the issue is the fact that each flare event has its individual time profile of development and decay with fluxes and energy spectra showing enormous variations. In general, solar particle beams and trapped protons show energy spectra with the differential flux dropping steeply toward higher energy. Therefore both types of radiation are substantially attenuated in the inherent shielding of a larger vehicle such as the Apollo ship. For the same reason, skin doses can be expected to be substantially higher than depth doses. This circumstance makes it difficult to assess the true exposure status in terms of the safety margin left to the threshold of acute effects if a mission in progress should be caught by a major flare.

Galactic radiation poses a problem only in regard to late damage from accumulated exposures over long time periods because of the low dose rates involved. The most characteristic property distinguishing it from both trapped radiation and solar particle beams is its extremely large penetrating power which defeats any shielding effort and leads instead to a strong build-up in any "shielding" layer. Therefore, the galactic radiation level in space has to be accepted as a ubiquitous, ever present phenomenon in much the same way as background ionization at sea level, yet it is not only several hundred times larger but also shows a different LET distribution with a substantially higher fraction of high LET components. Radiobiologically, the heavy nuclei of the primary galactic radiation constitute an unknown quantity since they deposit their energy in tissue in microbeam fashion exposing the cells along their paths to very high local doses. While the lethal effect of single traversals on individual cells has been demonstrated, human or animal data on effects from extended total body exposures at low dose rates are completely missing.

HUMAN RADIATION RESPONSE IN RELATION TO MANNED SPACE FLIGHT

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A decade ago radiation exposure was considered to be one of the formidable problems of manned space exploration. Although it still is a problem to be contended with, careful review of human experience supplemented by a vast amount of animal observations appears adequate to place the problem in context with other risks, at least insofar as relatively short duration missions are concerned. Apprehension regarding the space radiation problem was augmented by (a) the discovery of geomagnetically-trapped radiation zones, (b) the intensity and magnitude of solar flares, and (c) the misconception that maximum permissible exposure levels as applied to radiation workers represented levels of significant human response. Indeed, radiation intensities in the center of the earth's inner radiation zone are sufficient to deny this region of space for sustained manned space flight without adequate shielding, the amount of which may be prohibitive for some types of missions. On rare occasions, solar flare events occur that are of sufficient intensity and energy to pose a serious radiation threat. These events must be viewed as calculated risks with continued effort to lower the risk by further consideration of sophisticated methods of flare prediction and other protective schemes.

Fortunately for our current space program, the insistence on rigid protection guides (comparable to those applicable to radiation workers) for space crews seems to have subsided in favor of the Federal Radiation Council's "risk-versus-gain" philosophy which states in part ".....there can be no single permissible or acceptable level of exposure, without regard to the reasons for permitting the exposure.....and.....there can, of course, be quite different numerical values for the RPG (Radiation Protection Guide) depending on the circumstances." The National Academy of Sciences-National Research Council has published a Study Panel report on "Radiobiological Factors in Manned Space Flight" that proposes application of a risk-versus-gain approach and derivation of radiation protection criteria for space crews on the basis of a review of space requirements and risks independent of established criteria for more conventional exposures. The rationale includes the following points:

1. Radiation is only one of many recognized and accepted potential risks that may jeopardize the success of any flight mission.

2. Individual astronauts are carefully selected for their special skills and motivation. The application of existing standards of radiation safety established for large, occupationally exposed groups would unduly limit the ability of this small group of specialists to achieve their objectives.

3. The parameters of some radiation risks cannot be precisely predicted; therefore, optimal protective measures will not always be available or even feasible. Since any radiation shielding will add to the weight of a spacecraft, the reduction in risk to be achieved by the shielding must be balanced against the other uses to which this weight might have been put.

4. Since flight missions may vary in both duration and radiation exposure, the probability and importance of the radiation risk compared to those of other risks must be taken into account for each specific mission. A risk-versus-gain philosophy is most appropriate for this comparison, and the philosophy is particularly useful for evaluation of radiation risk.

Radiation effects in a complex organism such as man range from subtle changes at the molecular level to a central nervous system or shock-like syndrome producing death in a matter of minutes depending, of course, on the dose and dose rate. Not all of these effects are of immediate interest to manned space flight. Those of most interest are usually classified in terms of clinical or statistical response. Although probably well known to most of you, restatement and discussion of the more relevant of these responses in quantitative or semi-quantitative terms constitute the main substance of this presentation.

