PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS OF OVERLOADING FALLOUT SHELTERS

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PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS OF OVERLOADING FALLOUT SHELTERS

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April 15, 1963

ABSTRACT

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by Donald T. Hanifan, W. Vincent Blockley, Meredith B. Mitchell,
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A study was carried out to analyze the physiological and psychological factors limiting the survivable loading of fallout shelters, to determine the areas in which further information is most needed, and to suggest experiments for obtaining that information.

The report discusses the purpose and scope of the investigation, provides a definition of overloading and discusses its etiology and likelihood of occurrence, and considers the man-shelter-environment interaction in parametric terms. The significance of population characteristics and variability is discussed and a preliminary attempt is made to define the population of interest. The most outstanding environmental variables are listed and briefly considered, after which physiological and psychological variables are examined in considerable detail; an approach to predicting the effects of variables in combination is then presented together with a first "cut" at analyzing "two-at-a-time" variable interaction. Physiological response to probable shelter environments is discussed with particular emphasis given to the effects of excessive heat, carbon dioxide and certain toxic atmospheric contaminants; and to the effects of inadequate oxygen, food and water. Other factors such as noise level, disease, sleeplessness and the like are also discussed. Although psychological variables do not lend themselves to the relatively quantitative analysis that physiological variables do, investigators have distinguished more than 60 significant psychological variables. The reported and expected interactions between stressful environmental stimuli and psychological reactions are examined as well as interactions between the psychological variables themselves.

Various methods for increasing survivable loading limits are presented, including such techniques as drug administration, "psychological" control, and "physiological" control without drugs. Although further work is required before completely reliable criteria for shelter loading limits can be set, a preliminary attempt is made to establish a method for determining limiting values for environmental parameters. A number of suggestions are made for future studies, together with recommendations for pre-attack preparation, shelter design, provisioning, training in-shelter, management, and loading limits.

PREFACE

In April of 1962, Dunlap and Associates, Inc., Western Division, contracted with the Department of Defense, Office of Civil Defense, to study the overloading of fallout shelters on the basis of physiological and psychological principles, and to analyze limiting survival conditions in shelters. This report contains the results of that study.

A rigorous solution to the problem of determining the upper tolerance limits of a mixed population to a prolonged and complex environment would require solutions to some of the most significant and difficult problems facing the fields of physiology and psychology today. It would be presumptuous for any group to expect a modest expenditure of time over the course of a year to provide more than a first approach, a very first cut approximation - or perhaps an advance in some element of the larger problem.

In terms of the overall problem of the man-environment-shelter interaction, we can as yet provide only guidelines. However, in building the foundations for a more comprehensive and rigorous approach, many concepts, methods, and a considerable body of data were reviewed, and analyzed in terms of their usefulness to solution of the shelter overloading problem.

Certainly no "final answers" are given in this report. Rather, we bring together in one place some of the more useful data and techniques, discuss new approaches which we feel hold promise, and, with caution, put forth tentative predictions of the environments and responses which might be expected in overloaded shelters.

Although much we report is not new in concept, there are some highlights we feel may be of special interest. For instance, in trying to arrive at population descriptors which had meaning in terms of physiological processes, it suddenly occurred to us that the variation in the constant contained in the sweat loss equations of Hatch and of Kerslake, which has been claimed to represent variation in skin conductance, might correlate with body weight and thus provide a convenient means of connecting thermal processes with anthropometric measures. In searching through original thermal data for body weights, however, we managed to uncover evidence which pointed clearly to the fact that the constant must represent variation in sweat response due to heat acclimatization rather than in conductance, leading us to hypothesize the "heat acclimatization K factor theory" in this report. If the theory is borne out by experiment, a mechanism will have been provided for determining the distribution of heat response characteristics throughout the population in a way that has many practical implications.

In attempting to relate data from highly diverse sources, we have produced several charts which may also be of special interest. Included in the report are three charts summarizing interactions and effects of physiological, psychological and psychophysiological reactions to stressful environments (Figures III-45 through 47), and a "first cut" of a combined variables matrix which is intended to represent a very preliminary step in the treatment of interrelated factors in terms of their partial effects.

In writing this report, we had mixed motives. While it was considered essential to carry the analysis of shelter overloading as far as the data would permit it also seemed highly desirable to provide future researchers with reference materials and useful tools, some of which are often difficult to obtain without access to special sources. We have also made a point of including such basic tools as the Predicted Four Hour Sweat Rate Nomograph, which forms the basis for determining water requirements in shelters.

Numerous people have contributed to the performance of the work reported here. Mr. W. Vincent Blockley of Webb Associates, consultant to the program in the area of thermal physiology, has been primarily responsible for the thermal variables considerations. Mr. Meredith B. Mitchell has been primarily responsible for the psychological variables considerations and, with Dr. George Bell, M.D., for most of the drug evaluations. Mr. Peter H. Strudwick has aided in numerous aspects of the investigation, and has made major contributions to the study of nutritional factors. Mr. Richard E. Shoemaker and Mr. LeRoy Bolden have also made valuable contributions to the analysis of psychological factors. Appendix A was written by Mr. Ronald A. Westland and Appendix C by Mr. Lennard B. Weingarten. Technical assistance was provided by Miss Mary Jo Schrock, whose competent handling of numerous details has been indispensable to the accomplishment of the study. Figures were produced by Byron Bloch. Mr. Fred Carr of the Office of Civil Defense, who monitored the program, has been especially helpful in providing background material related to the shelter program.

Donald T. Hanifan
Principal Investigator
Dunlap and Associates, Inc.
April 15, 1963

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SUMMARY AND CONCLUSIONS

The purposes of the study reported here are to analyze the physiological and psychological factors limiting the survivable loading of fallout shelters, to determine the areas in which further information is most needed, and to suggest experiments for obtaining that information.

The report discusses the purpose and scope of the investigation, provides a definition of overloading and discusses its etiology and likelihood of occurrence, and considers the man-shelter-environment interaction in parametric terms. The significance of population characteristics and variability is discussed and a preliminary attempt is made to define the population of interest. The most outstanding environmental variables are listed and briefly considered, after which physiological and psychological variables are examined in considerable detail; an approach to predicting the effects of variables in combination is then presented together with a first "cut" at analyzing "two-at-a-time" variable interaction.

Various methods for increasing survivable loading limits are presented, including such techniques as drug administration, "psychological" control, and "physiological" control without drugs. Although further work is required before completely reliable criteria for shelter loading limits can be set, a preliminary attempt is made to establish a method for determining limiting values for environmental parameters. A number of suggestions are made for future studies, together with recommendations for pre-attack preparation, shelter design, provisioning, training in-shelter, management, and loading limits. Appendices are included which provide: 1) a mathematical examination of the consequences of different loading policies; 2) morbidity statistics; 3) a simplified method for making rough approximations of steady-state shelter air temperature, together with the predicted effect of overloading on the steady-state, saturated air temperature for a hypothetical 100 man underground shelter; 4) a mathematical derivation of equations for gaseous concentrations in ventilated spaces; and 5) a reference list of drugs which are potentially useful for administration to occupants of fallout shelters.

It is emphasized that two basically different aspects of survival must be considered: survival <u>during</u> shelter occupancy, and survival <u>after</u> release. Consequently, it is suggested that limiting conditions

should not exceed those for which a substantial proportion of the healthy population would leave the shelter in a condition which enables them to recover within a few hours to a day without requiring specialized medical assistance (when placed in a cool environment, allowed to rest, given adequate food and water, etc.). Although in the simplest terms, a shelter is overloaded when the number of inhabitants exceeds the number for which it was designed and provisioned, it is suggested that in a more precise sense, a shelter can be considered to be overloaded when conditions in the shelter lead to progressively increasing, uncompensated disturbance of normal physiological/psychological function of healthy inhabitants before the end of the desired period of shelter confinement. For purposes of the study, the conditions of primary concern are those conditions of "overloading" which could be alleviated either by reducing the number of shelterees or the duration of shelter stay -- given a pre-provisioned shelter of specified design.

After examining the numerous ways in which a shelter can become overloaded, it is concluded that a significant proportion of the population might encounter such conditions and, consequently, that planning for the overloaded case should receive serious consideration. Such planning should be approached both from the points of view of prevention and of minimization of effects.

Unfortunately, most of the literature reporting experiments on response to environmental stress is directly relevant only to special populations -- usually to healthy, young men or to special occupational groups. Even shelter habitability experiments usually have been restricted to a carefully screened population to reduce certain sources of undesired variability. Population variability can lead to large differences in such factors as rate of heat production, response to thermal conditions, water consumption, and production of gaseous, liquid and solid waste, all of which contribute directly to the extent and duration of survivable overloading.

A number of tables have been included to provide a preliminary characterization of the population which will have to be sheltered in the event of an emergency. However, only a small part of the task which needs to be carried out has been accomplished, namely, consolidation into a usable form of the large and scattered body of physiological and psychological data characterizing all segments of the United States population. Furthermore, much experimental characterization remains to be accomplished, particularly in the area of thermal response.

Physiological response to probable shelter environments is discussed, with particular emphasis given to the effects of excessive heat, carbon dioxide and certain toxic atmospheric contaminants; and to the effects of inadequate oxygen, food and water. Other factors such as noise level, disease, sleeplessness and the like are also discussed.

It is concluded that response to the thermal environment will ordinarily be the variable of greatest concern; accordingly, it is treated at length in the report. Of particular importance is the fact that a considerable variability in heat response in the population is expected due to the great differences in heat acclimatization -- characterizable in terms of a proposed "heat acclimatization K factor." A number of ways to increase thermal resistance and/or to decrease thermal effects are discussed, including increasing the heat acclimatization K factor, rapid total-body cooling, rotation to the ambient environment, and the like. "Effective Temperature" nomographs and "Predicted Four Hour Sweat Rate" nomographs are included to aid in determining water requirements. It is concluded that one quart of water per day is inadequate if any significant degree of overloading is anticipated, and that the resulting dehydration would lead to a high probability of heat stroke within a day or so. At 90 degrees effective temperature, as much as six to twelve quarts per day might be required! Furthermore, significant differences in sweat rates throughout the population suggests that water rationing policies and techniques be used which would provide for allocation of varying amounts to different shelter inhabitants on the basis of their sweat loss as measured by short term body weight decrement. It is also concluded, however, that overall water requirement would be lowered by increasing the velocity of air movement within the shelter, an effective air velocity of 50 to 75 feet per minute impinging on the surface of the occupants being a desirable minimum. Furthermore, the degree of allowable loading will probably be more than doubled by an increase in ventilation by outside air from three to six cubic feet per minute per person.

Methods are presented for determining the combined effects of lowered oxygen and increased carbon dioxide concentrations in the shelter. For most cases, it is concluded that even for a considerable degree of overloading, it is not likely that significant effects from lowered oxygen or increased carbon dioxide concentrations are to be expected, the notable exception being in the case of the "buttoned-up" shelter -- a possible requirement in the event of extensive fire near the shelter.

The possibility of build-up of trace atmospheric contaminants is also examined, and estimates of their concentrations are provided.

The major likely sources of such contaminants are flatus, feces, urine, sweat, vomitus, gases exhaled in the breath, tobacco smoking, fires and decay or fermentation of organic matter. The contaminants which are discussed in terms of their potential concentrations and toxicities include ammonia, hydrochloric acid, methane, hydrogen sulfide, indole, skatole, methyl mercaptan, phenols, lactic acid, volatile fatty acids, ethereal sulfates, hydrogen and carbon monoxide. It is concluded that toxic effects do not appear likely, with the possible exception of carbon monoxide, for which unacceptable concentrations might result from unrestricted smoking in the overloaded case, or from contamination of the ventilation intake air by prolonged fire and smoldering of remains near the ventilation inlet. A method is given for computing the combined effects of lowered oxygen and increased carbon monoxide concentrations, since the two conditions are additive in their effects. The possibility of accumulation of explosive gas mixtures is also considered; it does not appear to represent a likely source of danger.

The probable occurrence and effects of undernutrition are considered in quantitative terms. Although the concept of a definite, lethal body weight loss is subject to so many qualifications that it cannot be applied in any general sense, some data suggest that a "rule of thumb" lethal level for loss of body weight for normal, healthy people is about 20 per cent for the young, 40 per cent for adults exposed to acute starvation, and up to 50 per cent in cases of semi-starvation. For shelter occupants, it is suggested that allowable limits for body weight loss be established at 5 to 10 per cent for the young and 10 to 20 per cent for adults -- with full realization that many of them could sustain even greater losses, but that a very few would find even that much weight loss intolerable.

Equations and nomographs are presented which enable prediction of weight loss as a function of caloric intake per day, duration of shelter confinement, age, sex, initial body weight, and activity or energy expenditure. It is recommended that food rationing be established such that daily allocation is made not only on the basis of available food and expected shelter stay, but also on the basis of age, sex, initial body weight, and such special conditions as illness and pregnancy. Although caloric deficiency is not expected to be critical for most normal, healthy adults, such deficiencies can become critical for extended durations (two weeks or more) -- if severe -- in the case of children in rapid growth phase, pregnant women, very lean persons, and sufferers from certain diseases.

Among the other physiological variables given brief discussion are sleeplessness, morbidity and response to noise.

Sleeplessness may increase as a function of degree of overloading. It is pointed out that in the absence of adequate sleep, physical fitness declines and tolerance to almost all stresses is decreased. The inclusion of adequate supplies of sedatives in the shelter medical kit could mean the difference between survival, and death or premature escape for occupants of a severely overloaded shelter.

The incidence of disease in the shelter is discussed in terms of its probability of occurrence by type, severity of reaction, and spread to other shelter occupants, all of which are expected to increase as a function of increase in loading. The presence of disease tends to decrease tolerance to environmental stresses -- and is particularly critical if dehydration results from diarrhea or vomiting. In all, out of 100 entrants, about 1.4 may be suffering from some form of acute disease and about the same number from a chronic ailment.

Noise level will very likely increase markedly as loading is increased, making communication (and therefore management) difficult, increasing psychological tension and irritability, and tending to increase muscular tension and thus metabolic rate. Sleeplessness may be produced, particularly in susceptible persons. A family of noise tolerance curves is presented for threshold levels ranging from those producing sleep interference to those producing mechanical damage. It is suggested that "noise control management" be carried out.

Under a discussion of means for increasing survivable limits through use of drugs, the contents of the current medical kit (Kit C) are evaluated with respect to their usefulness and contraindications -- additions, deletions and/or substitutions being given where appropriate. Drug-induced hypometabolism ("hibernation") is also discussed and a scheme for "metabolic management" is presented.

One section is spent in an evaluation of controlling, through the use of drugs, more specific psychological reactions to the stresses of shelter living and thermonuclear attack. The reactions more or less amenable to drug control are overt aggression, anxiety, withdrawal, fatigue due to food or sleep deprivation, and hunger. The advantages and disadvantages of specific and general classes of drugs for shelter behavior management are discussed. Included in the evaluation are sedatives, tranquilizers, stimulants (among which are anorexiants) and metabolic depressants. It is suggested that special consideration be given to handing out "Elavil" or Compazine to all people as they enter a shelter. This procedure might serve to make new arrivals amenable to initiation and training and to reduce the initial tension connected with doubts concerning their survival. The leader's organizing problems might be minimized thereby and the discomfort from overcrowding -- if it exists -- could be kept down. It is quite conceivable that subsequent management and operations would be simplified if cooperation were achieved at the beginning. The shelter might be considered safe simply because it offers relief from anxiety right from the start. Individuals might tend thereafter to associate protectiveness with the shelter, a fact which may help to promote feelings of well-being and hope for survival.

Some techniques for controlling psychological reactions without drugs are also discussed. It is pointed out that control must be considered preventive as well as corrective, and suggestions for initially establishing a favorable psychological atmosphere are presented. Important preventive factors mentioned are: 1) pre-shelter training; 2) introduction to the shelter and shelter life in a positive and reassuring manner; 3) in-shelter communication of conditions within and without the shelter; 4) establishing a form of group therapy for occupants whose behavior indicates a potential personality problem for later shelter management; 5) maintaining a well-defined, meaningful, and organized program of activities; and 6) providing each individual -- through verbal comments and responsibilities -- with the feeling of personal worth and importance for the in-shelter and post-shelter society.

A significant discussion is presented covering the control of persons striving to leave the shelter before it is clearly safe to do so. A four-step procedure is offered for the management of these people, but it is suggested that the problem might be averted if adequate preventive measures are taken. In order to accomplish that, well-selected leaders are indispensable.

Psychological variables do not lend themselves to the relatively objective analysis that physiological variables do; yet investigators who have conducted relevant studies have distinguished more than 60 significant psychological variables. Two charts are presented illustrating the reported and expected interactions between stressful environmental stimuli and psychological reactions as well as interactions between the psychological variables themselves.

The charts begin with measurable stressful stimuli; however, other stresses may exist as well, such as separation from family members and inadequate leadership. Those factors are discussed with emphasis placed on leadership and communication.

Since one may view psychological problems in general as arising from stresses placed upon the individual, a discussion is presented of several theoretical concepts of stress relevant to the shelter situation. This is followed by a discussion of some specific psychological reactions which have frequently been reported in relevant studies: irritability, hostility and aggression, fear, depression and adaptation, and withdrawal. Particular attention was paid to studies which provided clues to the practical use of results, such as Janis' finding that the degree of anticipatory fear can be used as an indication of behavior under the subsequent, anticipated stress. In addition, a parallel is drawn between the problems of the shelter occupant as a result of thermonuclear attack and people who learn they have cancer.

The conclusion drawn from the many pertinent investigations is that evidence is inadequate to predict, among the entire shelter population, precisely what psychological factors will predominate at a given time or what course those factors will take, either in a normally loaded or overloaded shelter situation. However, there appear to be two distinct categories of findings: 1) those characterized by the three-stage sequence, <u>anxiety-depression/apathy-anxiety</u> and 2) those having the two phase pattern, <u>depression-adaptation/adjustment</u>. The primary factor differentiating the study conditions for those two categories is the reality of the overall stress. Generally, in studies for which results indicate the second category, the people observed were actually under real threat to their lives while individuals in the first group of studies generally knew the duration of their confinement and that normal conditions awaited them when their confinement terminated. From psychological theory, empirical findings, and reasoning, it has been proposed, however, that within the unique shelter environment in times of true stress it appears likely that behavior will be highly diverse.

Psychological studies are discussed which lead to the proposition that, since people will enter a shelter because they have some degree of hope that it will protect them, the degree to which a shelter will be able to tolerate overloading is an important function of the consensus, degree, and maintainability of the feelings of hope and confidence experienced by the shelter occupants.

Variables which will affect the shelter group interaction are also discussed. They include age differences; problems related to the relative number and interaction of males and females; and the possible results of having mixed males and females; racial, religious, ethnic and socio-economic groups.

Finally, the effects of psychological factors in an overloaded shelter are summarized. Crowding is differentiated from overloading in that crowding can be defined simply in terms of the space allotted to each individual, whereas loading must be defined with respect to people's reactions. And it is pointed out that establishing certain psychological environments, such as "enthusiasm," "high morale," and "confidence" can reduce overloading to simple crowding.

Thus, it is pointed out that one of the responsibilities of the shelter leaders is to establish that environment to the greatest extent possible. With exceptional leadership, it is conceivable that even an extremely crowded shelter might safeguard its occupants who -- in spite of their thirst, hunger, sore muscles and aching bones -- maintain a high morale, by being sustained on a vital diet of encouragement, sincere mutual interest, purpose, activity, hope, and confidence.

Since much of the information needed for establishing limits is missing, and since the need to establish limiting criteria for environmental exposure is immediate, it is suggested that somewhat modified limits, based on current data, can be used as an interim measure if at the same time a few basic remedial techniques are made available to the shelter manager. In particular, some of the control techniques involving administration of sedatives and metabolic depressants should be considered as a safety measure to make up for current uncertainties about the extent of variation in the general population. Given such safety measures, and given strong and wise shelter leadership, then critical levels for several variables can be defined for a shelter containing a mixed population. Specifically, the following levels of prolonged environmental stress appear to represent critical limits beyond which a widespread crisis would be likely to occur:

• Oxygen concentration	12-11%
• Carbon dioxide concentration	3-5%
• Effective temperature	90-94°F
• Dehydration (predicted from P4SR, urine output and water ingested)	5-10% of body wt.
• Acute starvation weight loss	
children	10-15% of body wt.
adults	30-35% of body wt.

Note that these values are only for stresses one-at-a-time. For instance, dehydration would considerably lower the effective temperature which could be tolerated; and increased effective temperature, by increasing sweat rate, increases dehydration.

A multitude of other factors are also involved. If more than one stress is to be imposed, the safe procedure would be to reduce the stress levels to at least half the values shown.

In conclusion, while much can be said about response to single stresses for a limited range of the population, it is not yet possible to establish entirely reliable limiting criteria in terms of the kinds of environments and occupants expected in the shelter. Therefore, a firm basis has not as yet been derived for limiting admittance to a shelter in the face of demands for entry. However, considerable alleviation of the adverse effects of overloading can be achieved through the use of dynamic policies and remedial measures, many of which are discussed, and extensive use of them as "stop gap" measures is recommended until the analysis has been carried far enough to enable reliable criteria to be established.

The report concludes with a number of suggestions for future study (pgs. 264-269) and a list of recommendations based on the outcome of the research accomplished to date (pgs. 270-275). Approximately 180 references are listed in three different locations in the report.

PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS OF OVERLOADING FALLOUT SHELTERS

I. INTRODUCTION

A. SCOPE AND PURPOSE

The purposes of the study reported here were to analyze the physiological and psychological factors limiting the survivable loading of fallout shelters, to determine the areas in which further information is most needed, and to suggest experiments for obtaining that information.

The need for the study derives from the assumption that any given shelter space may be limited due to a variety of considerations, including economic, and will not always provide optimum or even reasonable comfort for all who may enter. Given that assumption, it becomes critical to assign realistic limits to shelter loading beyond which the probability of survival of the occupants is likely to be unacceptably low.

The importance of the study becomes evident when one contemplates the possible destruction of sheltered people due to overloading versus the destruction of unsheltered people who might have survived if they had had the opportunity to enter a shelter. In considering such a trade-off of life, comfort becomes secondary to survival.

An answer to the problem would be to define the limits of shelter loading beyond which the probability of survival for those who enter the shelter would be less than for those who remain outside the shelter. A related problem is to identify techniques which may be practically implemented for increasing survivable loading of shelters, as well as to define survival limits given current techniques.

Two basically different aspects of survival are involved; survival _during_ shelter occupancy, and survival _after_ release; consideration of techniques for increasing shelter loading must therefore include consideration of their effects on subsequent survival outside the shelter.

Although both physiological and psychological reactions may be produced by shelter overloading, psychological reactions are considered here only insofar as they affect physiological responses or when they appear to endanger survival as a direct result of destructive behavior.

The primary factors considered in a formal framework are those of a physiological nature due to the relatively great susceptibility of such processes to quantitative treatment. However, behavioral effects are included where possible since it became clear that important interactions exist among them and physiological response.

The problem resolves itself to prediction of discrete events superimposed on a continuum of human response to increasingly stressful environmental conditions. In general, the continuum begins with a threshold below which no ill effect is perceptible and progresses through the successive zones of discomfort, severe but reversible effects, irreversible damage, and finally death. Previous attempts to define shelter occupancy limits have utilized subjective criteria primarily in voluntary experimental exposures as well as in numerous theoretical calculations based on engineering estimates such as the thermal "tolerance" curves utilized by heating and ventilation engineers. Even the term "tolerance" has not been used consistently in the literature and may refer to any of a large number of states.

This study deals for the most part with conditions of shelter loading which produce strains in the human beyond those observed in the comfort zone. Since definition of the region of severe but reversible effects probably represents the survival limit in question, special emphasis is given to that area. Although it might be argued that limited irreversible damage might be acceptable if larger numbers might be accommodated and therefore saved from radiation damage, that argument breaks down when one considers the requirement that survivors also must be able to cope with the rigors of existence in a post-attack world after release from the shelter, and the deleterious effects on the morale of the majority when there is severe damage to a few susceptible companions.

Numerous historical incidents serve to demonstrate the potentially disastrous consequences of overloading. For example, in the famous "Black Hole of Calcutta" case, 146 prisoners were locked overnight in a cell, with two small windows, designed to accommodate two men. Hopeless efforts to force the barred windows and door gave way to total confusion and riot as delirium supervened. Those who fell were trampled to death and many taunted the guards in the hope of provoking a quick death by bullet. Eventually the last succumbed to stupor due to the severe heat stress. All but about twenty were dead by morning.