Radiation effects (or more explicitly, their manifestations) may be divided into two general categories: somatic and genetic. Somatic effects are those manifested directly by the irradiated individual, in contrast to genetic effects which show up only in his progeny. Only the former are specifically considered here, since genetic effects are of general significance only if the exposed population is large. Somatic effects may be divided further into early and late. Early effects are taken arbitrarily as those occurring within 30 to 60 days after exposure to relatively high doses (greater than about 50 rads) delivered at relatively high dose rates (several rads per hour). Late effects are those occurring only after many months or many years. Late effects may result from a single high-intensity exposure or from gradual dose accumulation at low dose rate over protracted periods. They are assumed to be nonthreshold phenomena and probabilistic functions of the total accumulated dose. Although it is possible to avoid manifestation of early radiation responses by dose protraction, it is not possible to avoid actuarial risk of late effects. With respect to manned space flight, the more significant somatic radiation effects are as follows:

1. Early effects
    a. Skin erythema and desquamation
    b. Prodromal response
    c. Hematological depression
    d. Early lethality
    e. Decreased fertility and sterility
2. Late effects
    a. Permanent or delayed skin changes
    b. Increased incidence of cataract
    c. Increased incidence of leukemia and other neoplastic disease
    d. General life shortening

The probability of occurrence of late effects (including genetic effects) provides the basis for radiation protection guides or acceptable levels of exposure both for those employed in jobs involving radiation and for members of the general public. They are of secondary importance to manned space flight insofar as short and intermediate range missions are concerned. Those human responses of primary significance to manned space missions of the next few years can be defined in quantitative terms of a low LET radiation to provide a reasonable perspective of the current radiation problem.

Today's discussion of the quantitative (or semi-quantitative) response of man to radiation exposure is based largely on the NAS/NRC Study Panel report. In all cases, dose is expressed in energy deposited (rads, 100 ergs per gram of absorbing material) at the point of interest by 200- to 250-KVP X rays or high-energy gamma rays for which the quality factor (QF) is assumed to be unity. The information is derived from criticality accidents, nuclear weapons experience (including the Japanese bombings), diagnostic and therapeutic radiology, and other human exposure supplemented by a vast amount of animal experimentation. Information sources are not given here except to refer to the Study Panel report which gives the relevant citations. A variety of troublesome and difficult modifying factors (dose rate, dose fractionation, QF, dose distribution, radiation type) inherent in the space radiation environment must be taken into consideration in applying the basic dose-response judgments to space mission radiation risk evaluation.

Application of the basic dose-response judgments to actual space conditions can be made by theoretical means and will become more refined and sophisticated as more information on the space radiation environment accumulates. One of the outstanding contributors to this aspect of radiation risk evaluation is your previous speaker, Dr. Hermann Schaefer.

By no means is this tone of cautious optimism to be construed as meaning space radiation can be discounted as a potential risk. Rather, it is an attempt to place the immediate radiation problem in perspective. Radiation problems of the future will be more complex and will involve missions of many years duration and use of nuclear energy both for propulsion and auxiliary power.

PROTECTION OF MAN IN SPACE
(Radiation Shielding)

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I. Introduction

The major sources of radiation in space include galactic (or cosmic) radiation, trapped particles (Van Allen belts), and solar flares. Estimates of the fluxes and dose rates from each of these sources are listed in Table I.

II. Interactions of Radiations With Matter

A. Mechanisms of Interaction

On the atomic and molecular level, radiation interacts with matter to produce atomic ionization, atomic displacements, and nuclear reactions. Particulate radiation in being stopped or slowed down can also result in the production of secondary Bremsstrahlung (x-rays). These effects may be produced directly or indirectly and may be permanent or transitory. Because radiation interacts with matter, it can cause physical damage. However, the very nature of its interaction also permits it to be detected and to be shielded.

B. Units of Dose

The biological effects of radiation depend upon its quality and type, its energy, the rate at which it is absorbed, and other factors. Units which have been developed for expressing the effects of ionizing radiations include the roentgen, rad, and rem.

$O^+ \rightarrow e$

To produce 2 BILLION ION PAIRS/cm^3 = 1 ROENTGEN ((10^{19} atoms present in cm^3 air normally))

If took 1 Hour, & placed hand in it would have received 1 RAD (100 Ergs/Gm)

e^-'s have kinetic energy & → collisions & ↑ ion pairs

If hi energy bulletlike particle, produces pairs of ions in its path (which is localized)

∴ Energy ↑/Unit Path is important

∴ LET

+

RBE – Biol. Effect. – α particle = 5–10 or 20 (= RAD × RBE)

REM – Radiation Effectiveness, Man

If Series of Absorbers (Shield) → | | | |

50% 25% 12½% etc. Harder to shield →

If e^- → Bremsstrahlung = 2ndary X-Ray (This is how X-Ray Machine works)