In another instance, approximately 200 steerage passengers on the "Londonderry" were confined in a cabin 18 x 11 x 7 feet (approximately one square foot of floor space and seven cubic feet of air space per person) with the hatches closed and the door covered with a tarpaulin.

By the time one man forced his way out and alerted the ship's mate, 72 were dead and many were dying as a result of the frenzied violence brought on by the intolerable heat.

Both the above cases illustrate the consequences of severe heat stress brought about by gross overloading. (A comprehensive review of historical incidents of extreme overcrowding has been made by Biderman, et al., (1963).) However, not all cases of overloading will have such immediate and disastrous effects. In some instances, days or even weeks may be required for responses to environmental stresses to reach critical levels. In such long-duration exposures combinations of many stresses will contribute to the eventual conditions limiting occupancy. A highly complex set of interrelated physiological and psychological responses to a multitude of environmental and situational factors are involved in overloading; an understanding of the characteristics and implications of those responses is vital to the formulation of policies for shelter construction, provisioning and for management of inhabitants and shelter resources.

B. DEFINITION OF OVERLOADING

In the simplest terms, a shelter is overloaded when the number of inhabitants exceeds the number for which it was designed and provisioned. In a more realistic sense, a shelter can be considered to be overloaded when conditions in the shelter lead to progressively increasing, uncompensated disturbance of normal physiological/psychological function of healthy inhabitants before the end of the desired period of shelter stay. For purposes of this report, we are concerned with those conditions of "overloading" which could be alleviated either by reducing the number of shelterees or the duration of shelter stay - given a pre-provisioned shelter of specified design.

Although some degree of overloading can be tolerated if necessary, a limit to overloading exists beyond which irreversible damage or death would occur. Certainly the limiting condition we choose must fall safely short of such catastrophic end points. Although the limiting condition is extremely difficult to define at this point due to operational implications, it seems reasonable to hypothesize one in the region of severe but reversible effects at which a substantial proportion of the healthy population would leave the shelter in a condition which enables them to recover within a few hours to a day (when placed in a cool environment, allowed to rest, given adequate food and water, etc.) without requiring specialized medical assistance. This is not suggested as a condition which would be brought about under normal circumstances. Rather, it is reasoned that if a shelter manager were forced to decide on a critical course of action to save his charges - such as removing some of the shelterees to an unsafe radiation level to reduce the heat load for the remainder - such action should usually not be taken to reduce terminal stress to less than one which would result in the above condition. In other words, while sacrifices might be contemplated for the sake of sheer survival, certainly they should not be contemplated for anything less. And conversely, any sacrifices should be carried out in such a way that survival is, indeed achieved.

Given the kind of information which would make possible the prediction of shelter environment and human response to that environment, and given physiological and psychological tolerance limits consistent with the foregoing concept of limiting conditions, it may be possible to define loading limits for a given shelter and its provisions (for a given population) in either of two ways:

-- Given the number of shelterees, the limiting number of days of confinement are defined; or

-- Given a required number of days of confinement, the maximum allowable number of shelterees are defined.

C. ETIOLOGY OF OVERLOADING

Overloading can be brought about by many causes, any one or combination of which could limit the number of inhabitants which can safely be contained in a given shelter for a specified period of time. For instance, given a fixed rate of ventilation, the steady-state effective temperature of a shelter will increase as a function of the number of inhabitants and a load limit will be reached beyond which the heat stress is intolerable even with adequate water. The shelter is then critically overloaded with respect to the thermal environment or, more specifically, with respect to heat removal characteristics of the shelter. On the other hand, if the water supply had been planned for a given number of people at a specified maximum effective temperature, the shelter might become overloaded in any of the following ways:

a. External thermal load is greater than expected, thereby increasing shelter temperatures and increasing water requirements due to increased sweat rate.

b. Ventilating system partially or completely fails, thereby increasing shelter temperatures and increasing water requirements due to increased sweat rates.

c. Activity level of inhabitants is greater than expected as a result of psychological or other factors, thereby increasing water requirements due to increased sweat rate.

d. An epidemic of diarrhea or vomiting causes dehydration which increases water requirements.

e. An epidemic of fever increases water requirements.

f. Due to fires in the area, a substantial number of burn victims are included in the shelter population, thereby increasing water requirements.

g. Radiation exposure victims are included in the shelter, thus possibly increasing water requirements.

h. The planned number of occupants is exceeded so that internal thermal load is greater than expected, thereby increasing water requirements due to increased sweat rate and increased number of shelterees.

i. The planned number of occupants is so greatly exceeded that internal temperature increases rapidly to intolerable levels. Thermal tolerance is exceeded before water supplies become depleted.

Other ways in which overloading might be brought about could be listed. However, those listed above serve to illustrate the point. In all the examples, with the possible exception of "a" and "b", decreasing the number of shelterees would have alleviated the condition. Alternative means include increasing heat removal capability (e. g., increase ventilation rate), increasing water supplies (except for "i"), shortening the duration of enshelterment, decreasing activity levels and so on.

The major factors which can bring about overloading - and thus impose limits on either permissible number of inhabitants or allowable duration of enshelterment - are as follows:

a. Widely different population characteristics from those assumed for planning purposes

b. Limited water provisions

c. Limited food provisions

d. Limited rate of heat removal from the shelter

e. Incidence of ambient temperatures and humidity beyond those used for planning purposes

f. Limited removal rate of noxious or toxic gases from the shelter air

g. Limited rate of oxygen replenishment in shelter air

h. Limited sanitary facilities and means for controlling spread of disease

i. Limited medical supplies

j. Inadequate management and leadership

k. Inadequate facilities and/or environment (noise, lighting, discomfort, etc.) disturbing to sleep

l. Limited shelter space (floor area and contained volume).

Any or all of these factors could result in an overloaded condition, particularly if the required duration of shelter stay exceeds that used for planning purposes or if the shelterees should increase beyond the planned number. Each of the above factors is analyzed in subsequent sections of this report.

D. PROBABLE OCCURRENCE OF OVERLOADING

The probability of occurrence of various degrees of overloading (if all those desiring entrance were admitted) is a major factor in determining what pre-attack measures should and can reasonably be adopted to deal with it. Unfortunately, currently available information is inadequate as a basis for deriving a valid estimate of that probability. However, it is possible to speculate about some of the circumstances which might lead to overloading - or more precisely, to conditions in which either overloading is produced or people are turned away rather than admitted.

Two aspects of the shelter program must be considered. First, planning figures for shelter design and provisioning have been based on likely environments, normal inhabitants, and economical means of implementation. Food and water provisions, ventilating systems, sleeping and sanitary facilities and the like are based on that planning. Providing for low probability events in all shelters is probably unfeasible in most instances and would very likely lead to such exhorbitant expenditure per shelter that the total number of shelters made available would have to be curtailed drastically. Certainly, reliable information would be needed either to alter the trade-off between quality and quantity, or to vary the design of specified shelters to account for overloading.

Second, the shelter program is by no means completely accomplished. In some areas, very few fully provisioned shelters are available, a condition which would certainly result in serious overloading of existing shelters (or nonadmittance of many persons) in the event of an attack in the near future.

Even if adequate numbers of shelters were available to house the entire population, variation in local population during the day, from day to day, and from season to season, would very likely result in potential shelter overloading in some areas. Conventions, sports events, Christmas shopping, celebrations, etc., could result in local concentrations of people far beyond those planned for. The occurrence of an attack during a national holiday when a substantial proportion of the population is gathered together in dense clusters could well lead to highly overloaded conditions (if they were all admitted) - perhaps for as much as twenty per cent or more of the population.

As mentioned earlier, factors other than simple overcrowding can also result in an overloaded shelter. When a shelter is unable to support its inhabitants - for any reason - but could support a lesser number, it is overloaded. For instance, seasonal variation in the incidence of disease will no doubt influence the likelihood of epidemics in shelters and an epidemic would strain the limited resources of a shelter, thus bringing about an overloaded condition. Inadequate shelter management and leadership would also very likely result in effective overloading of shelters. The incidence of inadequate management and leadership to be expected is impossible to determine, except to say that it will no doubt occur due to many possible circumstances.

Considering all causes of shelter overloading, it seems certain that shelter overloading will occur, that its occurrence will partially be a function of the ratio of local population to amount of local shelter space, and that its occurrence will be greater during seasons in which disease incidence increases and during holiday seasons when people gather in large groups. It also seems clear that the probability of overloading will decrease as a function of time, providing shelter construction and provisioning continue.

Although it is impossible (without a detailed study) to attach a number to the proportion of shelters which might be overloaded during an emergency, the multitude of possible circumstances leading to overloading suggest that a significant proportion of the population might encounter such conditions and, consequently, planning for the overloaded case should receive serious consideration. The alternative - to leave people on the outside while others are admitted - does not appear to be a likely or desirable mode of behavior, particularly since the required duration of shelter stay is not predictable at the time of entrance.

II. APPROACH

In approaching the task of analyzing factors limiting the survivable loading of fallout shelters, it was necessary to distinguish between what would be ultimately desirable in the way of such an analysis, and what - of an immediately useful nature - was feasible to accomplish during the relatively short duration of this study. Hopefully, the study would satisfy both the requirement for immediately useful information and for data and techniques that could form a basis for extending the analysis at a greater level of sophistication. Furthermore, the desirability of defining the areas most critically in need of experimental investigation was also a guiding factor. The approach taken was designed to fulfill those requirements wherever possible within the frequently stringent limitations of the available, applicable data.

Our approach to the study is reflected in the organization of this report. First, a conceptual basis is established for a model within which interactions can be defined among shelter occupants, internal and external environment, provisions and shelter design. It is felt that, although the model is helpful for suggesting modes of interaction, its manipulation in a quantitative fashion is beyond the scope of the immediate study. However, the data and techniques made available during this study provide a substantial part of the groundwork required for a more sophisticated analysis utilizing the model.

The second step identifies the important environmental stimuli and human responses to them, and determines the ways in which those stimuli and responses might be influenced. Shelter habitability experiments, case histories of severe crowding and confinement, space vehicle ecology studies, basic physiological experimental studies, and theory form the basis for determining the important parameters to be considered.

Having explored the problem parametrically, population and environmental characteristics are studied to form a context within which each of the factors influencing loading limits can be considered in greater detail. It was decided that the assumption of shelter occupant characteristics similar to the general U. S. population, and environmental characteristics such as might be provided by the minimum shelter design currently specified in Office of Civil Defense planning documents, provide reasonable bases for the quantitative aspects of the preliminary analysis reported here. The full implication of population and shelter variability remains as a task to be accomplished; however, many of the basic tools for such an analysis are identical to those used in this study.

In the next step, a detailed analysis is carried out of the physiological and psychological effects of each of the more important environment stimuli or stresses, considered independently. In the analysis, tolerance limits are defined where possible and compared with the probable intensity of each stimulus or stress in a "representative" or hypothetical shelter situation.

Although very little relevant data were found that would enable a reliable estimate to be made of the effects of combined stresses, the next step considers the probable effects of environmental stimuli in combinations. Since relevant experimental data are rare, considerable use is made of speculation based on theory. Caution is advised until better data become available.

Given a basis in the preliminary analysis of shelter overloading, criteria are proposed for establishing shelter loading limits. The approach taken to establishing criteria should certainly depend heavily on moral considerations, policy, and expected conditions, and should not depend on physiological and psychological response considerations alone. Therefore, we provide factors to be taken into account rather than final answers.

In generating recommendations for OCD policies and practices, we approach the problem of overloading both from the point of view of prevention and minimization of effects. Where it seems economically and technically feasible, we recommend design, provisioning or policy development which would prevent the potentially drastic effects of overloading. Where these do not seem feasible, remedial measures are recommended which appear to be within the capability of well-trained shelter managers.

Finally, our approach to recommending future experimental study is simply based on what appears to us to represent the most critical gaps in the existing knowledge of response of a broad spectrum of people to the effects of the environments and situations which might be encountered in an overloaded fallout shelter. Economic and technical feasibilities are taken into account, but are not applied as overriding considerations since ingenuity and persistence overcome many obstacles which are seemingly insurmountable.

III. FACTORS LIMITING SHELTER OCCUPANCY

A large number of factors must be considered in any analysis of the effects of overloading fallout shelters. Those factors include the physical, psychological and social environment in the shelter; and the diverse characteristics of shelter occupants which determine their response and tolerance to the complex and changing environment of the shelter.

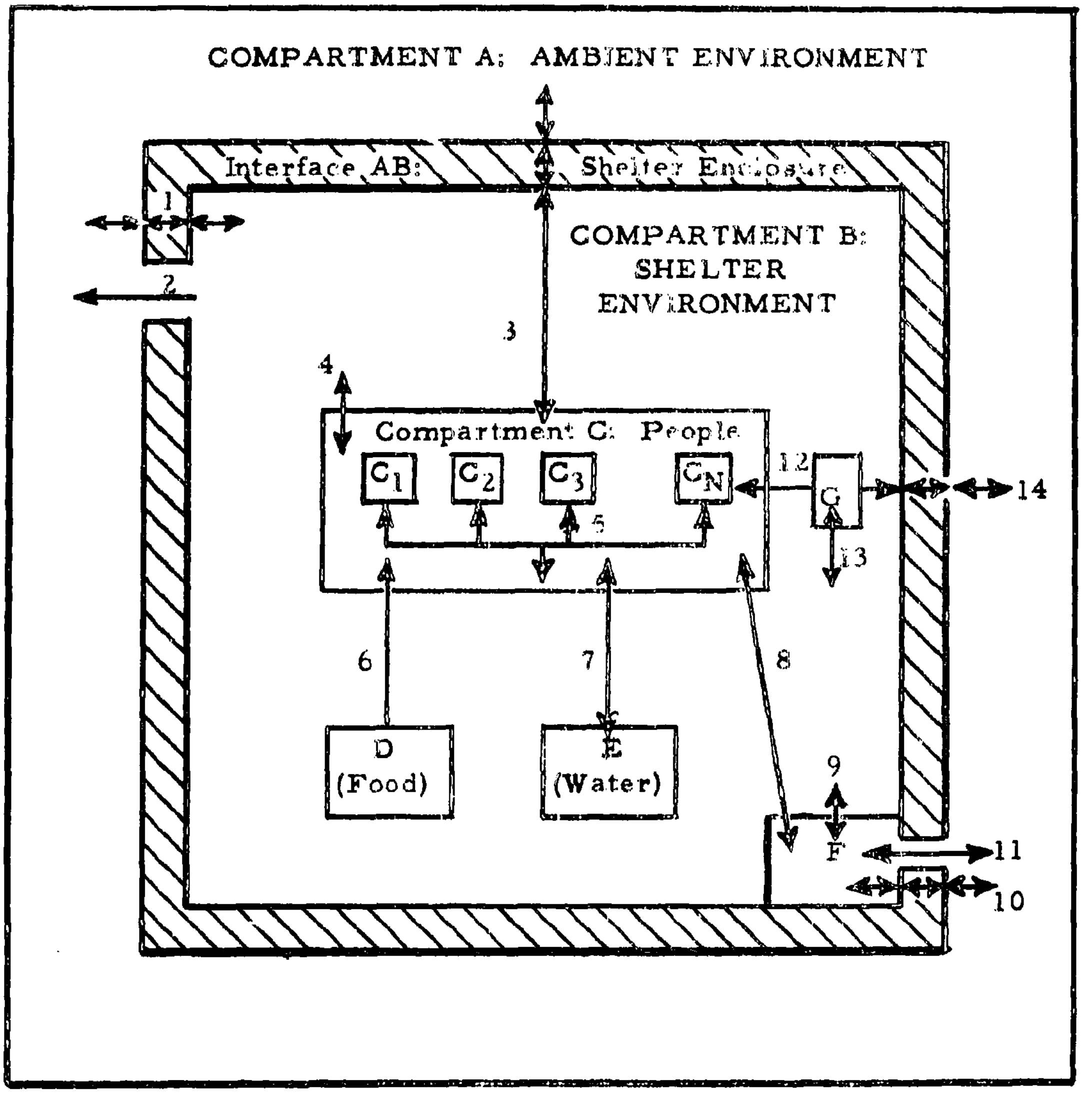
The following sections examine the major factors which determine shelter habitability, consider their interactions when present in combination, and discuss the criteria which seem most appropriate for establishing shelter loading limits. Although primary emphasis on thermal, atmospheric and nutritional variables is warranted by their importance in shelter habitability, many others influence the well-being of shelter occupants in significant ways. In particular, psychological response to the general situation as well as to the physical stresses will influence tolerance limits, the willingness to survive and to take corrective action, the nature and intensity of physiological responses, and, indeed, the willingness of shelter occupants to remain in the shelter in the face of increasing stress. The presence of contagious disease, chronic disabilities, noise, odors, radiation sickness, discomfort, and a host of other factors will all contribute to the probability that occupants of shelters may not be preserved in a condition which would enable them to be an asset rather than a handicap in the stringent environment of the post-attack world.

A. EXAMINATION OF MAJOR FACTORS

1. Parametric Considerations

In considering gross interactions within the man-environment-shelter system, it is convenient to view the shelter as a multi-compartment model in which the flow of energy and mass is defined as a steady-state moving from a given initial state to a terminal state representing the achievement of limiting criteria. As a function of time, concentration within each compartment and gradients across interfaces are definable. The general scheme is given in Figure III-1.

Compartment A represents the ambient environment. Note that the characteristics of the ambient environment influence the other compartments but ordinarily are not materially influenced by them. The parameters in Compartment A include such independently varying factors as temperature, humidity, solar radiation, wind velocity, partial pressures of gases, and so on.



F - Environmental Conditioning Equipment
G - Illumination Source

Figure III-1 General scheme for man-shelter-environment interactions.

Compartment B represents the internal environment of the shelter, and is a function of parameters existing in Compartment A, of the characteristics of the barrier between Compartments A and B (shelter enclosure) identified as Interface AB, of the collective characteristics of Compartments C_1, C_2, C_3, ... C_n representing shelter inhabitants, and of Compartments D, E, F, and G which represent food, water, environmental conditioning equipment, and illumination source. Interactions within and between compartments are listed in Table III-1.

Another useful way to consider the man-environment-shelter system is parametrically in terms of the important environmental stimuli and the primary adverse effects they may have on shelter occupants. That approach is taken in Table III-2, where stimuli or stressors and their primary adverse effects on occupants are in the center of the table, with "stimulus" information on one side and "effects" information on the other. Starting at the stimulus column and proceeding to the left, there are listed 1) the various possible sources of the stimulus, 2) ways in which the stimulus might be increased, and finally 3) ways in which the stimulus might be decreased. Proceeding to the right from the stimulus column there are listed 1) some of the more important primary adverse effects of the stimulus on occupants, 2) ways in which the probability and/or intensity of the effects (not stimulus) might be increased, and finally 3) ways in which the probability and/or intensity of the effects might be decreased. The outer edges of the table, then, list factors which could become the basis for corrective action based on shelter design, provisioning or management. Action could be based on limiting the stimulus, directly combating the physiological or psychological effects of the stimulus, or a combination of both.

In some cases, where the stimulus is produced by the occupants in proportion to the extent of the effects (or if stimulus and effects are intimately related in some other fashion), the same factor may be found on both sides of the table, a fact which suggests that control of that factor would produce large benefits. For instance, excessive heat in the shelter results primarily from the release of metabolic heat from the occupants, which in turn is proportional to their activity level. Note that decreased activity level appears on both sides of the table, which means that reduction of activity both decreases heat production and improves tolerance at any given time, thus producing a double benefit. However, a complicating factor exists because heat tolerance is also greater for people who are physically fit and physical fitness

TABLE III-1

ENVIRONMENT-SHELTER-OCCUPANT INTERACTIONS

Code No.*	Type of Interaction	Examples
1	Energy exchange directly across shelter wall between internal and ambient environments, excluding mass transfer.	Thermal exchange: radiation, conduction (note that energy path is between internal environment and inside wall, across wall, and between outside wall and ambient).
2	Mass transfer (and associated energy) between internal and ambient environments.	Exchange of CO_2, O_2, N_2 H_2O and possibly other gases via diffusion or forced ventilation; waste disposal; etc.
3	Direct energy exchange across shelter wall between people and ambient environment.	Radiative heat exchange across shelter wall between people and ambient environment.
4	Exchange of energy and mass between people and internal shelter environment.	Gas exchange via respiration; thermal exchange via perspiration, conduction, respiration, etc.; mass exchange via perspiration, respiration urination, defecation, etc.
5	Interchanges among people	Thermal exchange; psychological interaction, etc.
6	Decrease of initial supply of utilizable mass (and associated energy).	Food consumption
7	Change in initial potable water supply.	Decrease in potable water due to drinking, cooking, bathing, etc. Possible increases due to recovered or reprocessed water.

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*Refers to code numbers in Figure III-1.

Code No.	Type of Interaction	Examples
8	Direct interaction of people and environmental conditioning equipment.	Expenditure of energy through operation of manual ventilating equipment. Direct radiative and conductive thermal exchange between people and equipment.
9	Exchange of energy and mass between environmental conditioning equipment and internal shelter environment.	Heat exchange between air conditioner and internal shelter environment via radiation, convection, conduction and evaporation.
10	Direct energy exchange between environmental conditioner and ambient environment across shelter wall.	Conductive heat exchange via air conditioning system.
11	Direct exchange of mass and associated energy between environmental conditioner and ambient environment.	Convective and evaporative heat exchange via air conditioning system.
12	Effect on people of illumination source.	Radiative heat exchange between hot light bulb and people.
13	Direct energy exchange between illumination source and internal environment.	Heat exchange by conduction between hot bulb and shelter air.
14	Direct energy exchange between illumination source and ambient environment through shelter wall.	Radiative exchange across wall between hot light bulb and ambient.

TABLE III-2 SOME FALLOUT SHELTER ADVERSE STIMULI, THEIR EFFECTS ON OCCUPANTS, AND INFLUENCING FACTORS

STIMULUS DECREASED BY	STIMULUS INCREASED BY	SOURCES OF STIMULUS	ADVERSE STIMULUS (STRESSOR)	PRIMARY ADVERSE EFFECTS ON OCCUPANT	PROBABILITY AND/OR INTENSITY OF EFFECTS INCREASED BY	PROBABILITY AND/OR INTENSITY OF EFFECTS DECREASED BY
Decreased crowding Increased ventilation Increased air movement Decreased humidity Increased heat flux across walls Protection of walls from solar radiation Elimination of fires Decreased activity (metabolic rate) of occupants Refrigeration	Crowding Inadequate ventilation by cooler outside air Decreased air movement Increased humidity Low heat flow rate across shelter walls Solar radiation on external walls Fire in shelter or in vicinity Increased activity (metabolic rate) of occupants	Heat output by occupants Heat added by hot ambient air Increased humidity Fire	Excessive heat	Heat collapse: Apparent "air" hunger Nausea Faintness Headache Increased pulse rate Circulatory failure Heat stroke: Sudden rise in core temperature Increased metabolic rate	Poor physical condition Poor acclimatization Dehydration Loss of salt Women more susceptible Loss of sleep Prolonged exposure without relief Overactivity after onset Overweight Decreased sweat rate Long duration of exposure Hard work without proper conditioning Fever Diuretic drugs Protein diet Duration of exposure	Good physical condition Increased acclimatization Improved sweat response Adequate hydration and salt supply Mean less susceptible Adequate sleep Periodic relief by cooling Rest after onset Short duration of exposure Not working beyond levels consistent with physical condition Undernutrition?
Decreased activity Increased ventilation Adding oxygen from stored source Decreased crowding	Increased activity Decreased ventilation by fresh air Increased crowding Altitude	Oxygen consumption by occupants Fire	Lowered pO_2	Hypoxia: Chronic: Headache Respiratory difficulty Sleepiness Vertigo Difficulty in concentrating Sensory impairment Lassitude Fatigue Impaired judgment Damage to nervous system Acute: Euphoria leading to stupor and unconsciousness and finally death or irreversible damage to the nervous system	Age - also greater in infants Increased activity Carbon monoxide Excessive heat or cold Poor physical condition Certain respiratory, cardiovascular, renal and metabolic diseases Alcohol Histotoxins Drugs which increase metabolic rate Noise	Good physical condition Reduced activity Drugs which decrease metabolic rate

TABLE III-2 (continued)

STIMULUS DECREASED BY	STIMULUS INCREASED BY	SOURCES OF STIMULUS	ADVERSE STIMULUS (STRESSOR)	PRIMARY ADVERSE EFFECTS ON OCCUPANT	PROBABILITY AND/OR INTENSITY OF EFFECTS INCREASED BY	PROBABILITY AND/OR INTENSITY OF EFFECTS DECREASED BY
Decreased activity Increased ventilation Chemical absorption of CO_2 Fat and protein diet?	Increased activity Decreased ventilation by fresh air Carbohydrate diet Increased crowding	CO_2 production by occupants CO_2 production by fire	Increased pCO_2	Chronic, low concentration: Initial respiratory acidosis with gradual compensation Increased pulmonary ventilation Acute: Dizziness, stupor, leading to unconsciousness	Carbohydrate diet? Duration of exposure	Adaptation to low concentrations
Decreased smoking Decreased activity Oxidative conversion to CO_2 Elimination of sources from fire Increased ventilation by fresh air	Increased smoking Increased activity Decreased ventilation by fresh air Increased crowding	Fire Smoking Produced by metabolic processes of occupants	Carbon monoxide	Similar to hypoxia	Smoking Hypoxia Increased activity Poor physical condition Old age and infancy Duration of exposure	Non-smoking Increasing pO_2 of inspired air Rest Good physical condition
Confinement of waste in air tight enclosures Increased ventilation Decreased production of waste Decreased crowding	Exposure of waste to air Decreased ventilation Increased production of waste Increased crowding	Human waste (feces, flatus, urine, sweat)	Toxic trace gases, most of which have foul odors	Damage to various organ systems leading to death at higher concentrations and durations Nausea from odor	Synergism is shown for some mixtures Duration of exposure Sudden onset increases nausea	Adaptation to low concentrations Antagonism for some combinations Adaptation to odor for gradual increase in concentration
Careful, controlled dispensing Sealed containers Supplementation through foraging Increasing initial provisioning	Wastage Evaporation Increased crowding Contamination Underestimating requirements	Insufficient initial provisioning	Inadequate water	Dehydration and electrolyte imbalance leading to death for extremes	Exposure to heat causing increase in sweat rate Duration of exposure Activity Use of certain medicants Protein diet Disease Ingestion or breathing of toxic substances Diarrhea and vomiting Fever Diuresis Hemorrhage	Cooling Rest Carbohydrate diet

TABLE III-2 (continued)

STIMULUS DECREASED BY	STIMULUS INCREASED BY	SOURCES OF STIMULUS	ADVERSE STIMULUS (STRESSOR)	PRIMARY ADVERSE EFFECTS ON OCCUPANT	PROBABILITY AND/OR INTENSITY OF EFFECTS INCREASED BY	PROBABILITY AND/OR INTENSITY OF EFFECTS DECREASED BY
Good preservation Palatability Distribution taking into account individual differences in requirements Supplementation by foraging	Spoilage Hoarding Unpalatability Increased crowding	Insufficient initial provisioning	Inadequate caloric intake (intake less than energy expenditure)	Weight loss Irritability Weakness Decreased motivation Inability to concentrate	Increased activity Less tolerance in growing children and pregnant and lactating women Disease Underweight Decreased caloric intake Increased duration of restricted intake Diarrhea, vomiting Cold environment Drugs increasing metabolic rate	Physical fitness Overweight Increased calorie intake Decreased duration of restricted intake Drugs decreasing metabolic rate
Decreased crowding Administration of tranquilizers or sedatives	Increased crowding Administration of stimulants	Noise produced by talking and other activities of occupants	Excessive noise	"Tension" Irritability Communication difficulty Loss of sleep Increased metabolic rate	Presence of psychological stress Idleness or attempting to concentrate on mental tasks Duration	Earplugs Administration of tranquilizers or sedatives Diversions which direct attention away from irritating effects of noise "Adaptation"
Decreased crowding Erecting more bunks or obtaining pads Rotating sleep periods	Decreased crowding Destruction of existing sleeping facilities	Inadequate facilities and crowding	Hard, cramped sleeping surface	Sleeplessness and fatigue which produces sore muscles and lowers tolerance to other stresses	Presence of all other stresses (e.g., noise, light, heat, lack of privacy, fear, worry, etc.) Certain diseases	Administration of tranquilizers or sedatives Reduction in stresses such as noise, heat, light, etc.
Good sanitation Increased ventilation Isolation of diseased occupants	Unsanitary conditions, inadequate waste disposal, etc. Crowding Poor ventilation	Bacteria, virus, protozoa, fungi - introduced via ventilation air, occupants, insects, rodents, contaminated food or water, etc.	Disease	Diverse effects depending on disease. May lead to fever, diarrhea, vomiting, increased food requirement, increased need for rest, lowered tolerance to stress, etc.	Presence of all other stresses Inadequate medication Inadequate rest	Use of proper medication Rest Adequate food and water
Good decontamination procedures High protection factors Efficient filtering of ventilation intake air	Inadequate decontamination procedures on entering Low shelter protection factors Inadequate filtering of ventilation intake air	Nuclear blast fallout	Fallout radiation	Radiation sickness	Inadequate food, water, rest, medication, etc.	Adequate food, water, rest, medication, etc.

requires at least some periodic exercise. Furthermore, heat tolerance is improved by heat acclimatization, and heat acclimatization is most efficiently produced by exercising in a hot environment. In other words, a close examination of the table suggests that some optimum, periodic exercise regime must exist which maintains physical fitness, produces a degree of acclimatization, but which does not add more heat stress than can be more than compensated for by the increase in tolerance.

On the other hand, it is necessary to consider the fact that increased activity level also increases both the degree and effects of oxygen deficiency and excessive carbon dioxide, increases noise levels, and interacts with other factors contributing to the stressfulness of shelter overloading.

It seems clear that a very elaborate analysis would be required to determine fully the effects of overloading and the limits for survival. To accomplish that elaborate analysis, a considerable groundwork must be established which can form the basis for manipulation of the complex model that would be required. Laying that groundwork within the general, parametric framework established in Table III-2 has been one of the goals of the present study, and, along with a preliminary analysis of shelter overloading, is the subject of much of this report. The application of that groundwork through the manipulation of a model of the type illustrated in Figure III-1 is a next logical step in the formal analysis of shelter overloading.

2. Population Variables

A very significant aspect of the fallout shelter loading problem is the heterogeneityof the population to be sheltered. The population variables of age, sex, body mass and area, incidence of morbidity, ethnic group, occupation, education and the like, will have an important bearing on the kinds and extent of psychological and physiological effects of overloading in a shelter environment.

Unfortunately, most of the literature reporting experiments on response to environmental stress is directly relevant only to special populations--usually to healthy, young men or to special occupational groups. Even shelter habitability experiments usually have been restricted to a carefully screened population to reduce certain sources of undesirable variability. A direct application of such data to the problem of shelter confinement for the general United States population should not be attempted without considering the effects of population variability. One must keep in mind the fact that population variability can lead to large differences in such factors as rate of heat production, water consumption, and production of gaseous, liquid and solid waste, all of which contribute directly to the extent and duration of survivable overloading.

In the absence of much needed experimental data, adjustments for population variability are difficult and frequently speculative. In some instances where the source of response variability appears to be due largely to such factors as body mass or surface area, population differences can be allowed for by applying correction factors derived from standard tables of anatomical and physiological values. Fortunately, a considerable body of such data has been compiled for much of the population of interest.

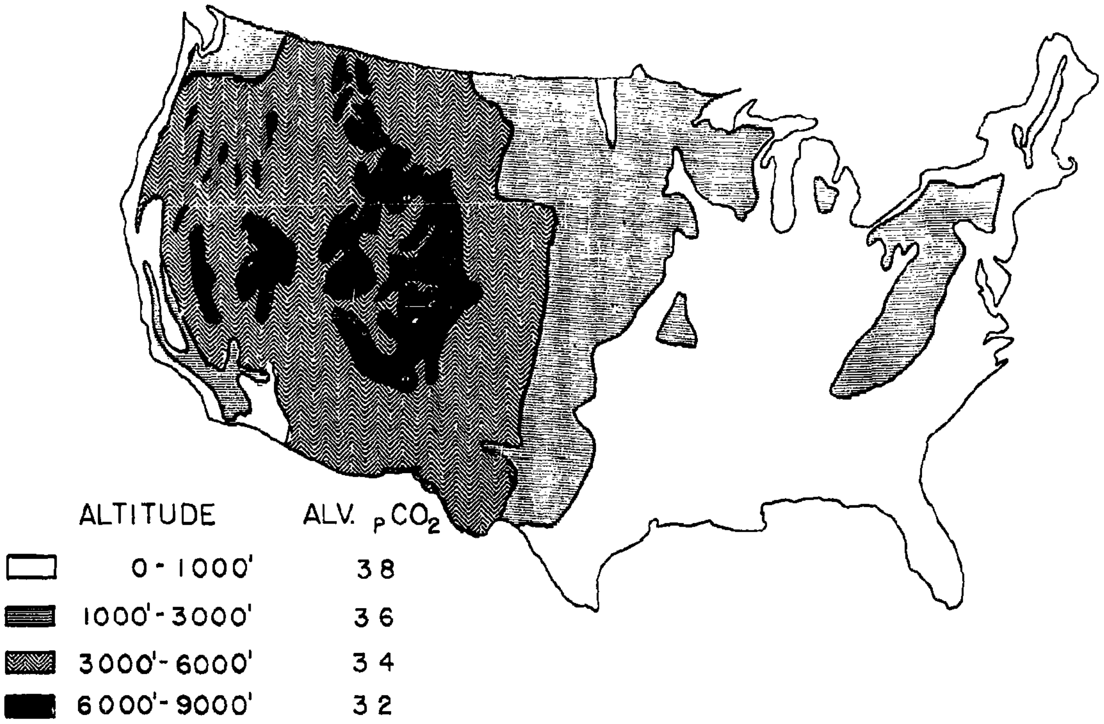
To aid in making adjustments for population variability, a base-line description of the population is provided with respect to a number of characteristics which were felt to represent important sources of response variability. The primary table (Table III-3) relates some essential dimensional and functional characteristics to the population descriptors age and sex and provides a base-line for computations in subsequent sections. A number of other tables have been included to provide a preliminary characterization of the population which will have to be sheltered in the event of an emergency. However, we have accomplished only a small part of the task which needs to be carried out, namely, consolidation into a usable form of the large and scattered body of physiological and psychological data characterizing all segments of the United States population.

Extensive account of variation of physiological characteristics throughout the population was not feasible during the course of this study. It is felt, however, that the major variables have been accounted for in such a way that further extension of the study to account for variability is possible. Indeed, consideration of the variation in response of special groups within the population is crucial. Considerable differences in loading limits are expected between young adults, children, the aged, hospitalized patients and the like. The problem becomes particularly important in homogeneous groups such as one might expect when entire shelters are populated by school children, inhabitants of retirement communities, patients in hospitals and so on. Such factors as incidence of disease, heat production, oxygen consumption, carbon dioxide production, weight loss with undernutrition, heat tolerance and acclimatization, etc., can be expected to vary greatly among such special populations.

Further sources of variation can be expected. For instance, respiratory and cardiovascular response to lowered oxygen or increased carbon dioxide concentrations depend in part on the partial pressures of oxygen and carbon dioxide in the lungs (alveolar pO_2 and pCO_2, see the section on atmospheric variables). Alveolar gas pressures, in turn, depend on the altitude of residence since significant biochemical adjustments are made by the body during long stay at altitude. Figure III-2 provides an estimate of the numbers of people residing at various altitudes within the United States.

Similar problems exist with heat; the greater the heat and level of work to which people are accustomed, the greater their tolerance for heat.

Obviously, to account for all such sources of variation, considerable further work needs to be done.



	Sea Level	3000'	6000'	9000'
Barometric Press. mm	760	681	609	543
Alveolar Po_2	103	89	77	66
Alveolar Pco_2	38	36	34	32
Alveol. Ventil. Ratio	1.00	1.05	1.12	1.18
Breath Holding Time - %	100	78	60	50
HbO_2 - % Saturation	96.1	94.5	93.0	91.5
O_2 Capacity - %	100	102	104	108
Plasma CO_2 - T_{40} - %	100	96	93	90

	0-1000'	1000'-3000'	3000'-6000'	6000'-9000'
No. of People in the U.S. x million	94	32	4	1

Figure III - 2 Numbers and cardiorespiratory characteristics of residents at altitudes from sea level to 9000 feet (Rahn, 1955)

TABLE III-3 DISTRIBUTION OF AGE, SEX AND MEAN VALUES OF ANATOMICAL AND PHYSIOLOGICAL MEASURES IN THE GENERAL UNITED STATES POPULATION

BASED ON 1961 ESTIMATE = 183.64 MILLION

Age	Total	Mean Ht.		Mean Wt.		Mean Area	Mean Basal Heat Prod.		Mean Resting O_2 Consumpt.*		Mean Resting CO_2 Prod.*	
Yrs	% of Sex	In	Cm	Lb	Kg	Sq M	Kcal/hr	Btu/hr	L/hr	Cu ft/hr	L/hr	Cu ft/hr
MALE: ALL CLASSES (49.4% OF TOTAL POP. = 90.74 MILLION)												
1st Yr	2.40	19.9	50.5	7.8	3.5	0.21	8.37	33.2	1.71	.0604	1.45	.0512
1-4	9.16	35.9	91.2	31.4	14.2	0.63	37.2	147.6	7.59	.2680	6.45	.2278
5-9	10.74	48.6	123.4	53.3	24.2	0.92	48.5	192.5	9.90	.3496	8.42	.2974
10-14	10.00	58.2	147.8	86.5	39.2	1.26	57.5	228.2	11.73	.4143	9.97	.3521
15-19	7.67	67.3	170.9	137.9	62.6	1.70	71.1	282.2	14.51	.5124	12.33	.4354
20-24	6.32	68.4	173.7	154.7	70.2	1.82	71.3	283.0	14.55	.5138	12.37	.4369
25-34	12.36	68.2	173.2	158.0	71.7	1.83	68.8	273.0	14.04	.4958	11.93	.4213
35-44	13.16	66.9	169.9	152.6	69.2	1.78	65.1	258.3	13.29	.4693	11.30	.3991
45-64	19.76	66.0	167.6	150.0	68.0	1.75	61.8	245.3	12.61	.4453	10.72	.3786
65 +	8.43	65.0	165.1	143.8	65.2	1.70	56.6	224.6	11.55	.4079	9.82	.3468
Weighted Mean (All Males)		60.1	152.5	119.2	54.0	1.48	60.4	232.5	11.95	.4222	10.16	.3589
FEMALE: ALL CLASSES (50.6% OF TOTAL POP. = 92.71 MILLION)												
1st Yr	2.25	19.7	50.0	7.6	3.4	0.20	8.15	32.3	1.66	.0586	1.41	.0498
1-4	8.65	35.4	89.9	30.2	13.7	0.60	32.5	129.0	6.63	.2341	5.64	.1992
5-9	10.14	45.2	114.8	49.5	22.5	0.90	44.3	175.8	9.04	.3193	7.68	.2712
10-14	9.45	59.1	150.1	90.0	40.8	1.29	55.0	218.3	11.22	.3962	9.54	.3369
15-19	7.30	63.8	162.1	121.0	54.9	1.54	56.5	224.2	11.53	.4072	9.80	.3461
20-24	6.16	63.6	161.5	123.0	55.8	1.57	55.3	219.5	11.29	.3987	9.60	.3390
25-34	12.33	63.4	161.0	127.2	57.7	1.58	55.3	219.5	11.29	.3987	9.60	.3390
35-44	13.39	63.1	160.3	138.0	62.6	1.64	56.4	223.8	11.51	.4065	9.78	.3454
45-64	20.25	62.5	158.8	146.4	66.4	1.68	55.3	219.5	11.29	.3987	9.60	.3390
65 +	10.08	61.7	156.7	138.5	62.8	1.62	51.0	202.4	10.41	.3676	8.85	.3125
Weighted Mean (All Females)		57.4	145.8	110.5	50.1	1.40	52.6	202.1	10.39	.3671	83.84	.3120
Weighted Mean (Males & Females)		58.7	149.1	114.80	52.0	1.44	56.5	217.1	11.16	.3943	9.49	.3352

*All Gas Volumes at STP

TABLE III-3

(continued)

SOURCES OF BASIC DATA

1. For the column "Total Percent of Sex," World Almanac and Book of Facts, New York World-Telegram and Sun, 1963, pp. 254 and 256
2. For the columns "Mean Height" and "Mean Weight," Spector (1956) pp. 178-180.
3. For the column, "Mean Area," Spector (1956) pp. 178-180 plus Sendroy and Cecchini (1954) p. 4.
4. For the column "Mean Basal Heat Production," Sargent (1962) for first year infants; Spector (1956) Table 239, p. 259 for all other age groups.
5. For the column "Mean Resting O_2 Consumption," computed from mean basal oxygen consumption, assuming one Kcal is equivalent to 4.9 liters oxygen consumed, expressed at $0^{o}C$ and 760 mm Hg (STP).
6. For the column "Mean Resting CO_2 Production," computed from mean resting oxygen consumption, assuming R.Q. = 0.85.

METHOD OF CONSTRUCTION

Since Source No. 1 (above) lists actual numbers of population, the percentages under "Total Percent of Sex" had to be calculated to derive the values presented in the table. Similar calculations were performed to obtain the percentages under "geographical area" from values listed in Source No. 4.

All the entries in the "Mean Height," "Mean Weight," and "Mean Area" columns were derived from figures given for the U.S.A. white population. To have averaged in the non-white population would have taken more time than the resulting increase in accuracy would warrant. The maximum error obtained by not including statistics for non-whites in the height column was calculated to be less than 0.3 percent.

Since the age groupings in the above table and that in Source No. 2 are not identical--the latter presents data for each year through age 19 -- weighting procedures were necessary. Based on the population statistics

TABLE III-3 (continued)

for each age, found in Source No. 4, each of the height and weight values in Source No. 2 were weighted and averaged within each of the tabulated groups.* Where age groups did correspond (e.g., the last group, 65 years and older), the values were taken directly from the table in Source No. 2.

The derivation of "Body Surface Area" was still more complex. First, the height and weight figures given in Source No. 2 for each age group were used to enter the graph in Source No. 3. Therefore, a body surface area table like that in Source No. 2 was derived. Then the values in this second table were treated in the same way as the height and weight figures to obtain weighted averages for the age groups in the final table. Thus, the "Mean Area" values do not necessarily correspond to those values which would be obtained from the corresponding height and weight averages in the Table, but are weighted values of the predicted surface areas for each year within an age group.

Basal heat production for the first year age group was based on the formula given by Sargent (1962) for both boys and girls:

$$\text{Kcal/hr} = 2.18 \times \text{wt. in kg.} + 0.737$$

Basal heat production for the 1 - 4 year group was actually based on the 3rd and 4th year data from Spector (1956) Table 239. All other age classes were computed using Table 239 from Spector after applying weighting factors to adjust for distribution of ages within each class interval. Basal heat production was computed by multiplying the weighted basal metabolic rate in Kcal m^{-2} hr^{-1} times the mean body surface area for each age class.

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*For example, the height and weight values for the 5 - 9 group of males was calculated as follows:

$$\frac{[(\underline{5}) \times 1.11] + [(\underline{6}+\underline{7}) \times 1.055] + (\underline{8}+\underline{9})}{5.22}$$

where numbers in parentheses represent the value for that age given in the Source No. 2 table; $(\underline{6}+\underline{7})$ is shown this way because the number of 6 year old boys in the population is about the same as the number of 7 year old boys.

TABLE III-4

PROBABLE NUMBER OF SHELTEREES ENTERING WITH SPECIFIC DISABLING DISEASES PER 100 PEOPLE

Disease (diagnosis)	Yearly Case Rate per 100 People	Average Probable Number of Shelterees Entering with the Disabling Disease per 100 People
Minor Respiratory:		
Influenza & grippe	7.44	.1676
Bronchitis	5.11	.1016
Coryza & cold	5.88	.0648
Tonsillitis & peritonsillar abscess	1.78	.0352
Sore throat	2.18	.0319
Laryngitis	.214	.0034
Croup	.203	.0027
Other Respiratory:		
Sinusitis	.488	.0114
Pneumonia, all forms	.774	.0503
Pleurisy	.248	.0091
Tonsillectomy & adenectomy	.159	.0367
Other	.204	.0109
Allergy & Related:		
Asthma	.396	.0171
Urticaria	.079	.0008
Eczema	.068	.0021
Contact dermatitis, by plants	.087	.0014
Infectious, General:		
Measles	1.87	.0578
German measles	.515	.0080
Whooping cough	.893	.0754
Mumps	.860	.0233

TABLE III-4

(continued)

Disease (diagnosis)	Yearly Case Rate per 100 People	Average Probable Number of Shelterees Entering with the Disabling Disease per 100 People
Infectious, General (contd):		
Chicken pox	.110	.0361
Scarlet fever	.477	.0313
Dyptheria	.100	.0054
Erysipelas	.046	.0022
Tuberculosis, all forms	.264	.1358
Smallpox	.031	.0019
Reactions to smallpox vaccination	.167	.0016
Other	.451	.0268
Noninfectious, General:		
Malignant neoplasms, all sites	.203	.0391
Benign & unspecified tumors & cysts of female genitals & breasts	.296	.0165
Other, benign & unspecified	.120	.0040
Thyroid gland	.160	.0118
Diabetes mellitus	.119	.0331
Anemia, all forms	.170	.0108
Debility & malnutrition	.151	.0050
Other	.175	.0024
Nervous System & Mental:		
Cerebral hemorrhage, embolism, thrombosis	.203	.0473
Neuritis & neuralgia	.466	.0146
Nervousness	.279	.0151
Psychoneurosis	.269	.0358
Other	.440	.2109
Eye & Ear:		
Inflammation of conjunctiva & eyelid	.329	.0049
Other, eye	.188	.0180

TABLE III-4

(continued)

Disease (diagnosis)	Yearly Case Rate per 100 People	Average Probable Number of Shelterees Entering with the Disabling Disease per 100 People
Eye & Ear (contd):		
Earache	.365	.0028
Otitis media	.794	.0167
Other, ear	.115	.0012
Mastoid	.095	.0076
Heart & Circulatory:		
Rheumatic fever	.193	.0700
Heart	1.03	.1716
Hypertension & arteriosclerosis	.423	.0434
Hemorrhoids	.142	.0072
Varicose veins & ulcers	.121	.0172
Lymphatic system	.389	.0084
Other, circulatory	.220	.0083
Digestive:		
Minor digestive:		
Functional digestive disturbances	2.67	.0273
Diarrhea & enteritis	1.68	.0210
Other, digestive:		
Teeth & gums	.586	.0058
Mouth	.057	.0012
Ulcer of stomach & duodenum	.163	.0209
Appendicitis	.842	.0494
Hernia & abdominal cavity	.218	.0259
Cholecystitis & biliary calculus	.409	.0208
Other, gallbladder & liver	.158	.0052
Other, digestive	.553	.0173

TABLE III-4

(continued)

Disease (diagnosis)	Yearly Case Rate per 100 People	Average Probable Number of Shelterees Entering with the Disabling Disease per 100 People
Kidney & Urinary:		
Nephritis	.240	.0483
Pyelitis	.149	.0057
Other kidney	.244	.0109
Cystitis & urinary calculus	.232	.0072
Other, urinary	.069	.0019
Skin & Cellular Tissue:		
Furuncle & carbuncle	.272	.0067
Abscess, cellulitis, & ulcer	.151	.0037
Other local infection	.286	.0071
Impetigo	.114	.0049
Scabies	.087	.0042
Other, skin	.280	.0087
Bones & Organs of Movement:		
Arthritis & chronic rheumatism	.854	.2559
Lumbago, myalgia & myositis	.349	.0072
Female, Menstrual:	1.23	.0083
Total Acute:		1.3718
Total Chronic:		1.3976

SOURCE OF BASIC DATA

The source of illness data was the study published by Collins et al. (1955), which is the most comprehensive compilation that has come to our attention, representing five surveys with 80,768 full-time person-years of observation. The column "Yearly Case Rate per 100 People" was taken directly from their "appendix table 2," which is included in this report

TABLE III-4

(continued)

Source of Basic Data (contd):

for reference purposes in Appendix B. The second column "Average Probable Number of Shelterees Entering with the Disabling Disease per 100 People" was computed by dividing the yearly days of disability per 1000 people by 365 times 10. The yearly days of disability was taken from Table 9 of Collins *et al.* (1955), which is also included for reference purposes in Appendix B of this report.

Considerable seasonal variation exists in the incidence of certain illnesses, which should be accounted for in analyses specific to a particular time of the year. To provide a basis for adjusting the values in the second column for seasonal variation, a set of curves from Collins *et al.* (1955) is included in Appendix B of this report.