∴ Shielding MO more hazardous > original β

Efficiency of X-Ray production by Target is directly proportional to Z No. (No. protons in Nuc)

Permissible Dose	Average	Emergency
Workers	5 REM/yr	25
Gen Pop Individual	0.5/yr	15
General	5/30 yrs	5
Astronauts	55/yr	200

TABLE I

RADIATION IN SPACE

Source	Radiation Types	Flux (#/cm^2· sec)	Energy (eV)	Dose Rate (rads)
Galactic	proton-85% alpha-14% heavier nuclei-1%	2.5	10^8-10^{20}	5 - 12/yr.
Trapped Radiation				
Inner Belt	proton electron	2×10^4 2×10^9	10^6-10^{10} 10^4-10^6	25/hr.
Outer Belt	proton electron	10^4 10^{11}	10^5-10^6 10^4-10^7	200/hr.
Solar Flares	proton alpha	10^9 - 10^{12}	10^6-10^{10} 10^6-10^{10}	1,000-30,000/hr. (at maximum); 500-2,000 (total dose)

Apollo Monitoring

1. Neutral Detection System
2. Van Allen Belt Dosimeter
3. Radiation Survey Meter
4. Personal Radiation Dosimeter
5. Passive Dosimeters

Protection Approaches

Shielding – Physical
– Electrical – 10 Mill Volts Req.
Needs 10^7 [illegible] to do
– Plasma device being worked out.

Operational – Tr.-Path
– Trip Timing
– Capsule Arrangements – Orientation of Shielding

Shielding Problems

Orbital Flights – No Problem
Protons (>1 Bev) – No Hope
Protons (10 Mev – 1 Bev) Main Problem
Electrons (< 10 Mev) – Bremsstrahlung

Lighter Elements more effective as shields against protons

Hi Z Matls more effective against X Rays
– Storm Cellar

Gen. Protons attenuated markedly by depth (in the skin)

C. Shielding Concepts

Both electrical and physical methods for protecting astronauts have been considered. The latter appear more feasible at present. Theoretical and practical considerations show that the best shielding materials are those of low "Z" (for initial absorption of incoming radiations) supported by a secondary barrier of high "Z" material for protection against Bremsstrahlung.

III. Protection of Astronauts

A. Radiation Protection Guides

Guides which have been set for the protection of astronauts in the Apollo program are shown in Table II and are compared to recommended limits for radiation workers and the general population.

TABLE II

PERMISSIBLE DOSES
(REMS)

Category	Average Conditions	Emergency Conditions
Radiation Workers	5/yr.	25
General Population		
Individuals	0.5/yr.	15
Average	5/30 yrs.	5
Astronauts	55/yr.	200

B. Protection Approaches

1. Electrical Shielding

It has been calculated that an electrically charged spacecraft could successfully protect its occupants from the proton flux of solar flares. Such a spacecraft, however, would have to be charged to many millions of volts and it has been estimated that it would require 10^7 kilowatts to maintain the necessary charge.

2. Physical Shielding

For deep space missions, the "storm cellar" approach appears to offer distinct weight saving advantages. Under this system, the spacecraft would include small shielded vaults into which the astronauts could retreat during periods of intense (solar flare) radiation.

3. Operational Safeguards

Operational safeguards to assure minimum dose during space travel include (1) proper selection of flight paths, (2) scheduling the trip to avoid periods of maximum solar flare activity, and (3) special orientation of the capsule during such periods, if encountered.

C. Dose Measurements

The objective of inflight dosimetry is to obtain data on the absorbed dose, to have knowledge of the distribution of the dose as a function of tissue depth, and to be provided with the readings in real time. Instruments developed for this purpose include particle detectors, survey meters, and personal radiation dosimeters.

D. Observed Dose Levels

Observed dose levels during earth orbital missions have been minimal. The major contributor has been the "South Atlantic Anomoly" where on certain earth orbital missions the astronauts have spent only 10% of their time but received 90% of their dose. With deep space missions, the major concern would be solar flares.

IV. Commentary

A. Applications of Nuclear Power

The use of radioisotopic power (so-called SNAP) sources in spacecraft present few, if any, radiation protection problems. The application of nuclear power as a propulsion system would require special considerations.

B. Supersonic Transports (SST)

The problem of protection of people from space radiation is not limited to the astronauts. Data show that passengers in supersonic transports could receive significant doses during solar flares. In all probability, some type of warning system will have to be developed to permit such planes to go to a lower altitude during such periods.

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