TABLE III-5

ANNUAL INCIDENCE OF ILLNESS AND MORTALITY AMONG WHITE INFANTS OF EACH SEX

Disease		Illness Cases Under 1 Year (%)	Mortality Cases Under 1 Year (%)
All Causes, both sexes		100	100
	Male	53	58
	Female	47	42
Respiratory, both sexes		49	11
(colds, influenza, pneumonia, etc)	Male	54	57
	Female	46	43
Digestive, both sexes		16	6
(diarrhea, enteritis, etc)	Male	52	58
	Female	48	42
Communicable, both sexes		12	
	Male	49	
	Female	51	
Malformations and diseases of early infancy, both sexes		3	73
	Male	53	58
	Female	47	42
All Other, both sexes		19	11
	Male	53	57
	Female	47	43

Source: Collins et al. (1955). Illness and mortality among infants during the first year of life. Public Health Monograph No. 31.

TABLE III-6

INCIDENCE OF PSYCHOLOGICAL DISORDERS IN THE GENERAL POPULATION-PERCENTAGE

Disorder	Coleman*	Pasamanick**	Public Health*** Monograph No. 25
Psychotic	0.5	1.7	0.2
Psychoneuroses	4.6	5.1	0.4
Psychophysiologic, autonomic and visceral	11.1	1.8	
Character	1.1		
Chronic Organic personality	0.6		
Chronic Alcoholics	0.4		
Mental Defectives	2.3	2.6	0.2
Children with emotional and behavioral problems	5.6 (of children 13 yrs & under)		
Nervousness			0.8

*Coleman, James C., Abnormal Psychology and Modern Life, Scott, Foresmen and Co., Chicago, 1956. Values on pp. 2, 3,&17 were used to derive percentages per 175 million population.

**Pasamanick, Benjamin, "A Survey of Mental Disease in an Urban Population V: An Approach to Total Prevalence by Sex," J. of Nervous and Mental Dis., 133, 1961, pp. 519-523. These percentages were taken from the table on page 521, "Prevalence of Mental Disorders in Baltimore 1952-55."

***Collins, Selroyn D., et al., "Sickness Experience in Selected Areas of the United States," Public Health Monograph, No. 25, 1955, pp. 9 and 21.

Rates per 1000 were divided by 10 to obtain percentage figures.

TABLE III-7

U. S. MAJOR OCCUPATIONS BY SEX

Percentage of the Population 14 Years and Over

Major Occupation	Both Sexes	Male	Female
Primarily sedentary*			
Professional, technical, etc.	10.8%	10.8%	10.7%
Managers, officials & proprietors (except farm)	10.8	13.6	5.1
Clerical and kindred workers	14.6	6.8	30.4
Light to medium labor			
Farmers and farm managers	3.7	5.3	.6
Sales workers	6.1	5.6	7.1
Craftsmen, foremen, etc.	13.1	19.1	.9
Operatives, etc.	17.4	18.8	14.7
Private household workers	3.4	.1	9.9
Service workers (except private household)	9.4	6.5	15.4
Heavy labor			
Farm laborers and foremen	4.5	4.4	4.8
Laborers, except farm and mine	6.1	9.0	.4
TOTAL employed (of population 14 years and over)**	53.6% (of 129.76 million)	73.5% (of 63.34 million)	34.7% (of 66.42 million)

Reference: <u>1963 World Almanac and Book of Facts</u>; New York World-Telegram and the Sun, New York, 1963, pp. 251 and 256

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[*] Groupings were not taken from any reference; they were added for differentiating job types.

[**] Percentages in this row were calculated from the "total employed" row on p. 251 and the "14 years and older" row on p. 256.

TABLE III-8

SCHOOL ENROLLMENT

(Public Schools only)

	TOTAL (millions)	Average No. Students per Teacher*	Average No. Students per School**
Elementry			
Students	24.69	28.4	260
Teachers	0.87		
Secondary			
Students	12.82	21.8	500
Teachers	0.59		

Reference: <u>1963 World Almanac and Book of Facts</u>, pp. 539 and 541.

*These values derived by dividing the total number of students by the total number of teachers (shown in the first column).

**These values derived by dividing the total number of students (from p. 539) by the number of U.S. public schools (p. 541).

TABLE III-9

MARITAL STATUS OF THE POPULATION 14 YEARS AND OLDER

	TOTAL (in millions)	Single %	Married %	Widowed %	Divorced %
MALE	62.8	25.5	68.8	3.6	2.1
FEMALE	66.0	19.2	65.8	12.2	2.8

Reference: <u>U.S. Census of Population for 1960,</u> PC(1)-1B-U.S., p. 1-155.

3. Environmental Variables

This report is primarily concerned with physiological and psychological factors limiting shelter loading; however, such limits cannot be expressed without reference to environment since the human factors of concern are primarily response to environment. To complicate the matter, the environment in a shelter is at least partly determined by the human response which was itself a product of the environment. In other words, the shelter is a semi-closed system in which the response of the occupants and the shelter are intimately related as functions of each other.

Of particular concern to this study is the fact that the degree to which the occupants influence the shelter environment or, to state it differently, the proportion of the shelter environmental characteristics attributable to human characteristics, increases with degree of loading. In very severe overloading the shelter environment is almost entirely a function of the human contribution - particularly when the environment was marginal even at normal loading.

For example, in the unoccupied shelter the temperature and humidity are determined by ambient wet and dry bulb temperatures, the rate of ventilation of the shelter by ambient air, the temperature of surrounding soil, and so on. The thermal environment in the shelter is completely determined by ambient conditions. At the other extreme, if the shelter were packed to its geometrical capacity with people releasing 300 to 600 Btu per hour, the thermal environment would become intolerable within a few minutes and it would matter little whether the ambient environment was very hot or very cold. But of course the condition of interest to this study lies considerably short of packing to geometrical capacity. The main point is that in overloading the interaction of man and environment becomes of greater significance than for normal loading; and that the results of design studies, simulations and experimental studies at normal or near-normal loading (i. e. , design conditions) do not necessarily provide the kind of environmental information which can be used directly in an analysis of loading limits.

However, we did not attempt to construct a sophisticated man-shelter environmental model in the analysis reported here. Such an undertaking would have required extensive use of a computer to account for the multitude of interactions and an analytical approach which was clearly outside the feasible scope of the present preliminary study. Rather, we have attempted to arrive at some interim estimates of loading limits while laying the groundwork for a future study of greater analytical scope. We have considered human response to environmental extremes which might be achieved in the overloaded shelter, or the extremes to which humans might be exposed without permanent damage - without regard to the specifics of the man-shelter interaction in arriving at those extremes. We have also considered the contribution of the occupants to the environment, but again without fully defining all interactions.

Both quantitative and qualitative aspects of each of the more important environmental factors are discussed in subsequent sections in terms of their physiological or psychological effects. The following discussion, then, is intended to provide an overview of the environmental factors thought to be particularly important in contributing to the stressfulness of overloading.

a. Air Temperature

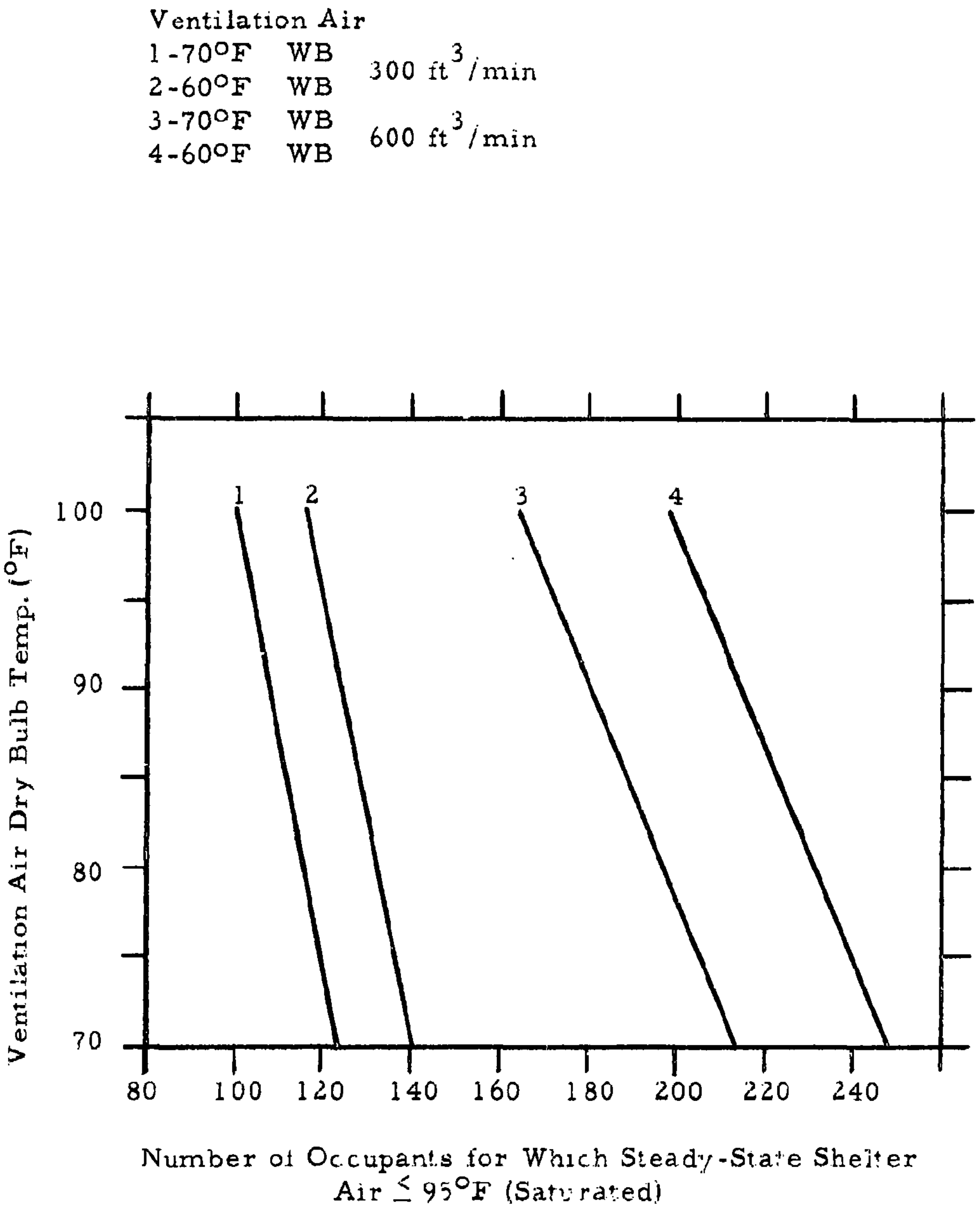
Given a fixed ventilation rate of three to six cubic feet per minute per person, shelter air rapidly becomes saturated by water vapor in overloading so that it is usually sufficiently accurate to determine physiological response as a function of saturated air temperature. Holding other factors constant, shelter air temperature increases as a function of overloading. Figure III-3 shows approximately how the steady-state air temperature of a representative 100 man underground shelter might increase as a function of overloading. Appendix C discusses the basis for Figure III-3 and includes additional illustrative material.

b. Atmospheric Composition

The constituents of the shelter atmosphere tend to act on the body synergistically or antagonistically and thus should be considered in terms of their combined effects. This is especially true for carbon dioxide, oxygen and carbon monoxide as well as for certain toxic atmospheric contaminants. The more important gaseous constituents which will likely be present in the shelter atmosphere are as follows:

(1) Oxygen

Oxygen is present in normal, ambient air at a concentration of about 20.93 percent, and its partial pressure, which is actually the more important measure, is dependent on altitude. Since it is utilized by the human body, its concentration in the shelter tends to be lower than


Ventilation Air
1-70°F WB
2-60°F WB
300 ft³/min
3-70°F WB
4-60°F WB
600 ft³/min
1
2
3
4
100
90
80
70
Ventilation Air Dry Bulb Temp. (°F)
80
100
120
140
160
180
200
220
240
Number of Occupants for Which Steady-State Shelter Air ≤ 95°F (Saturated)

normal, and is a function of ventilation rate and rate of utilization, which in turn is a function of overloading, among other factors. The equations derived in Appendix D can be used to determine its concentration in the shelter. Insufficient oxygen leads to impairment and eventually to death if the concentration is reduced below critical limits.

(2) Carbon dioxide

Carbon dioxide is present in normal, ambient air at a concentration of about 0. 03 percent. Since it is produced by the human body, its concentration in the shelter tends to be higher than 0. 03 percent and can be calculated by using the equations in Appendix D. In excess, carbon dioxide has toxic effects.

(3) Carbon monoxide

Carbon monoxide is a toxic gas which is produced by the incomplete combustion of hydrocarbons and other organic compounds. It is produced in small quantities by the human body and in larger quantities by smoking and by fires in the vicinity. The equations in Appendix D can be used to calculate its concentration in the shelter given assumptions about its rate of production.

(4) Trace contaminants

A number of trace contaminants are likely to be present in shelter atmosphere in addition to carbon monoxide. The ones considered in this study are waste products of the human body and include skatole, indole, methylmercaptan, hydrogen sulfide, methane, hydrogen, ammonia, and other constituents of feces, flatus, sweat, urine, vomitus and exhaled breath. Many of them are toxic in rather small concentrations.

c. Noise

While not expected to reach damaging levels, noise will tend to increase as a function of loading and is expected to add to the overall stressfulness of the shelter environment.

d. Lighting Level

While lighting level is important in terms of visual requirements, it is not expected to vary significantly as a function of loading.

e. Fallout Radiation

The presence of fallout radiation is a given in this analysis. Its major importance to the overloading situation is the fact that ambient radiation level determines the required duration of stay in the shelter and has implications for foraging and rescue strategy. Furthermore, if some of the shelter entrants receive large doses, additional stress is added to the shelter situation which has implications for loading limits.

f. Provisioning

The provisions of food and water can be considered a part of the shelter environment, and are crucial in determining the loading limits which must be placed on shelter occupancy. For instance, limited water reduces the tolerance of shelterees to heat stress.

g. Sanitary Facilities

Sanitary facilities must also be considered a part of the environment since they determine in part the probability of disease epidemic and the extent to which trace contaminants from human waste enter shelter air.

h. Physical and Mechanical Configuration

Sleeping facilities are among the more important aspects of the physical configuration within the shelter. Mechanical hazards should also be considered, as well as such considerations as air duct design and distribution of outlets, provisions for muscle - power operated fans, placement of showers and drains for possible re-circulation of water, etc.

The following sections contain a more detailed examination of the foregoing factors as part of the consideration of physiological response to probable shelter environments.

4. Physiological Variables

The human is a relatively adaptable organism which, through highly complex processes, is able to maintain functional effectiveness in the face of considerable variation in the environment. A large body of research literature exists which defines and describes innumerable adaptive responses to environmental change. In this study, we have applied the more relevant of those findings to the definition of human response to environments anticipated in the shelter.

However, certain limitations exist in the literature which place limits on the precision with which we are able to predict human response to shelter life - particularly in the case of the stressful situations anticipated for the overloaded shelter. The major limitations are as follows:

a) Data on response to combinations of stressful environments are rare.

b) While data were often available for relatively short-term or intermittent exposures, data on chronic exposure to many stressful environments were simply not available.

c) A closed or semi-closed environment is characterized by a more or less gradual increase in the level of stress, whereas most physiological response data are based on constant level exposures.

d) Relatively little relevant physiological response data exist for the complete range of age, sex, and physical condition found in the general population. By far the greatest share of the well-developed, quantitative data refer to special populations such as Air Force cadets, male college students and the like.

In the face of such limitations in the literature on experimental findings, it was necessary to resort to theory or to be satisfied with rather large safety factors in predicting the maximum stress to which shelterees could be subjected without permanent damage.

In the following sections, physiological response to possible shelter environments is discussed. Particular emphasis is given to the effects of excessive heat, carbon dioxide and certain toxic atmospheric contaminants; and to the effects of inadequate oxygen, food and water. Other factors such as disease, sleeplessness and the like are also discussed.

a. Thermal Variables

In any enclosed space with limited ventilation and a high density of occupancy (particularly beyond normal design limits for loading), one of the most important sources of danger to life is inadequate heat removal. This fact arises from the irreversible nature of the failure of body systems when internal temperature exceeds by more than a few degrees its normal operating level.

As the number of occupants of a shelter increases, the rate of increase of effective temperature as well as the maximum effective temperature at the steady state condition will increase. Limits on occupancy will be achieved by either of two conditions:

The effective temperature exceeds tolerable limits, even with adequate water;

Water balance suffers due to an insufficient water supply and results in dehydration and collapse even at otherwise tolerable effective temperatures.

(1) Preliminary considerations

The spectrum of human response to heat and humidity is a broad one, ranging from the state of complete thermal comfort to the upper extremes of pain-limited exposures to radiant and convective heat gain. One useful way of dividing this broad spectrum into manageable segments is on the basis of a time parameter. We can define a thermal zone in which a life-time of continuous exposure should cause no special effects, and bordering on it a zone in which exposures lasting up to months are tolerable by the general population, occasional relief being required to prevent the accumulation of deleterious effects (e. g., seasonal heat waves in tropical countries).

A third zone of thermal environments relate to exposures which are tolerable or survivable for days to weeks, and a fourth zone includes conditions which lead to breakdown of some sort within a very few hours. At the extreme end of the spectrum are those environmental situations in which a human is never able, unaided, to establish a thermal equilibrium, so that the duration of exposure which he can survive is determined either by the rate at which his body stores up heat or by the development of pain on the surfaces of the body.

The boundaries between the zones postulated are necessarily vague, but it is reasonably clear that our concern in the shelter overloading context is with the third and fourth zones, in which the time factor extends from several hours to several weeks. The first and most significant observation to be made about these thermal zones is that the problem of individual variation between healthy individuals is most acute here. At less severe environmental stress levels differences in response between people tend to be mainly dependent on differences in the state of health, or the presence of distinct physical disabilities, while at more severe levels individual differences begin to disappear as the external elements in the physical heat transfer situation assume a more and more controlling role.

Before undertaking a discussion of the sources of individual variation, which we anticipate as our central problem in setting survival limits for shelters, it would be well to review briefly the nature of the general physiological adjustment to environmental warmth. This is most easily visualized if one imagines a person subjected to successively increased levels of temperature and/or humidity in successive one-hour periods while maintaining a constant activity level and metabolic rate. If the initial condition is one which meets the criteria for perfect thermal comfort, sweat production will be at a minimum for the particular work rate concerned, and absent for a person at rest. The skin will be relatively cool, with a spatial distribution of temperatures such that the extremities are in the eighties, and skin temperatures increase as one moves closer to the central trunk areas of the body.

If the environment is now stepped up to one corresponding to the upper end of zone 1 of the scheme outlined above and diagrammed in Figure III-4 the following changes will occur over the succeeding hour:

- skin temperatures in the peripheral areas will rise, decreasing the variability from place to place over the body.

- blood flow to the extremities will increase slightly.

- sweat production may be initiated or increased, the degree depending on the capacity of the environment to accept heat from the body by convection, radiation and conduction.

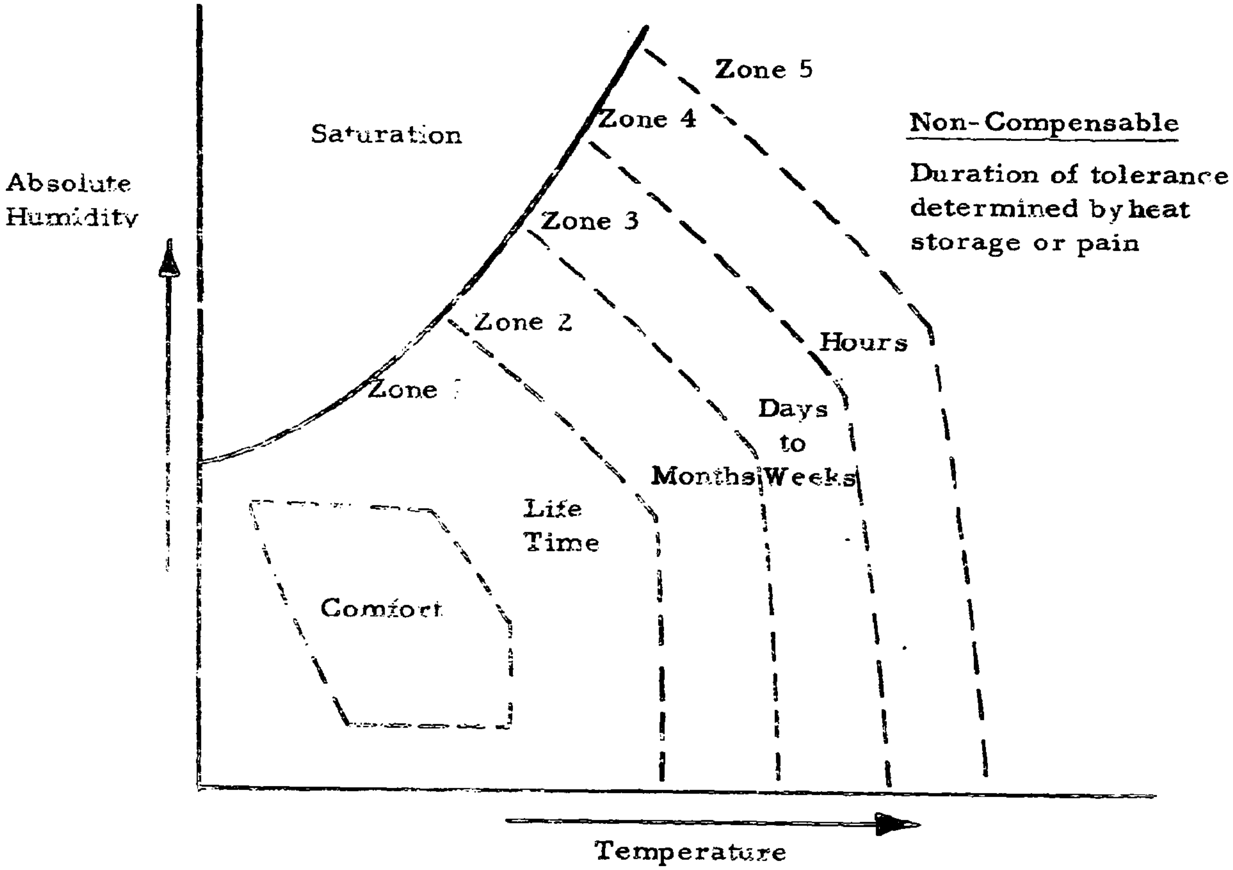


Figure III - 4 Thermal tolerance zones.

- the heart rate, and possibly the cardiac output, will increase slightly.

The steps to zone 2 and 3 conditions lead to further increases in heart rate, peripheral blood flow, skin temperature, and sweat production; but in no case do the levels reached in these physiological measures approach the maximum values of which the organism is capable, even if the exposure is prolonged to the point where the subject collapses. Only in zones 4 and 5 does one see near-maximal heart rates, sweat rates, and blood flow rates, and even here one discovers that each increase in severity of the stress leads to a further increase in the compensating adjustments such as sweat rate. (It is intriguing to realize that it is the control system which is deficient in these ultimate storage-limited heat exposures, not the protective mechanisms themselves; more capacity for combating external heat load is always available, but it cannot be elicited at the stress level where it might effectively cancel out or compensate for the load. Rather, still more load must be added to elicit an additional compensatory response.)

Having constructed a hypothetical experimental situation as a means of illustrating the gross physiological adjustments to environmental heat load at a constant metabolic rate, we are unable to predict with any certainty what the final outcome or end-point of this experiment would be in a real case.

To recapitulate, we have described an exposure of one hour under comfort conditions, followed by one hour in each of zones 1, 2 and 3; in each progressively warmer environment the subjects' defense mechanisms have been called into play to progressively greater degrees. In the language of engineering, the physiological strain has increased in proportion to each increase in the environmental stress. The question which is much more difficult to answer for the human organism than for physical systems is this; "what degree of strain is associated with a high probability of failure?"

As a matter of fact there is no simple answer to this question at all; if our hypothetical experiment were to be extended into zone 4, where tolerable exposure duration is measured in hours, we would be unable to depend on any single physiological measure, or combination of measures, as a basis for deciding whether collapse was imminent. An exception to this situation would be the case of a person with a distinct impairment of some function vital to thermal regulation - e. g., a limitation in sweat capacity; the steady rise in body temperature which this would cause, reflecting the internal storage of heat, would be translatable directly into a reasonably accurate prediction of the time of collapse. By definition, however, in the case of the impaired individual the test environment would fall in zone 5 for him rather than zone 4.

The question of the relationship between thermal strain and probability of collapse is best approached in stages, with consideration limited initially to individuals or groups which are homogeneous with respect to age, previous experience with heat, and general physical condition.

(a) Body temperature

Traditionally, medical prognosis in cases of overheating has been based on the rectal temperature, which is representative of internal, or "core" conditions. Heat death or heat stroke, as it is usually called, is characterized by a sudden increase in core temperature as a result of abrupt failure of the homeostatic control systems of the body. When the body is exposed to a homogeneous environment, the danger of heat stroke increases progressively as the level of rectal temperature rises.

A rectal temperature of 106°F is generally accepted (according to Ladell, 1952) as carrying a high probability of heat stroke. In the South African gold mines, the carefully selected and acclimatized Bantu workmen are not asked to work beyond the point where their rectal temperature has reached 104°F. In setting up "safe" limits for the duration of work in mine rescue operations, the time to reach a rectal temperature of 102°F was used in Britain. It should be noted that all three of these "rules of thumb" have a common context, namely the situation of men working relatively hard.

It is much more difficult to find reliable evidence for ultimate limits of core temperature in the resting normal individual. After reviewing an extensive medical literature on heat death, Herrington concluded that the absolute limit, beyond which recovery cannot be effected, lies above 108°F and probably is close to 109.5°F. He notes that in fever therapy procedures, patients are maintained at a rectal temperature of 105.8° for several hours; however, the fact that ice packs or other means are frequently used to cool the head during such treatments seriously reduces the pertinence of this finding to the present problem.

A critical element in dealing with the question of lethal probability associated with various levels of rectal temperature is the availability of therapeutic treatment. It is of little practical value to know that a person may recover successfully from a rectal temperature of 108°F when given the correct medical treatment (heroic cooling with ice-water immersion or the equivalent) if the situation under analysis is one in which no facilities or competence will exist to accomplish such treatment.

(b) Special factors in the group exposure problem

A second element of possibly even greater practical significance, concerns the social circumstances surrounding the cases of heat stroke for which we have quantitative data. In almost all cases the individuals concerned were either isolated during the period of heat accumulation or under restraint and careful supervision, or members of a highly motivated and disciplined military unit. In a large heterogeneous group such as that with which we are concerned in the shelter situation, psychological factors such as anxiety, fear, compassion, ignorance and the like may be decisive in determining the consequences of attaining a level of heat accumulation or body temperature elevation which is even far below the actual lethal threshold.

When one considers the many case histories involving severe thermal stress under uncontrolled, crowded conditions, it seems likely that, for essentially undisciplined people confined together in large numbers, the critical danger point is that temperature or thermal state at which individuals believe they are facing imminent death from "suffocation" or overheating. This point is probably not far, if at all, above the level of "voluntary tolerance" at which many experimental studies of heat stress are terminated. At the typical "tolerance end-point" of such experiments subjects are extremely restless, displaying writhing movements, deep sighs and irregular breathing; they may feel nauseated or faint, and some may vomit.

It is clear that various measures might be taken which could delay the outbreak of panic; these could range from indoctrination to sedation to punitive disciplinary control by a policing group. In general, however, the strong possibility of deaths and casualties from mayhem must be carefully weighed against any theoretical scheme of estimating mortality on the basis of simple death from overheating. As a matter of fact, even if an assumption is made that total discipline is maintained (so that milling and trampling are prevented) the disturbance of the heat balance within the shelter through increased metabolism associated with growing muscle tension, convulsive movements, excessive respiration, etc. would create a discontinuity in any calculated environmental temperature history based on near-basal metabolic rates. Such a discontinuity might easily lead to a sort of fulminating or exponentially increasing thermal load and acceleration of deterioration ("vicious cycle").

(c) Epidemiological approach

Alternative to the use of a direct physiological criterion for assessing probable mortality rate in a particular shelter situation is a system based on occupational health survey data and experimental studies which attempt to define the limiting environments in which thermal equilibrium can be maintained. As an example of the former, we have the analysis of Wyndham (1962) for South African native mine workers giving the number of fatal and non-fatal cases of heat stroke per thousand exposed individuals at various wet-bulb temperatures. The following table summarizes the data:

Wet Bulb Temperature (°F) (essentially = dry-bulb, saturated)	Number of heat stroke cases per thousand exposed	
	fatal	non-fatal
84	.05	
90	.30 (.38)*	
91		1.0
93		2.0
94	1.08 (1.45)	
95	1.5 (2.)	6.0

*Value in parenthesis = 95% confidence limit

These figures pertain to highly acclimatized natives, working at moderate to heavy rates; the two factors tend to cancel each other in relation to an unselected American shelter population at rest. It is of some interest to compare the highest temperature for which Wyndham gives mortality and morbidity rates with the widely accepted upper limit for the maintenance of thermal equilibrium in resting young men, namely 97°F saturated, or more generally 0.85 (wet bulb temp) + 0.15 (dry bulb temp) = 97°F.

When the thermal stress of the environment, in terms of the above weighted average of wet and dry bulb temperature, exceeds 97°F, the tolerable duration of exposure is limited. That is to say, physiological breakdown will become serious after some finite period of exposure. Provins and Hellon (1962), of Oxford University, have derived the following expression from the collected data from a large number of tolerance time experiments covering a very wide range of thermal environments.

$$y = 8.65 \pm 3.51 + \frac{175.11 \pm 60.34}{x - 36.06 \pm 0.32} \qquad \text{Eq. 1}$$

where y = tolerance time in minutes

x = weighted average environmental temperature in °C, $.85\ t_{W.B.} + .15\ t_{D.B.}$

Notice that the value of the constant in the denominator of the fractional component is equal to the upper limit of equilibrium maintenance referred to above, on the Centigrade scale. If a temperature index of one Centigrade degree (1.8°F) higher than this limit is postulated, the tolerance time predicted by this equation is almost exactly three hours. This prediction is confirmed by at least one experimental point in the data of Provins and Hellon.

The significance of these findings to the shelter survivability problem is startling. To begin with, the prediction equation assumes a neutral or cool thermal state prior to beginning the heat exposure; if the 37°C or 98.6°F environment is experienced after a prolonged period of exposure to an environment on the borderline of physiological compensability, with a resultant accumulation of stored body heat, the point of collapse is certain to be reached more quickly than the three hours indicated by the equation. As a first crude approximation, it is reasonable to postulate that three hours of exposure to 98.6°F weighted average environmental temperature under such circumstances might result in death for many unacclimatized individuals.

The essential point to be made here is that only a "hair's breadth" separates environments which can be endured indefinitely by well "acclimatized" and physically fit people (as long as the water and salt balance and the effectiveness of the sweat mechanism can be maintained), and those which swiftly lead to disruption and death for a normal, healthy, but unacclimatized individual. Similarly, referring again to the case of the African mine workers, a difference of only 4 Fahrenheit degrees in saturated or weighted environmental temperatures separates conditions in which heavy work can be undertaken at moderate risk of death and those which are survivable for less than three hours while sitting quietly. This in turn leads to the implication that a change in the activity level of shelter occupants, such as fear induced struggling or the like, could suddenly alter the prognosis for survival from good to desperate.

Actually, none of the currently used thermal indices seem entirely satisfactory for use in resolving the question of heat tolerance in a mixed population. However, in addressing ourselves to that problem in a shelter overloading context, we immediately encountered the problem of acclimatization in the population at large. In considering the wide range of natural acclimatization which might be expected in the shelterees, and in speculating about the possibility of adapting shelterees to heat, a concept was formulated which seems to us to represent a new and fruitful approach. The sections which follow are intended to lay the groundwork for that approach with full realization that much remains to be accomplished.

(2) The "neutral boundary concept"

A British physiologist, A. R. Lind, has recently proposed a new criterion for the identification of an upper limit of acceptability for hot climates in which men are expected to work for up to 8 hours each day (Lind, 1960a). His scheme is based on the fact, first described in 1938 by the Swedish worker Nielsen, that in a given individual there is a characteristic value of the rectal temperature associated with any particular level of energy expenditure, which does not vary over a wide range of environmental conditions from cool to warm. In environments of increasing temperature or humidity, this characteristic equilibrium value of the rectal temperature (which may take as long as an hour or more to become established after the start of work) is achieved at the cost of increased sweating, higher skin temperatures and higher rates of blood flow to the skin. The "Neutral Boundary Condition" (NBC) defines the environment beyond which the rectal temperature no longer stabilizes at the same level; for each succeeding increment in environmental temperature the equilibrium rectal temperature is correspondingly increased. These relationships are illustrated in Figure III-5a which is based on data from Lind (1963a) for three men walking on a treadmill at an energy expenditure level of 300 Kcal/hour.

Figures III-5b and III-6 illustrate how the Neutral Boundary can change as a function of the energy expenditure or work level, when the environmental conditions are defined in terms of Effective Temperature.* It should be noted that the nature of the

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*Effective Temperature is defined as the saturated air temperature which produces the same thermal sensation, when the air is still, as the actual combination of temperature, humidity and air movement.

Note:

The diagonal slashed lines indicate the range of values.

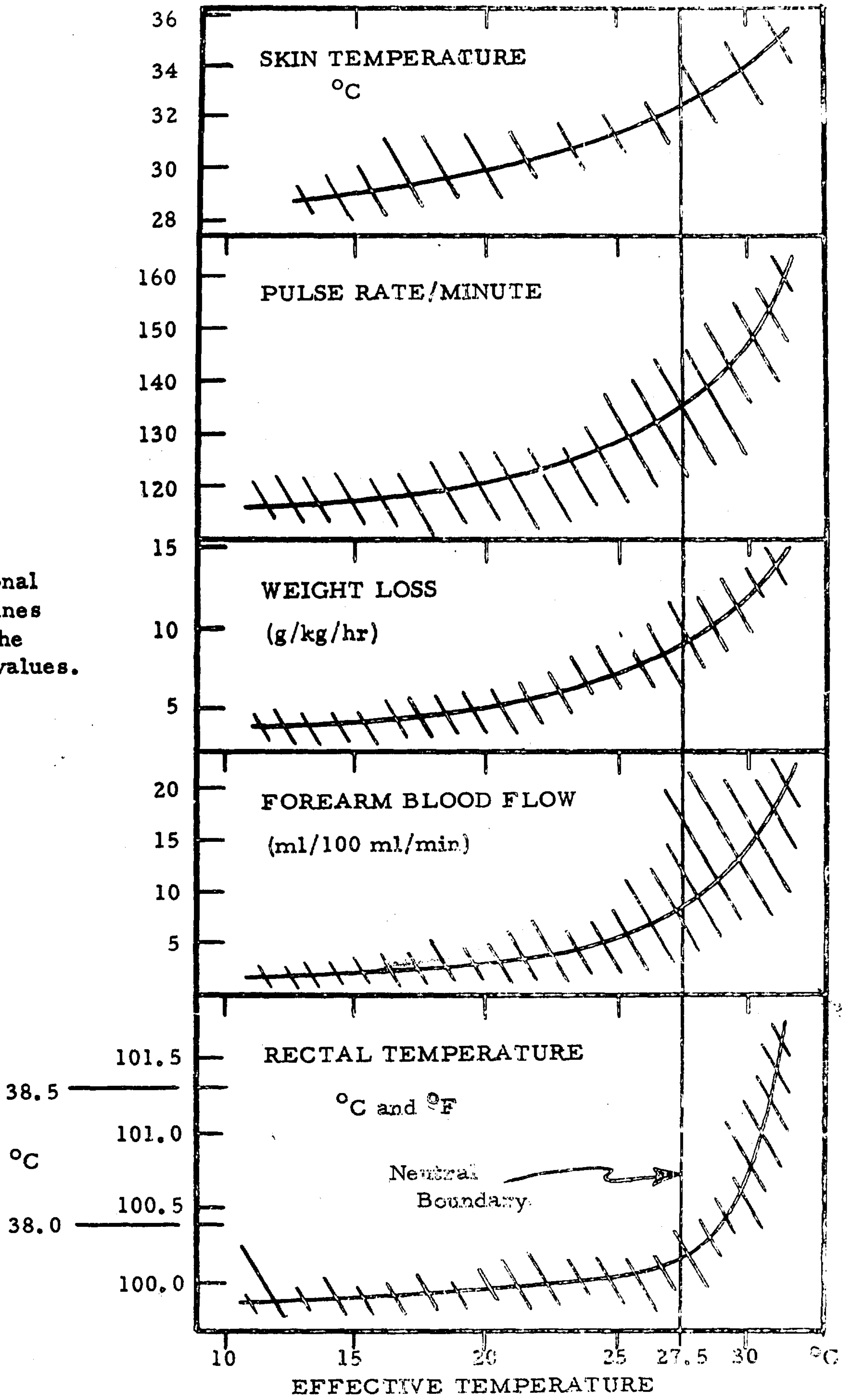


Figure III - 5a. Various physiological responses from all 3 subjects when they worked at a rate of 300 Kcal/hr in a wide range of climates (CET).

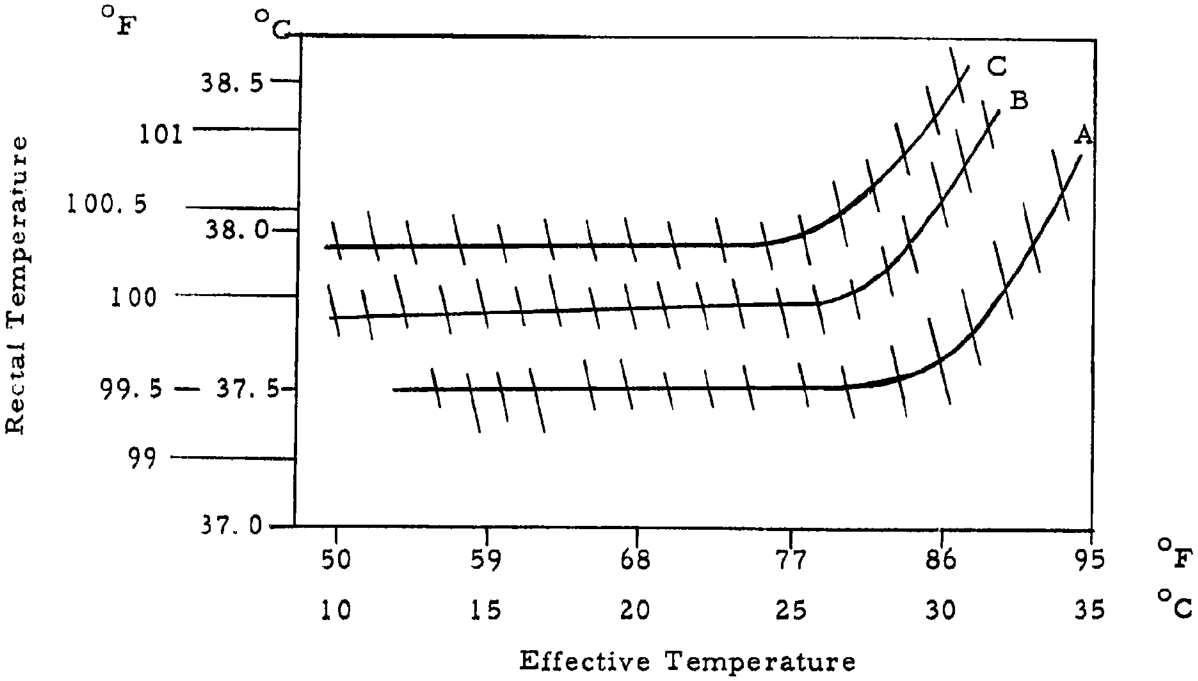


Figure III-5b Equilibrium rectal temperatures of one subject working at energy expenditures of

180 Kcal/hr -- Curve A
300 Kcal/hr -- Curve B
420 Kcal/hr -- Curve C

in a wide range of climatic conditions (CET).

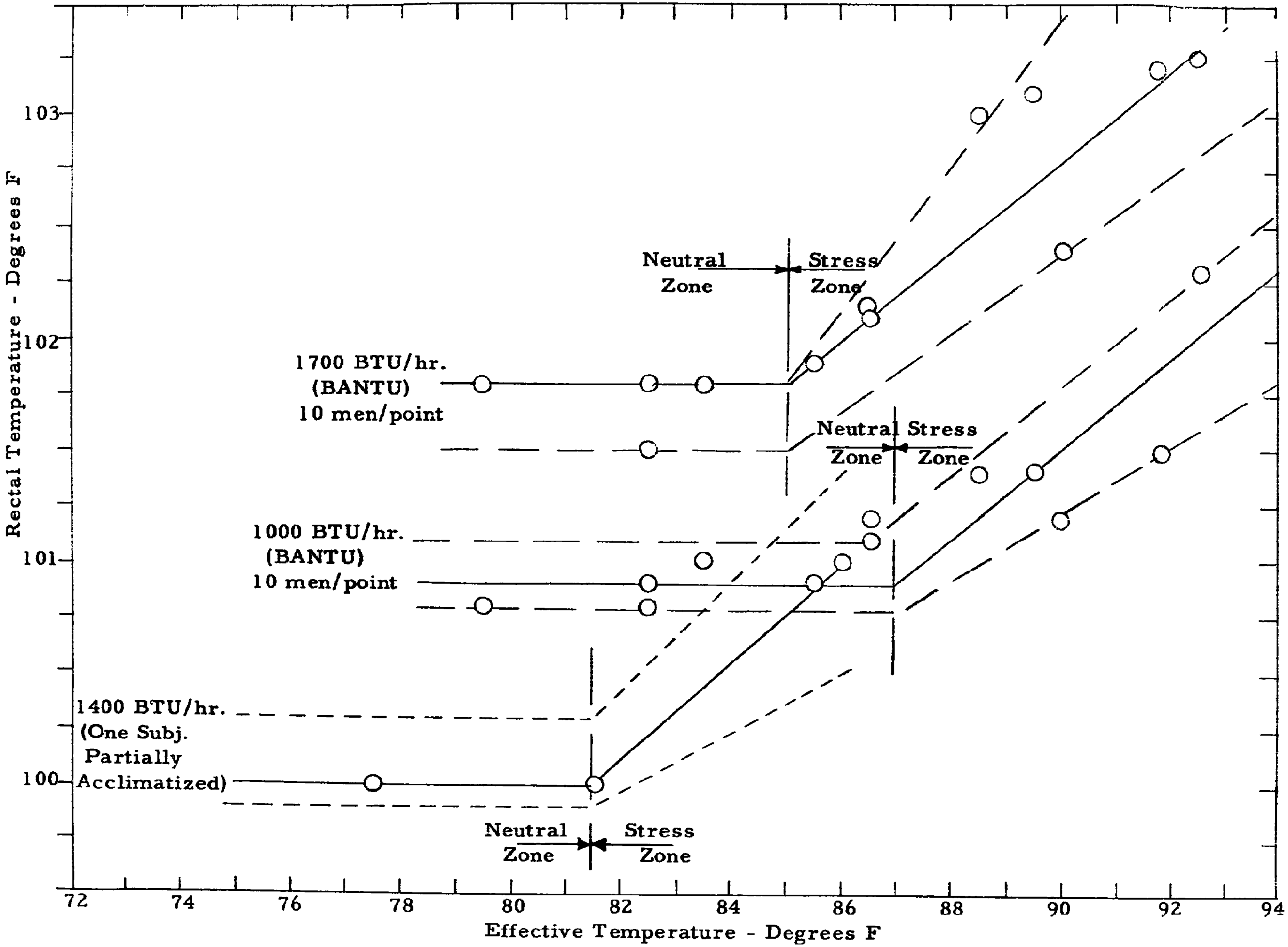


Figure III-6 Definitions of the boundary between neutral zone and stress zone for three subject groups and conditions. The lowest band of data is derived from 45 one-hour experiments on one partially acclimatized European subject working at 1400 Btu/hr on a treadmill. The upper two bands of data are for a population of unacclimatized South African native (Bantu) mining recruits, each point being the average for a different group of men working at the rate of 1000 Btu/hr or 1700 Btu/hr respectively. Data from Lind (1960a) and Wyndham, et al. (1954).

relationship between the NBC (Neutral Boundary Condition) and metabolic rate is heavily dependent on the particular index which is chosen to represent the environmental stress. This will be discussed in more detail later.

In the evidence presented so far, there is no particular proof that the point of discontinuity in the plot of final rectal temperature versus heat stress index has critical significance. Up to this point, Lind's argument was based mainly on the fact that no other parameter showed an abrupt and distinct change as the severity of the environment was increased, although common sense and general experience tells us that somewhere between the Effective Temperatures of 20 and 32°C (68 and 89.5°F) there must exist a limiting condition of some sort. The significance of the rectal temperature discontinuity can be rationalized on the theoretical ground that it represents the point at which a simple increase in the flow of blood directed through the skin is no longer sufficient to compensate for the increased obstruction to heat loss represented by an increased environmental heat stress index.

Another way of looking at the meaning of the NBC is that the rectal temperature has been deliberately regulated by the body's thermoregulatory control system at all milder environments (presumably to a value which is efficient for the particular work involved) - but at more severe environmental conditions (beyond the NBC) the control system is limited in its ability to regulate rectal temperature. The latter therefore is driven to some value determined primarily by the physical factors involved in the heat balance equation, and the control system functions only to prevent a rise of rectal temperature beyond this necessary minimum, as distinguished from having selected it.

That both the above rationalizations have merit is indicated by observations of the influence of acclimatization and training on the characteristic neutral-zone rectal temperature on the one hand, and on the NBC on the other hand. Before proceeding to a discussion of these points, however, we must establish the empirical validity of the NBC concept by reference to several additional studies of Lind, only one of which has been published as yet.

The most significant result comes from a study performed at Natick using 128 U.S. Army volunteer subjects who were neither trained in treadmill walking, physically fit to any particular degree, nor acclimatized to heat (Lind, personal communication). The men were divided into four approximately equal groups, and exposed once only to one of four environments. Of the two groups who experienced climates in the neutral zone all the men completed the prescribed three hours of marching at 3.5 mph, and displayed essentially identical average rectal temperatures at equilibrium. In the group exposed to the climate just beyond the NBC (as established by previous experiments) five of 29 men failed to complete the second hour, and an additional three men were removed during the third hour. The average rectal temperature of those completing the second hour was 0.5 degrees Fahrenheit higher than at the same time in the groups exposed to the climates in the neutral zone.

In the most severe environment the average rectal temperature at the end of the first hour was 0.8 deg. F higher than that for groups 1 and 2 in the neutral zone; three men were unable to continue past that point, another ten had to be taken out during the succeeding hour, and only 13 men finished all three hours out of the original 29 who started.

Thus 25 percent of the men in group 3 were unable to complete a three hour exposure to an environment just beyond the NBC, and 53 percent of a similar group failed a more severe environment, although the conditions were no more severe than were tolerated by a group of British coal miners for a full eight hour day, working seven of those hours at the same rate of energy expenditure as the military subjects at Natick.

The general principle of the Neutral Boundary Concept can be applied to intermittent work and to resting conditions as well as to continuous work at a fixed rate. Data for such conditions are more sparse, but suffice to show that a boundary can be established on a basis analogous to that used for continuous work (Lind, 1963b).

The single most important question remains to be grappled with, namely, what determines the location of the NBC for a large mixed population and what factors can be manipulated to reduce the probability of encountering heat casualties in environments bordering on the NBC? This leads naturally to the discussion of acclimatization.

(3) Acclimatization

The characteristic ability to withstand the stress of heat which a particular individual exhibits at any point in time is the net resultant of his anatomical, physiological and psychological characteristics, plus his state of conditioning or training. The former group of factors is primarily related to genetic influences and long-term developmental history, while the latter factor is a function of his immediate past history with respect to activity and climatic exposure. Studies of the heat stress tolerance of various ethnic and socio-economic groups in Africa and Australia (Strydom and Wyndham, 1962) have indicated strongly that of the two elements, the conditioning factor is of far greater significance than the ethnic or genetic factor, and the activity history is far more important than the climatic exposure history in determining the conditioning factor.

In Figure III-7, the average responses and standard deviations of five very dissimilar groups of human beings to the same environment and work regime are shown. These data were obtained by taking a portable environmental chamber, resembling a tent, to various parts of the world where groups of subjects of a distinct definable ethnic and social background could be gathered together. The figure presented illustrates only a few of the startling contrasts revealed by this pioneering investigation. Notice, for example, the great difference between white Australians and white South Africans; the latter live under a social-economic system in which the performance of muscular labor is considered demeaning. The Australians, on the other hand, take great pride in their physical prowess, their strength, and their ability to endure hardship. These men are generally heavy and florid in appearance. According to the senior author, Dr. Strydom, who was interviewed in Holland in September of 1962, the Australian men appeared to be highly unsuited to withstand the stresses of a hot climate; they tended to be overweight, red of face, and to perspire freely.

When the South Africans subjected themselves to the formal process of heat acclimatization, in which they worked for extended periods in severe heat day after day, they displayed a rectal temperature pattern with time closely comparable to that of the native laborers who are brought from the hinterland and put through the same acclimatization process

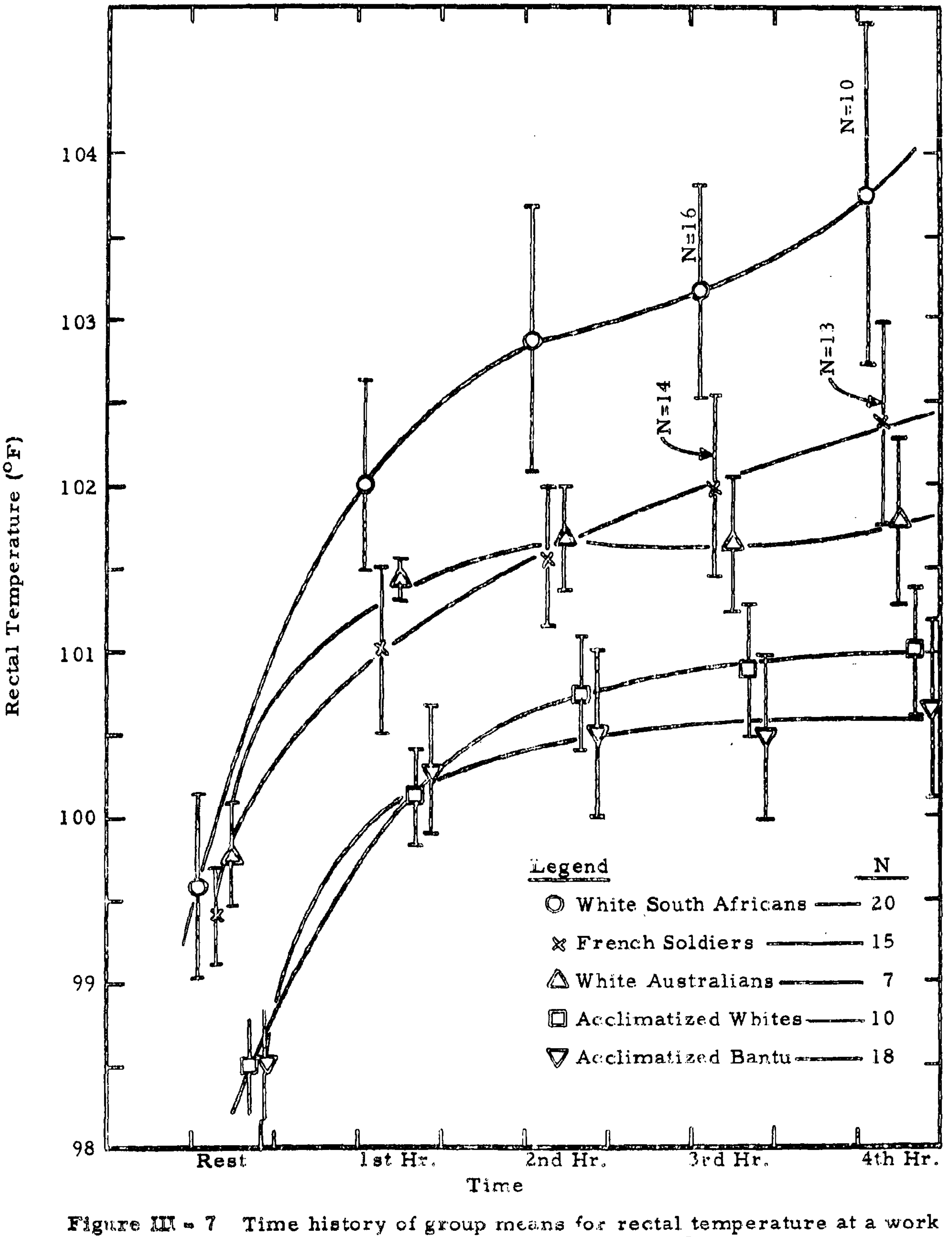


Figure III - 7 Time history of group means for rectal temperature at a work load of 1200 Btu/hour (step test) and 90°F Effective Temperature. Men wearing shorts only.

for the purpose of enabling them to perform manual labor in the extremely hot conditions deep within the South African gold mines. The intermediate position on the chart of the data for the Australians and French soldiers assigned to African duty in Morocco, illustrates the difference between so-called "natural acclimatization" and the carefully organized kind of "artificial acclimatization" which is carried out by the applied physiologists of the South African mining industry.

The notation on four of the data bars in Figure III-7 indicates that the number of subjects has been reduced by the collapse of one or more of the original subjects during the preceding hour. The continuous upward trend of the upper two curves, therefore, is due to the failure to maintain equilibrium on the part of a portion of the test group and should not be interpreted as meaning that all of the subjects were storing heat from the second hour on. Only by detailed examination of the raw data for individual cases will it be possible to relate these findings precisely to the neutral boundary concept of Lind. It is hoped that in the future, this type of analysis can be carried out.

Haldane and Priestley, in their book, Respiration, published in 1935, observed that:

> "It is somewhat noteworthy that men accustomed to hard outdoor work seem to be much less sensitive to heat or cold indoors than other persons. This is probably due to the fact that, although they are not accustomed to external heat, they are accustomed to what in this reference comes to much the same thing, namely, greatly varied internal heat production, which involves the same capacity for vasomotor adaptation as exposure to external heat or cold. Those who are most affected by external heat or cold indoors are persons who are not only unaccustomed to external heat, but are also unaccustomed to hard muscular exertion."

As was pointed out by Nielsen in 1938 and reaffirmed in recent years by him (1962) and by Lind (1960-1963) there is a distinct deep body temperature level associated with any given activity of fixed metabolic cost in the trained individual, which is independent of environmental temperature over a broad range. In an untrained individual the deep temperature reached by the body at equilibrium for the same work will be distinctly higher, and will decline steadily in successive periods of work as training progresses. Figure III-8 collects data from several sources to indicate the nature of the relationship between rectal temperature at equilibrium and metabolic rate, and shows

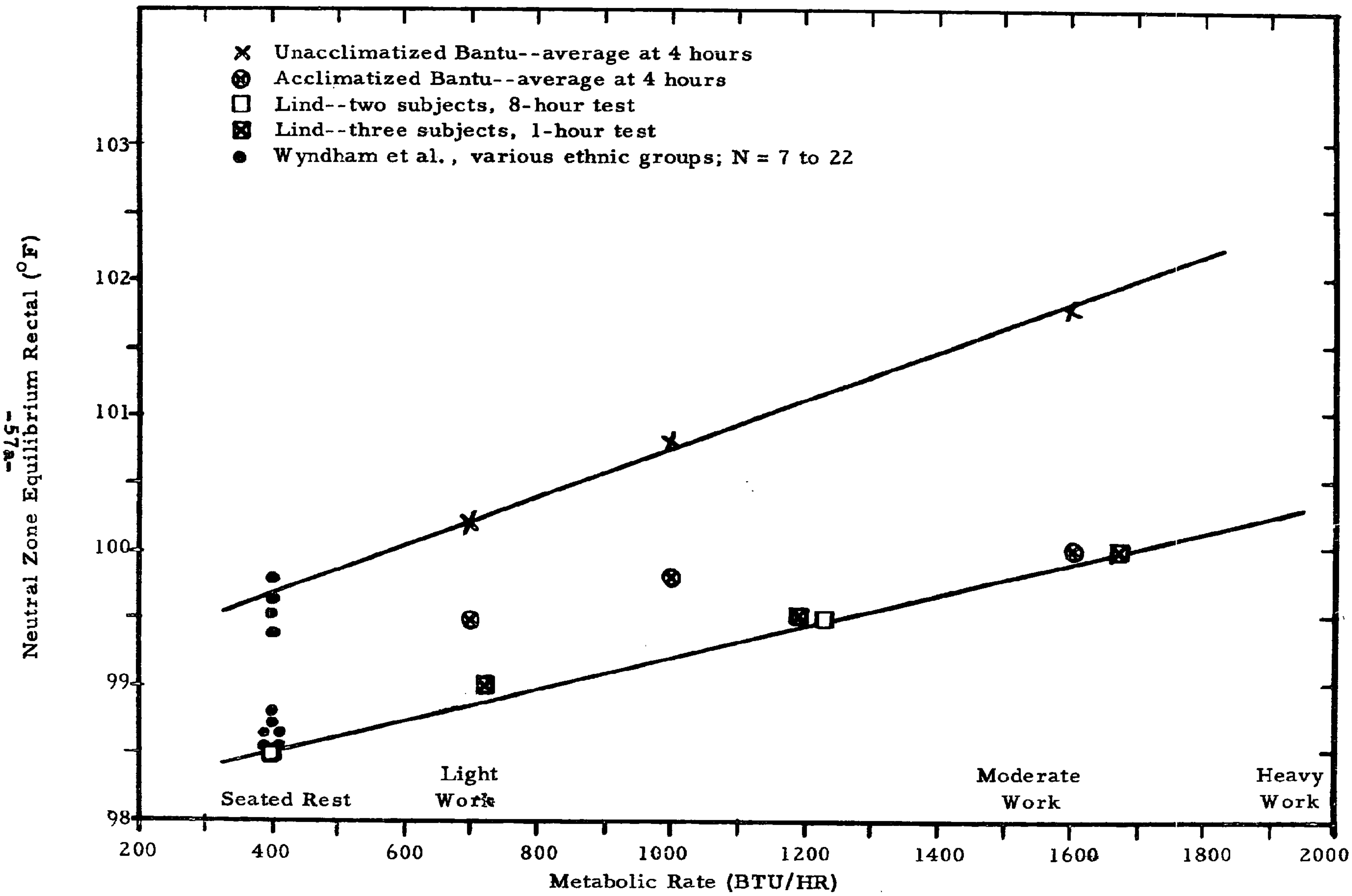


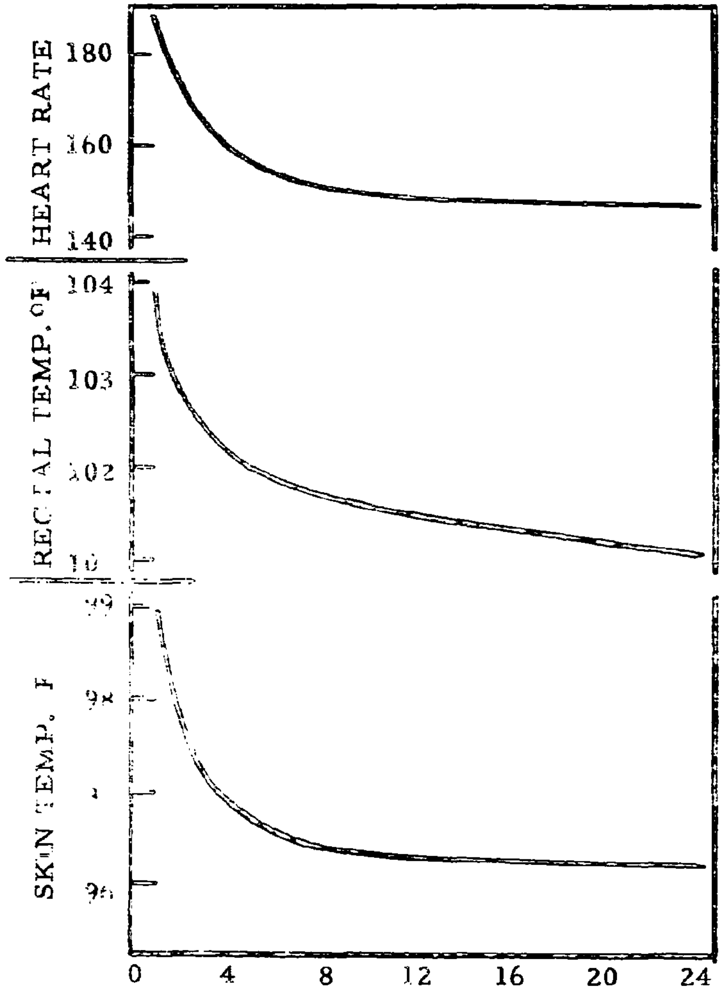
Figure III - 8 Equilibrium rectal temperature in the neutral zone as a function of metabolic rate, showing the effect of heat acclimatization.

the effect of acclimatization. It should be noted that the data pertain to cool and mildly warm environments, falling within Lind's "prescriptive" or neutral zone where rectal temperature is not influenced by the environment. In the case of the Bantu miners particularly, the acclimatization period was concurrent with their initial training for the work involved; the effect of muscular and general fitness training, therefore, cannot be separated from that due to the exercising of the thermoregulatory function.

In various classical studies of the acclimatization phenomenon it has been customary to complete a period of training in the experimental task, under cool environmental conditions, before initiating a series of combined work-plus-heat exposures (Eichna, et al., 1950; Horvath and Shelley 1946; Robinson, et al., 1943). Figure III-9 is taken from Eichna, et al., (1950) and Horvath and Shelley (1946), and illustrates the dramatic reduction in the body temperatures and heart rates in the first few successive daily exposures of about one hour each.

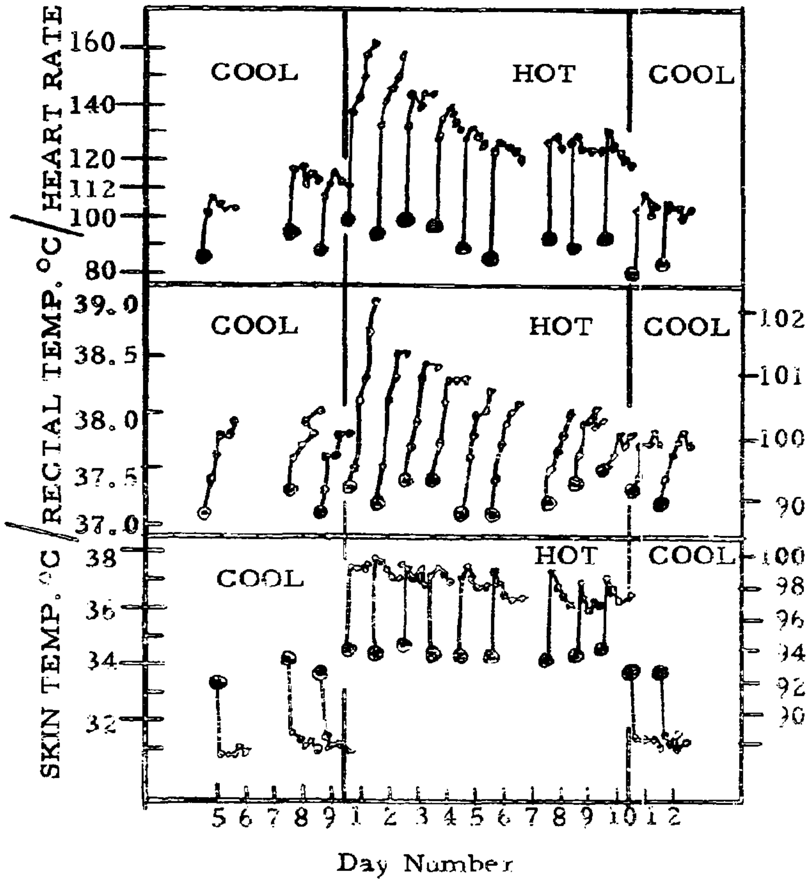
Even more dramatic is the picture presented in Figure III-10; the work involved here is walking at a speed of 3.5 miles per hour up a grade of 5.6 percent, which involves between 450 and 575 Kcalories per hour of energy expenditure. These men had trained themselves to this activity by daily practice, and had completed a 40-mile hike in one day. On the other hand, none of them had been exposed to heat since the preceding summer when they experienced their initial heat experiment on February 20 and March 24 respectively. On this first day, they walked on the treadmill until they were exhausted, which occurred for the two subjects whose results are illustrated at about 90 minutes. Two months later for one man and one month later for the other, they walked at the same speed and grade for four and a half hours "with ease," and were maintaining thermal equilibrium when the experiment was terminated with no sign of an end point, although no rest periods were taken during any of these experiments.

A clarification of what happened to these individuals between the two exposures to identical environments and work loads to cause such an enormous difference in their responses is crucial to our understanding of the general problem of setting tolerable limits for thermal stress. In the case of subject S. R., there were 23 work periods in the heat



Average trend of physiological state at the end of daily work periods for 5 subjects during acclimatization at 104°F, 23% RH. (After Robinson et al.)

Figure III - 9.



● – Initial conditions each day in cool environment

• – Successive readings during one hour of work on each day

Averages for 3 individuals, temperature 123°F, 15% RH.

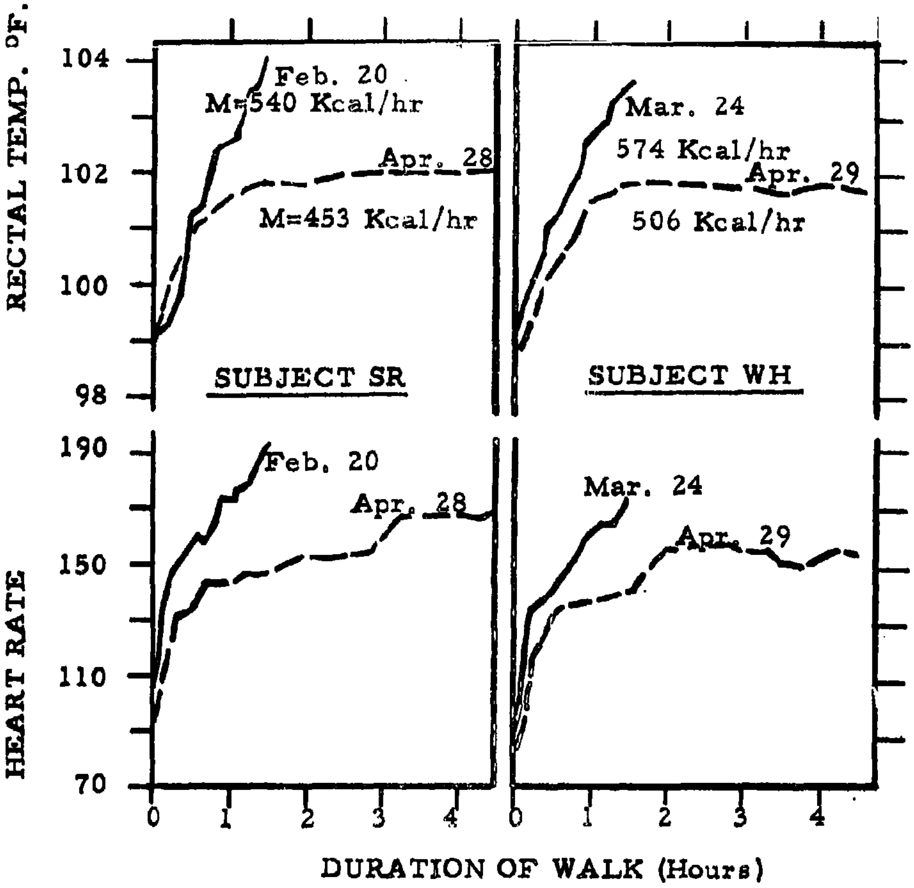


Figure III - 10. Acclimatization to heat as shown by the lowering of body temperatures and heart rates of two men walking at 3.5 m.p.h. on a 5.6 per cent grade (room temperature 104°F., humidity 23 per cent), E. T. 84°F.

a. Subject SR was acclimatized by 23 exposures between February 20 and March 20. After March 20 his only exposures were on April 16 and 28.

b. Subject WH was acclimatized by 11 exposures between March 24 and April 8. After April 8 his only exposures were on April 22 and 29.

between February 20 and March 20 (included in the data for Figure III-9); from that time until the endurance test on April 28 he was exposed only once, on April 16.

Subject W. H. experienced only 11 exposures during his acclimatization processing, the last one on April 8; thereafter he also was exposed only once, on April 22, before the endurance test.

In the twenty years that have passed since those experiments were conducted, a great deal has been learned about the acquisition of acclimatization, its rate of decay, and the procedures which are most efficient in achieving retention of the acclimatized state with a minimum of heat-stress exposure. As will be seen later, these findings indicate that subjects S. R. and W. H. in Figure III-10 were not highly acclimatized by modern standards at the end of their prescribed acclimatization regime, and had probably lost a considerable proportion of that acclimatization in the three to five weeks which elapsed from that date to the endurance test. Using modern techniques for producing and retaining a high degree of acclimatization it should be possible to achieve a far higher degree of tolerance for heat than these men possessed at the time of these tests; it is difficult to imagine what the ultimate achievable improvement in the ability to work in the heat might be, considering that S. R. and W. H. showed far less physiological strain at the end of four and a half hours following their acclimatization than after one and a half hours before the treatment.

(4) Physiological basis of heat acclimatization

It has been well known for many years that a person who is "acclimatized" to the heat is able to work under hot conditions without undue elevation of heart rate or development of fatigue, whereas the identical conditions of work and environment led to a state of complete heat exhaustion on the first occasion that he experienced it after a history of cool living and working conditions.

Only recently, however, has the concept of degree of acclimatization become clarified. The classical technique for producing "heat acclimatization" experimentally has been to repeatedly expose the subject under study to the same duration and amount of work in an identical hot environment for one hour or more per day, for from 9 to 14 days.

Usually, the conditions were chosen so that on the first day most subjects had considerable difficulty in getting through the ordeal without collapsing; by the fifth or sixth day they would find the task relatively easy, and changes in their response patterns would be only minor from then until the last treatment day.

What most investigators failed to point out, or to grapple with in a quantitative sense, was that the degree of acclimatization must vary according to the severity of the work level chosen and the environmental heat load selected.

In the last year or two, two English scientists have independently attacked the mystery of acclimatization by another route; David Kerslake at Farnborough has been exploring the effectiveness of hot baths (40 minutes in 39°C water (99.5°F)), (Brebner, et al., 1961) while Ronald Fox at the Medical Research Council, Hampstead, has pioneered a system of "heat treatments" in which oral temperature is maintained at a constant elevated level in a reclining man by means of under-ventilation of a simple plastic sealed suit after being driven up rapidly in a steam bath (Fox, et al., 1962).

From the academic point of view, these latter experimental techniques permit the separation of the mechanisms of fitness training by repeated exercise from those of "thermoregulation training," which seems to be just as real. It should be noted that no substantial exercise regime can be maintained for an hour or more without a distinct and substantial increase in rectal temperature. It is thus reasonable to say that a certain, though small, amount of heat acclimatization, or thermoregulation training, occurs when prolonged exercise is undertaken day after day, even in a cool climate.

According to Fox, the essential element of heat acclimatization is the training of the sweat response mechanism; whatever apparent cardiovascular system improvements may occur in the classical type of acclimatization process, he feels, are due to the physical fitness training aspect and to the steady reduction from day to day in the degree of elevation of body temperature caused by the fixed exercise.

The sweat response training which takes place is in two categories:

1) improvement in the sensitivity of the sweating control mechanism and a reduction in its threshold (i. e., sweating starts at a lower skin temperature);

2) improvement in the capacity of the sweat gland itself to secrete sweat under a particular stimulus.

These characteristics of the process involved in acclimatization are revealed in a positive and repeatable manner by Fox's technique of holding body temperature (oral) constant throughout the heat exposure and from day to day.

Data from the earlier literature describing the conventional work-in-heat procedures can be organized to illustrate the gradual improvement of sweat response from day to day, and also to reveal the increased improvement achievable when a more severe work regimen and a higher temperature or humidity are used as the controlled environment.

Figure III-11 represents such data, taken from the work of Eichna, Horvath, et al., carried out at the Army's Medical Research Laboratory at Fort Knox during World War II (Eichna, et al., 1950) and (Horvath and Shelley, 1946).

Each symbol is identified by the number of the day in the sequence of repeated exposures; two different levels of heat stress are involved, the difference in severity resulting from differences in clothing, wind speed, humidity and type of work. Techniques and experimenters were largely the same in the two studies, and the assumption has been made for the purposes of this illustrative figure that the two groups, numbering three in one case and sixteen in the other, can be treated as samples of the same population.

Several interesting points may be noted from Figure III-11. In the dry environment (circles) the adjustment of the sweating response entailed the production of only slightly more sweat on successive days of exposure, but this was accomplished at progressively lower skin temperatures. In the humid environment, in which relatively heavy clothing was worn the adjustment entailed an increase in the amount of sweat secreted, but little improvement in skin temperature. The reason for the latter situation, of course, is the fact that additional sweat production is relatively

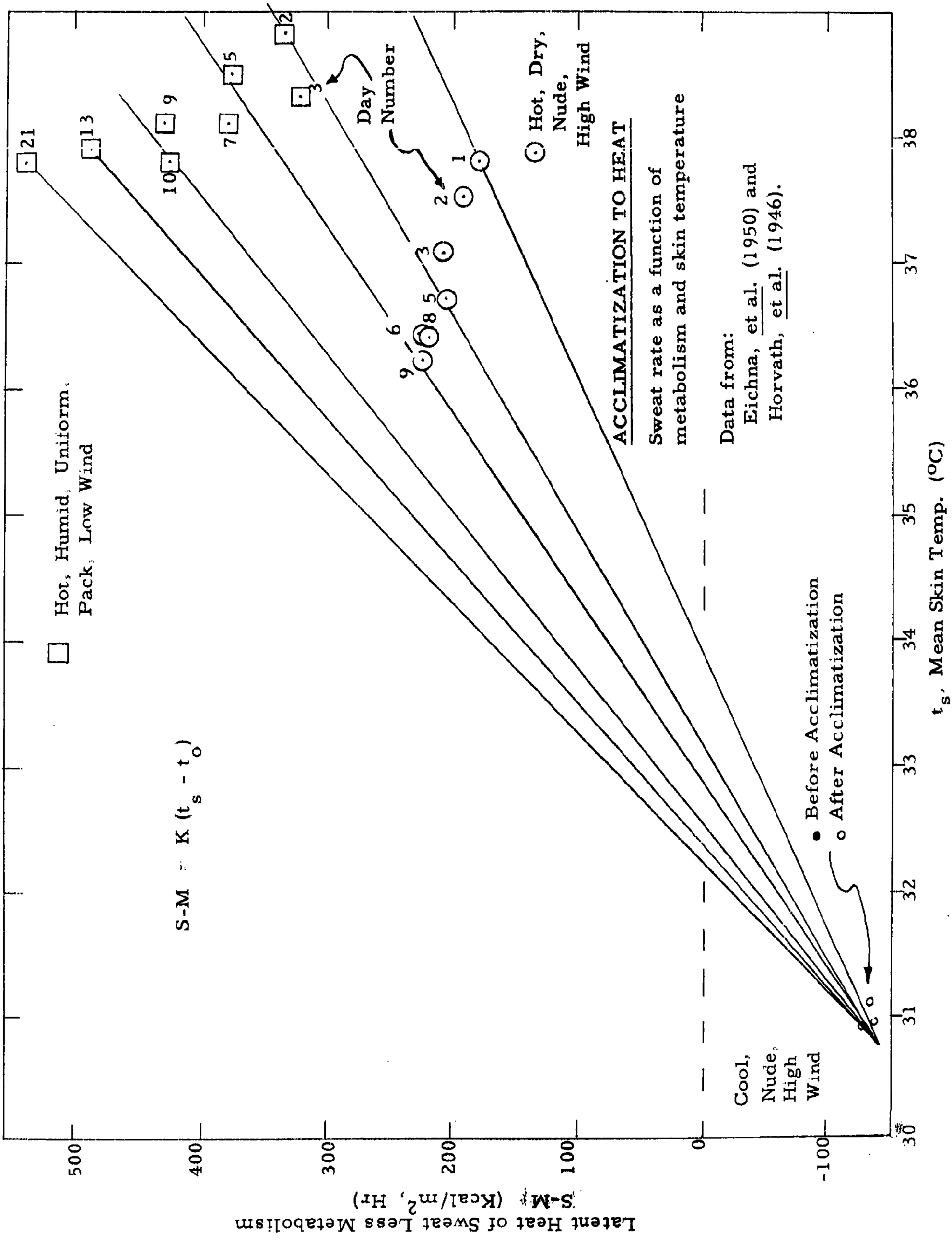


Figure III-11

ineffective in improving the heat loss by evaporation when the humidity in the air is high (34 mm Hg vapor pressure in this case), the body surface is already wet, and clothing is worn.

Note that the skin temperatures and sweat rates were the same for the nude group before and after their heat acclimatization experience and from day to day. It is suggested that this evidence supports the assumption (in the absence of data to the contrary) that the clothed group would have had essentially the same sweat rate at the "cool" (78°F) condition when nude and working at the rate of the nude group.

The most significant point about the figure is the changing slope of the lines joining the cool condition and successive days in the hot room. Increasing slope means increasing <u>sensitivity</u> of the sweat response mechanism - more output per unit change in skin temperature at a given metabolic rate. The decreasing intercept value on the zero line of the ordinate scale means a progressively lower threshold for sweating.

Finally, the co-linearity of day five at the less severe condition and day two at the more severe, and of day nine in the dry heat and day five in the humid environment, tells us that the same degree of acclimatization is reached in approximately half the number of days under the more severe condition. Furthermore, it is clear that considerably more "acclimatization" is achievable after the plateau has been reached in the milder condition (days six to nine). The significance of the relationship between sweat rate, metabolism, and skin temperature will be explored in considerable detail subsequently.

(5) Relationship of sweat rate and oral temperature during conventional acclimatization

At the Medical Research Council laboratories in London the standard procedure for acclimatizing subjects to heat was for years a routine in which brief periods of stepping onto a 12 inch stool alternated with periods of rest (Macpherson, 1960). The average metabolic rate over the four hours for which this routine was followed amounted to about 110 Kcal/m^2 hr or 200 Kcal/hr for an average-sized man, or twice the resting metabolism for an alert seated man.

In Figure III-12 the average results are presented for a group of 15 soldiers who were being prepared for the large-scale British Army field trials in Aden in 1961 (Edholm, et al., 1962). Each symbol is identified by day number, number one being the first day of the acclimatization period of 23 daily exposures (week days only), and number 24 the final uniformity trial for comparison with the first one, labelled "-45", which was carried out a month and a half before the acclimatization process began.

The method of presentation in this chart emphasizes the magnitude of the concurrent improvement (i. e., reduction) in body temperature and the increase in sweat output. Unfortunately, skin temperature data were not provided in the report of these experiments, but it can be assumed with certainty that it fell progressively along with oral temperature.

The slight increase in sweating and decrease in oral temperature between the original uniformity trial and the first day of acclimatization represents the moderate effect on thermoregulation of general military training activities. Between day one and day five the major change is in temperature; the increase in sweat output develops later in the process, when changes in body temperature are minimal. The cluster of points for days 16, 22 and 24 indicates that a plateau has been achieved, that is, that the work routine is now being accomplished with no more increase in body temperature than is called for in a cool environment.

In terms of the Neutral Boundary Concept discussed earlier, the 23 days of acclimatization brought the test environment within the neutral zone for this group of men, whereas previously it was distinctly beyond the neutral boundary, lying in the stress zone. To complete the picture, it should be mentioned that the post-work heart rate declined from an average of 175 beats per minute on day -45 to 120 on day 22.

The estimation of a reference datum point representing sweat production and body temperature under cool conditions (square symbol in Figure III-12) allows us to represent the state of acclimatization at successive stages of the process by means of the slope of lines joining the cool datum to that day's sweat output and oral temperature. In effect, this slope expresses the amount of increased sweat output which is associated with one degree of oral temperature elevation. We might conceivably term this an "acclimatization index,"

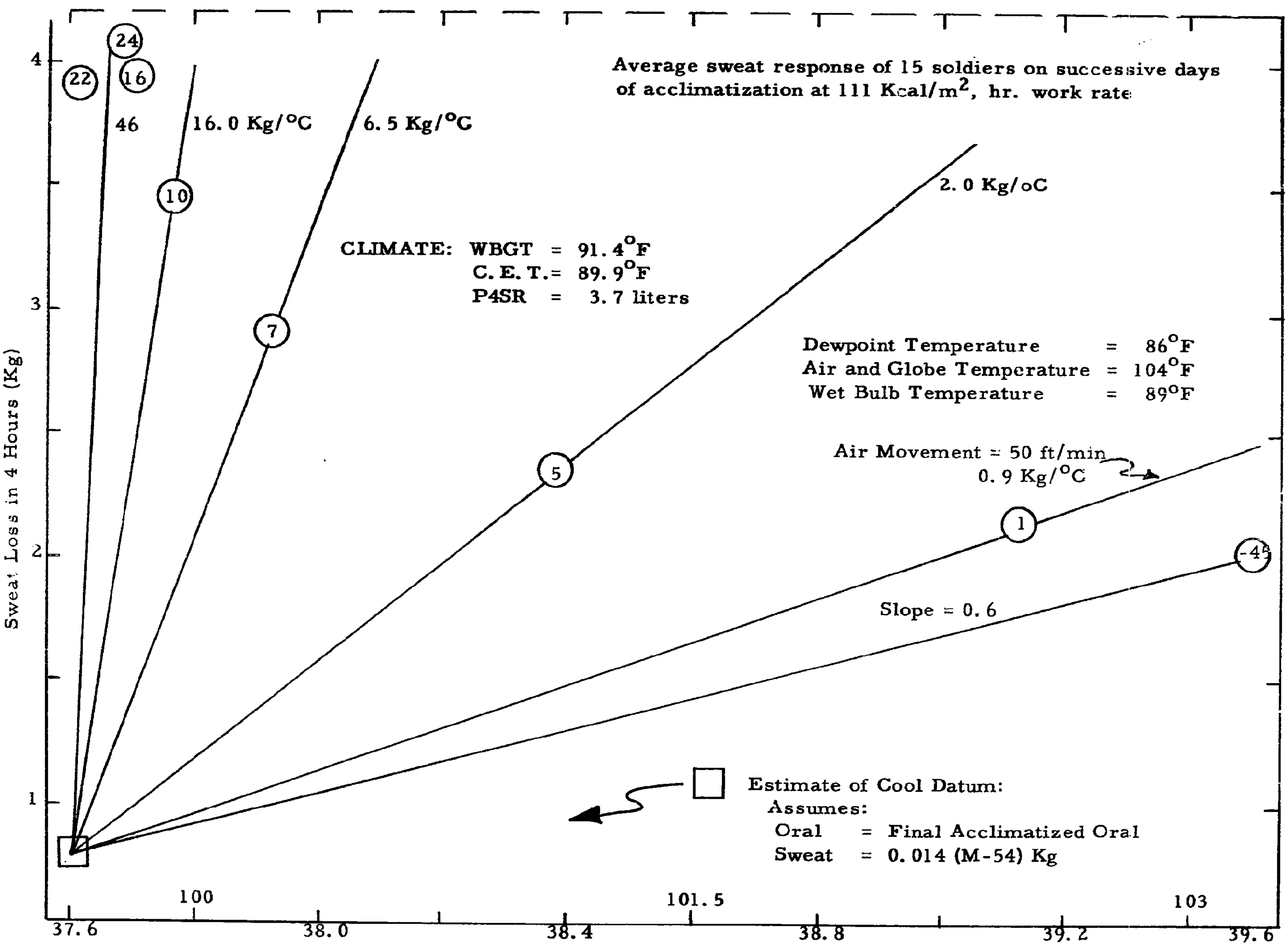


Figure III-12

and plot its value as a function of number of accumulated days of acclimatization. Figure III-13 shows such a plot, and reveals several reasons why this parameter is unsuited for the role of an index of acclimatization.

To begin with, the slope parameter changes least in the first few days, whereas we know very well that the biggest improvements in actual acclimatization occur then; conversely the slope is increasing rapidly in magnitude at the end of the period when all other evidence indicates a plateau or stable condition. Not so obvious is the fact that the slope index refers only to one particular level of activity and has no generality of meaning for other environments and other tasks.

To find a suitable quantitative measure for acclimatization we must return to a further consideration of FigureIII-11 and its implications.

(6) Skin temperature and sweat rate

In 1954 Kerslake demonstrated that surprisingly straight lines were produced when sweat rate was plotted against a calculated subcutaneous skin temperature parameter which was derived from the measured surface skin temperature and the calculated rate of heat flow through the skin: the regression lines for the data obtained on four subjects are reproduced in Figures III-14 and III-15. The equations of these four straight lines have the general form

$$S = K(t_s + \frac{H}{K} - C) \qquad \text{Eq. 2}$$

where S is the latent heat equivalent of the sweat output, in Kcal/hr;

H is the heat flow through the skin, obtained as the difference between heat gain by convection and radiation, and heat loss by evaporation;

t_S is the mean surface skin temperature;

K is a proportionality constant for sweat rate as a function of temperature;

C is an intercept constant representing some reference or base-line skin temperature.

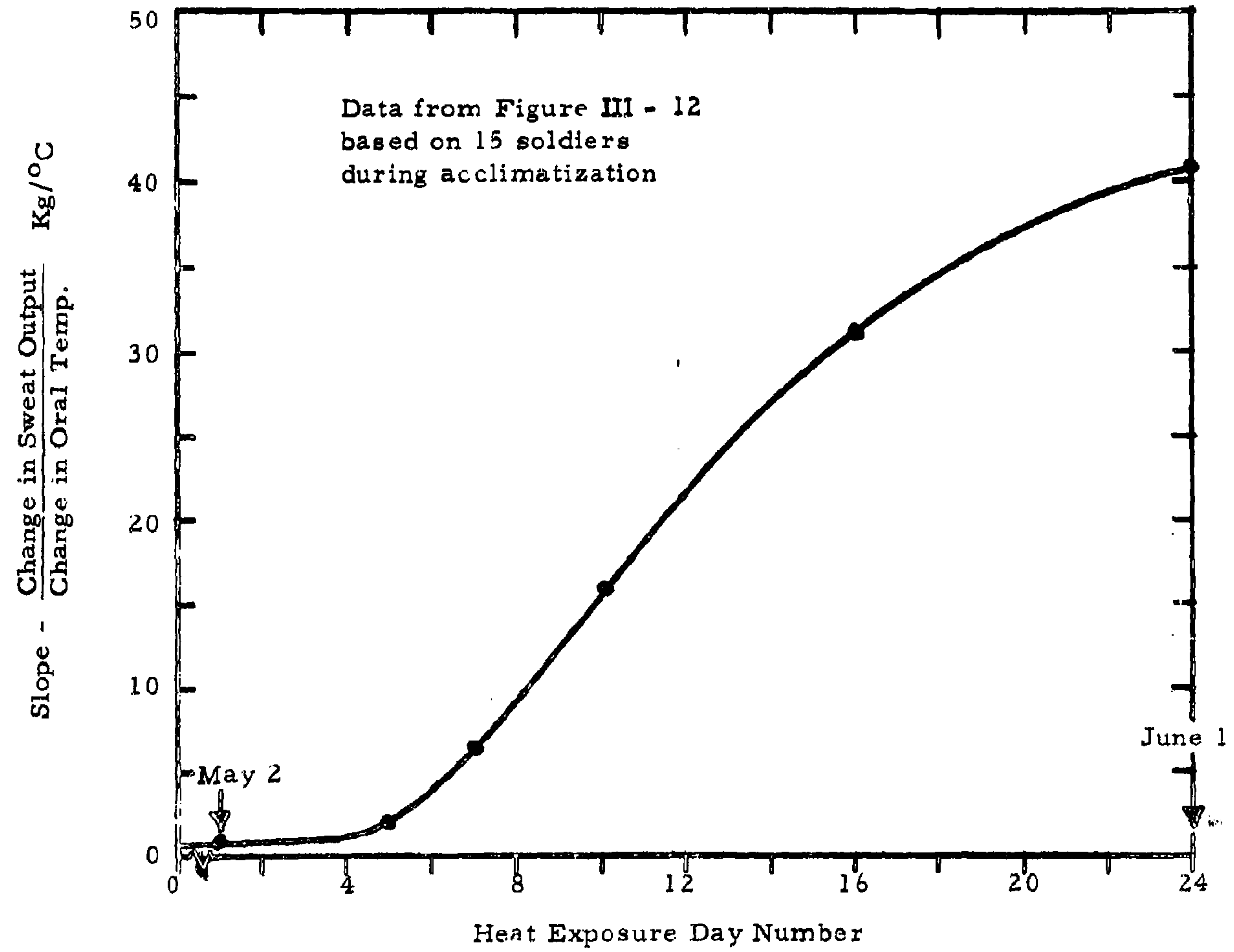
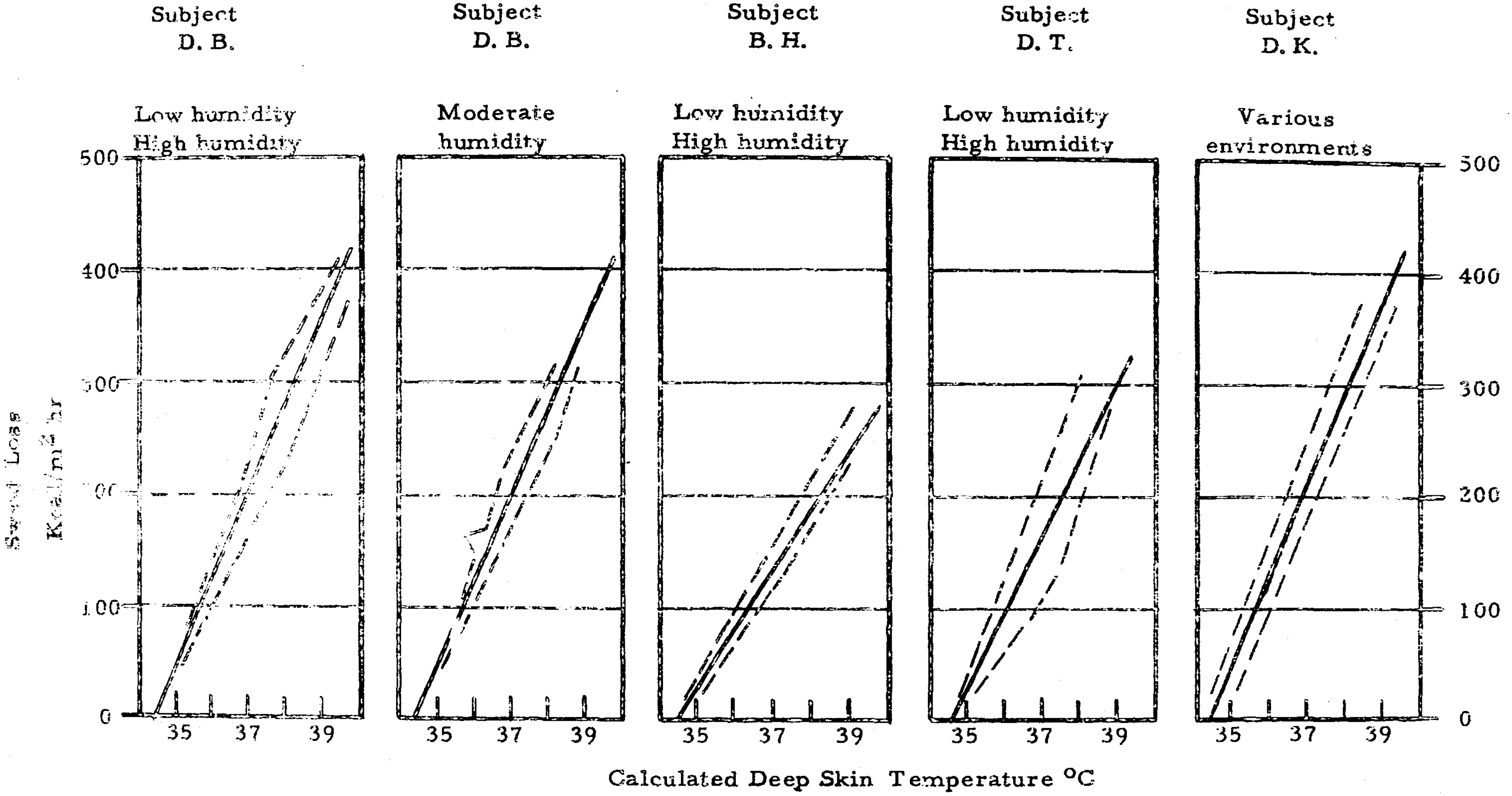


Figure III - 13 An example of the use of an index to illustrate the development of acclimatization.



Note: The dashed lines indicate the range of observed values.

Figure II-14 The sweat response patterns of four individuals under numerous conditions

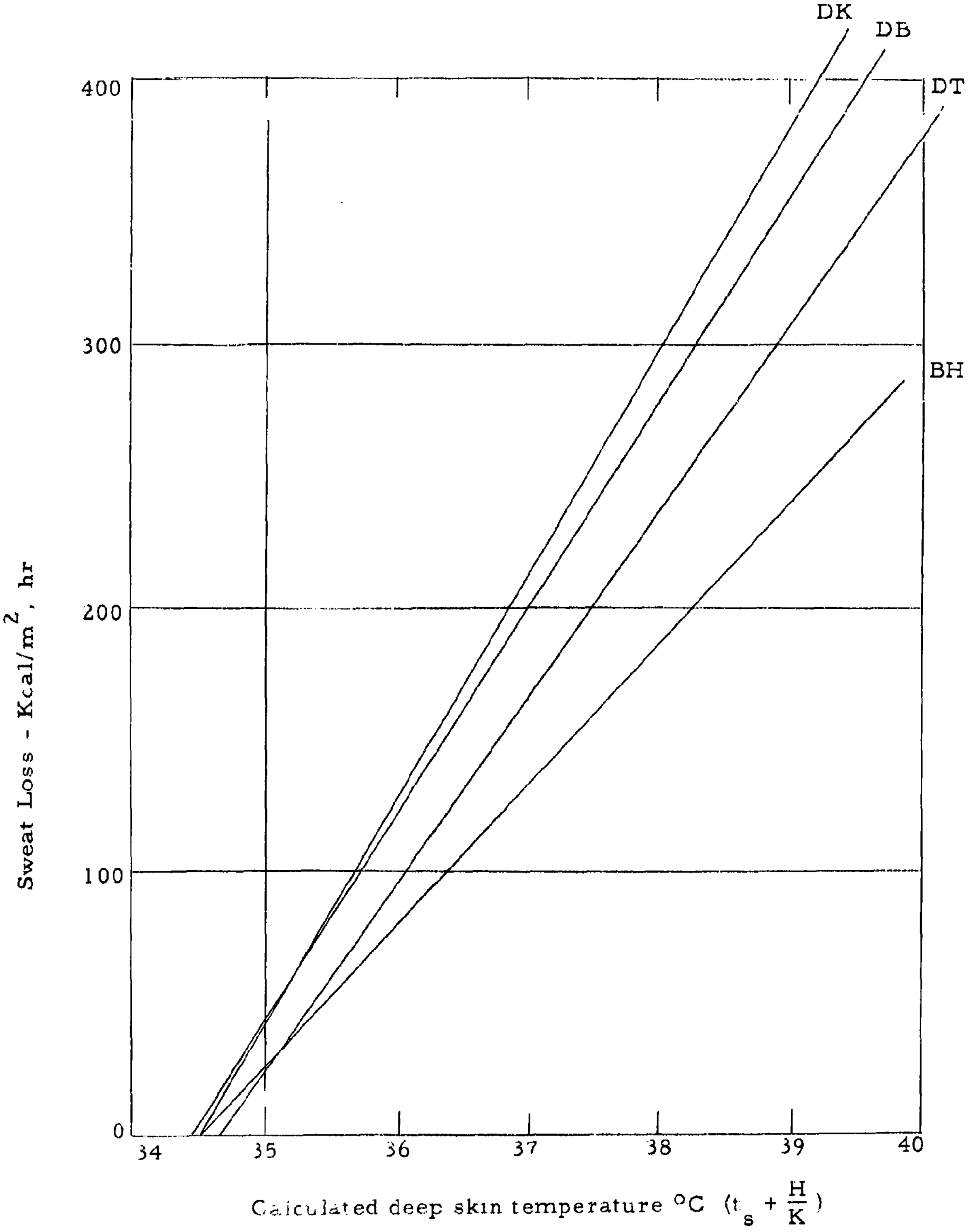


Figure III-15 Comparison of four individuals as to sweat response.

Kerslake's experiments involved short periods of heating at a variety of work levels, environmental temperatures and humidities, in which the steady state was usually not reached. While noting the consistency of his results with a hypothesis that sweat rate is controlled through sensory nerve endings responsive to temperature and located near the sub-cutaneous blood vessel plexus, Kerslake did not specifically propose a control system based on this assumption.

In 1961 Hatch (1963) analyzed a number of data collections from the war years dealing with sweating men in thermal equilibrium, and showed that respectably linear correlation was obtained by plotting the parameter (S-M) against skin temperature. (S-M) represents the difference between the latent heat equivalent of the sweat output and metabolism. At equilibrium, the heat flow through the skin is equal to metabolism, so that the equation form proposed by Hatch, viz.

$$S-M = K(t_s - t_o) \qquad \text{Eq. 3}$$

(where t_o is a reference or base-line temperature) is directly convertible to that of Kerslake in Equation (2) above, viz.

$$S = K\left(t_s + \frac{M}{K} - t_o\right) \qquad \text{Eq. 4}$$

Hatch also analyzed a few experimental series involving non-equilibrium conditions, and simply introduced a term for body heat storage, which is subtracted from M to give the heat flow through the skin.

It should be noted that if there is a net heat gain from the environment, so that the rate of storage is actually greater than the metabolism term, the heat flow through the skin is reversed in direction from the usual case, and the subcutaneous temperature is lower than the surface skin temperature rather than higher, as is usual.

The general expression, attributable to steady state and storage situations alike, becomes

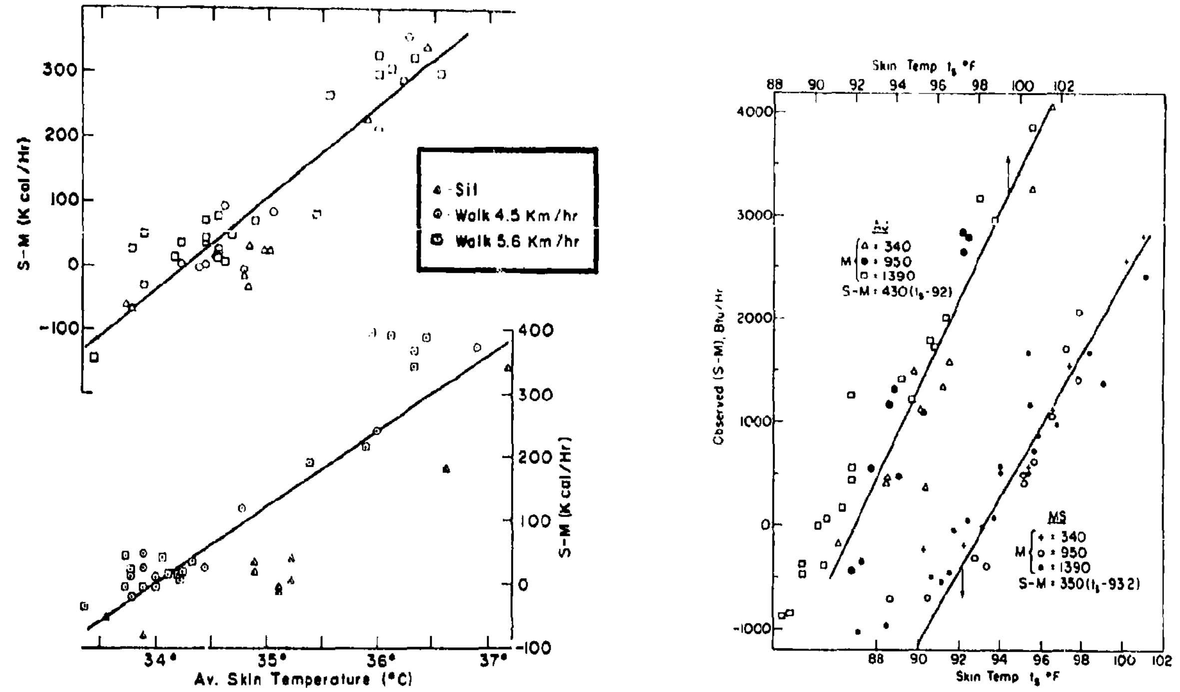
$$S - (M - Q_s) = K(t_s - t_o) \qquad \text{Eq. 5}$$

where Q_s represents the body heat storage rate in Kcal/hour.

In Figure III-16 Hatch's curves for five individuals and one group are presented to indicate the degree of scatter about the line of regression which is typical of these kinds of data, taken from work done many years in the past and unsegregated as to chronological order of acquisition, special conditions, etc. In the same figure are plots for two individuals, taken from a more recent study (Belding and Hertig, 1962). It is of interest to note the range of variation in the numerical values Hatch obtained for these five individuals and the one group; K varied from 307 Btu/hr, °F for the group of British Naval ratings studied in Singapore to 548 Btu/hr, °F for one of the U.S. Army soldier subjects studied at Fort Knox, Kentucky. The corresponding reference temperature values associated with these regression lines are 91.5 to 93.6°F. Converting the slope coefficient to the metric units used as the main system in this report, the range reported by Hatch is 138 to 246 Kcal/hr, °C; he suggests as an average value 430 Btu/hr,°F or 194 Kcal/hr, °C.

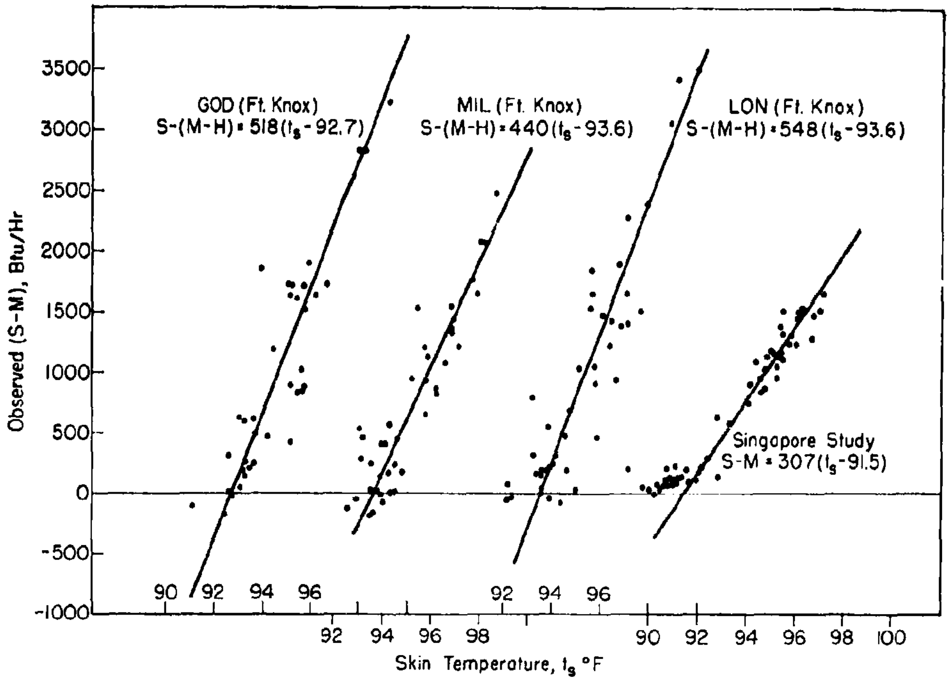
All the subjects chosen by Hatch for analysis were "acclimatized" to some degree. In the case of the Singapore soldiers, it was a "natural" form of acclimatization, acquired in the course of living and working in a tropical climate. In the case of the three Fort Knox subjects in Figure III-16, it was probably a very high degree of acclimatization indeed. Before starting these experiments, the men completed an intensive series of 10 daily four hour work periods in environments of increasing severity from day to day, ranging from 89 to 94° E.T. This "artificial acclimatization" regime of the Fort Knox group (Nelson, et al., 1947) followed a preliminary period of training for the marching work involved in the tests; each week during the gathering of the data shown in the figure, the men spent Monday performing a "re-acclimatization" four-hour march in environments similar to the original ones. Tuesday through Saturday the men spent 7 1/2 hours of each day in the heat chamber in a variety of environments ranging from 70 to 94° E.T., marching in the morning and standing quietly in the afternoons.

All things considered, it is not too surprising that the subjects chosen by Hatch have the highest degree of acclimatization (according to the new criterion which we are about to introduce in this report) of any individuals or groups for which suitable data have been available for analysis.



Steady state relationship between S − M and skin temperature (sweating and deep skin temperature). All data on same 2 subjects (*programs 1* and *2*).

Relation between sweat rate, metabolic level, and skin temperature. Robinson's two subjects, operating at three activity levels.



Relation between sweat rate and skin temperature for three subjects (standing at rest) employed in the Fort Knox studies, and collective data on several subjects who followed a work-rest schedule in the Singapore studies.

Figure III - 16 Examples of Individual Sweat - Skin Temperature Relationships (From Belding & Hertig, 1962 and Hatch, 1961)

In the next series of figures, we present data extracted from many diverse reports in the literature representing a wide range of male subjects and a few females, which are arranged to indicate the value of K in the equation

$$S - M = K(t_s - t_o) \qquad \text{Eq. 6}$$

It is this term K, the proportionality constant which expresses the sweating response as a function of subcutaneous temperature (or of a skin temperature and heat flow across the skin) (see page 68) which is proposed as the essential yardstick by which the state of heat acclimatization of individuals or groups may be compared. Since, as was expressed in the introductory remarks to this sub-section (page 55) the state of acclimatization is considered by us as merely a special case of the general fact of individual difference due to various causes, the parameter K becomes more broadly a measure of the ability to resist heat stress.

(7) The sweat response coefficient (K) as a measure of "acclimatization"

If the proposition put forward in the preceding paragraphs is valid, then an attempt to assemble data on sweating and skin temperature in the form suggested by Hatch would be doomed to failure for analyses involving:

(a) data for a group or individual whose state of acclimatization changed during the period of data collection;

(b) data for a group whose size and composition varied from one condition, for which an average response was plotted, to another. (The probability of finding a group which was homogeneous with respect to acclimatization or sweat response is extremely low.)

(c) a group whose state of fitness training changes during the investigation.

Recent conversations with colleagues of Dr. Hatch at the University of Pittsburgh, Drs. Belding and Hertig, have indicated that, in fact, several attempts to apply the analytical technique to certain blocks of data gathered in their own laboratories, as well as elsewhere, have been largely unsuccessful. It is strongly suspected that one or all of the factors enumerated above were involved; thus the failure of the approach in the hands of the Pittsburgh group is taken to be an indication of the basic soundness of the theory advanced here rather than as casting doubt on the validity of the relationship originally suggested by Hatch. It should be noted that the theoretical reasoning in the original paper (Hatch, 1961) visualized the K factor as representing the conductance of the layer of bloodless skin external to the capillary plexus and did not make any consideration of the acclimatization question, much as Kerslake's discussion of seven years before had similarly ignored this factor.

In Figure III-17 we have taken some raw data filed by Belding and Hertig with the Auxiliary Documentation Institute of the Library of Congress, and drawn eye-fit lines to roughly relate experiments at the beginning and towards the end of the period of study, which lasted some two months. The authors state that all four subjects "had previously been acclimatized for work in the heat," but do not say how or when. This analysis indicates that from start to finish there was a consistent reduction in the threshold of sweating, as indicated by the reduction in t_o, the skin temperature where $S = M$. As is emphasized in the composite plot of Figure III-18 there is very little difference in the final K values (slopes) between the two individuals who experienced 14 and 15 experiments each, although their initial slopes or K factors were quite different. This indicates the development of either fitness or acclimatization or both.

A further indication of individual differences is provided in Figure III-19 which presents the data of Ferres, Fox, et al., (1954) for so-called "naturally acclimatized" men, that is to say, soldiers who had been in Malaya for six months or more. An attempt was made to prevent the men from acquiring any further acclimatization in the course of the experiments, and since each pair of men experienced two environments, an approximation of their joint K factors can be estimated for those pairs whose test environments produced distinctly different levels of sweating. As can be seen from the figure, the sweat responses within this group varied over a very wide range, and they were therefore very different in their states of acclimatization according to our new criterion.

The question of sex differences in heat resistance is a perennial one, and has never been settled. Figure III-20

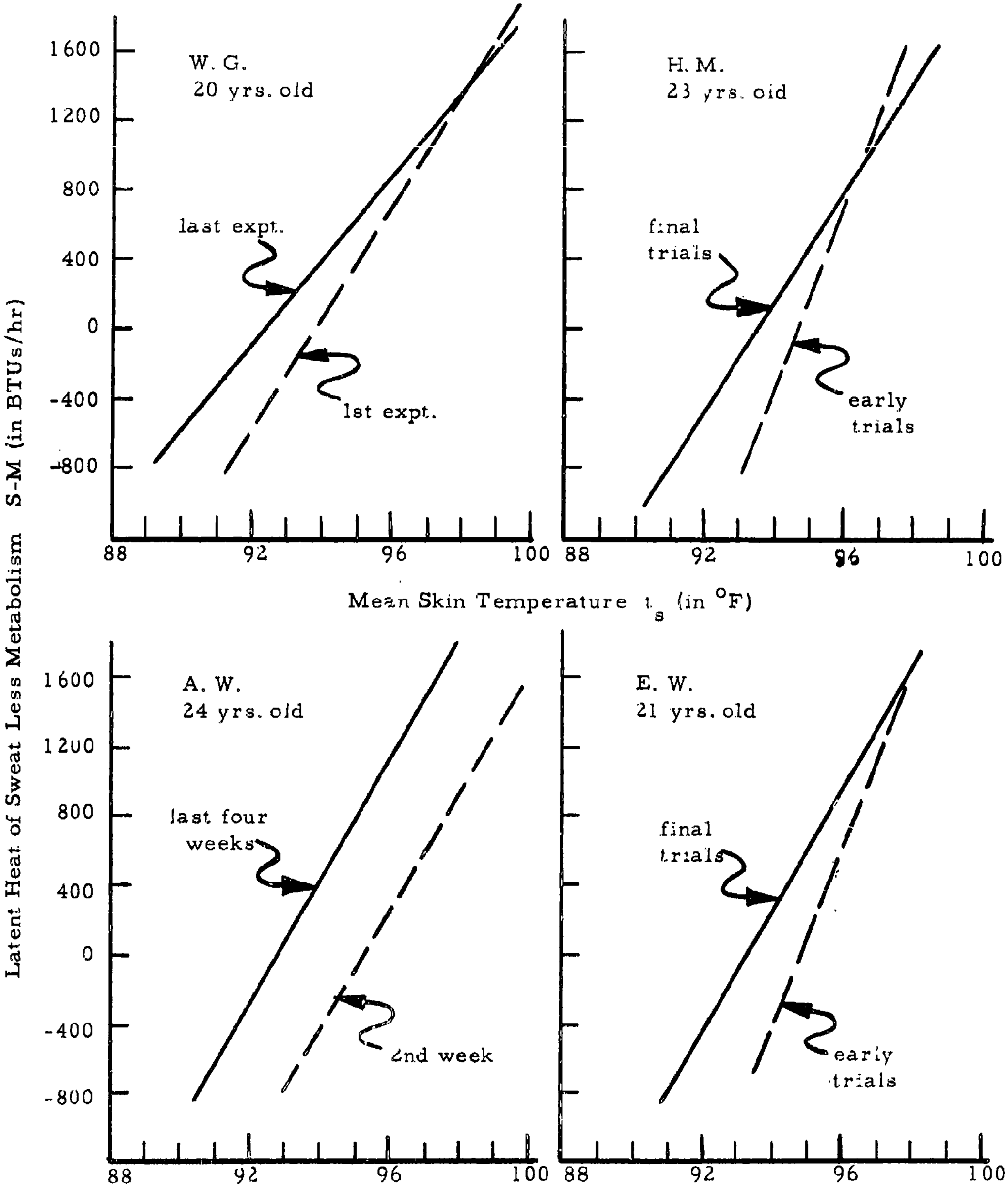


Figure III-17 Sweat response during work and rest for four individuals exposed occasionally over many weeks (data from Belding and Hertig 1962).

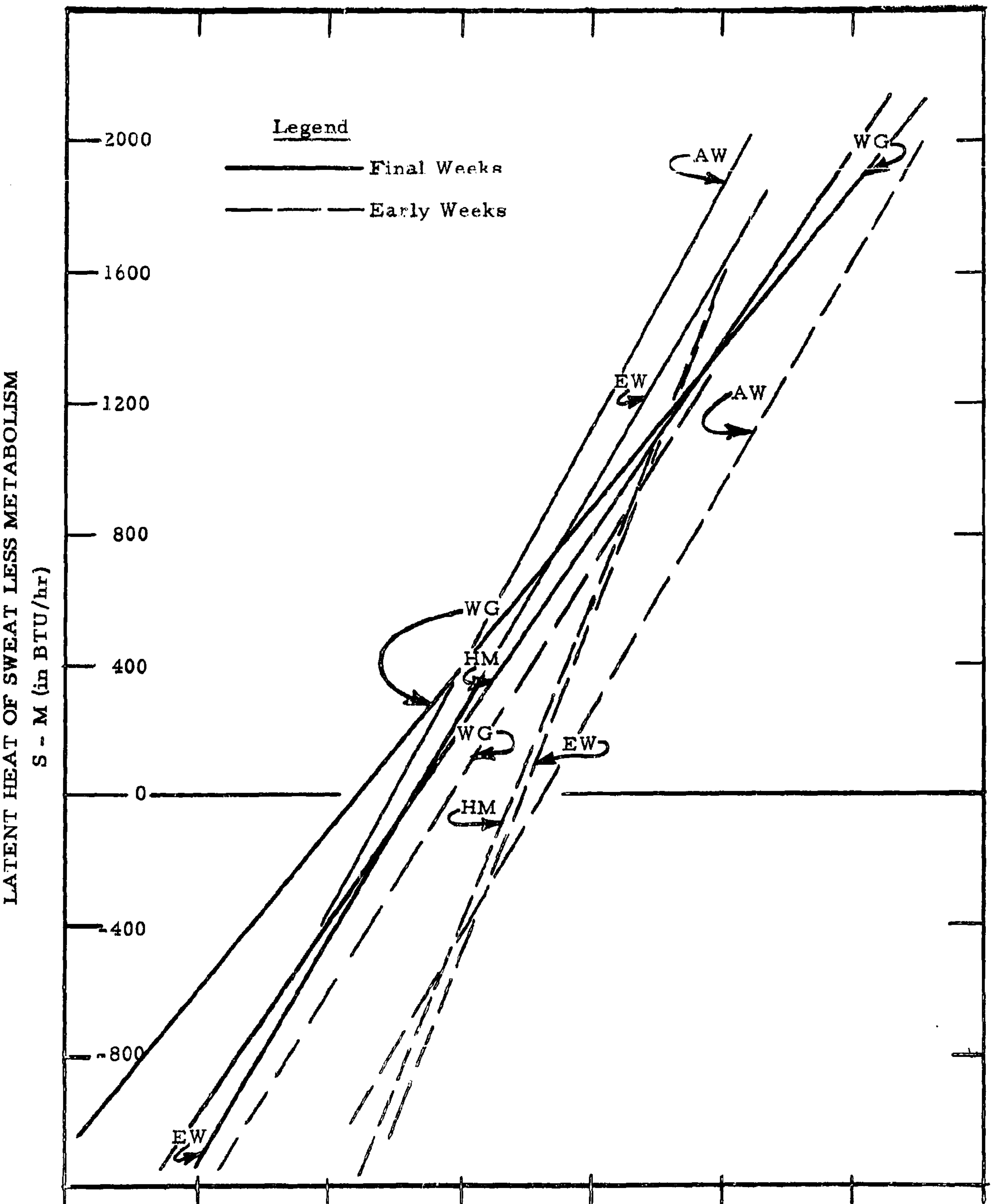


Figure III - 18. Composite of eye-fit lines of relationship at start and finish of the experimental series shown in Figure III-17

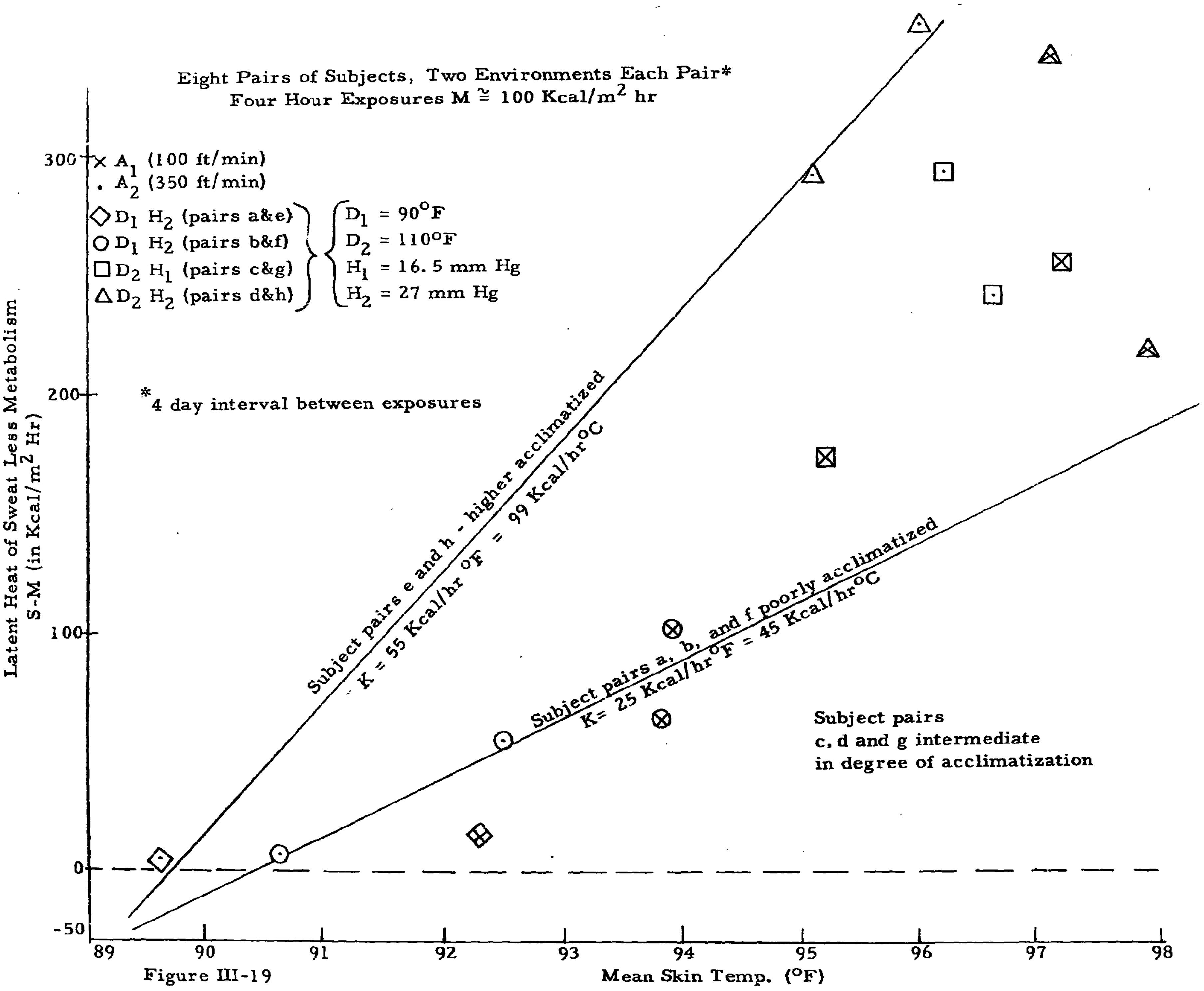


Figure III-19

presents data from two parallel studies of small groups of female volunteers (Hertig and Sargent, 1963) and, for direct comparison, a group of three males studied in one of the same laboratories under the same conditions. This was an investigation of acclimatization, aimed at answering the question of whether women can in fact be acclimatized in the same way men are. The answer was "yes", but the authors failed to note that the degree of improvement in the resistance to heat stress of the women was somewhat disappointing, and after the acclimatization they were far below a group of men before their acclimatization processing. The figure is semi-diagramatic, in that an assumption has been made that both groups of women had identical responses to the work regime in a cool environment, whereas in fact only the Pittsburgh women were so measured.

Using this same relatively safe assumption, and detailed data kindly supplied by Dr. Sargent at the request of the writer, Figure III-21 was constructed to show the development of acclimatization during the ten days of processing, in terms of the K factor for sweating. It will be noted that the change in K for each girl was very similar - essentially identical for three of them - although the initial values were quite variable. On the average, there was roughly a doubling of the K factor, as is illustrated in Figure III-22 which presents the mean data for the group. It is worth noting here that Hertig's group at Pittsburgh showed only half the increase in K factor in their ten days of effort that Sargent's Illinois women achieved. This may be explained, at least in part, by the following factors:

a) the Illinois treadmill speed was 0.8 kilometers per hour faster;

b) the air velocity was 280 feet per minute lower;

c) the Oxford index (0.85 wet bulb temp. plus 0.15 air temp.) was 5 degrees F higher;

d) the Effective Temperature was 3.5 degrees F higher;

e) the Illinois experiment was performed in summer, that at Pittsburgh during the winter.

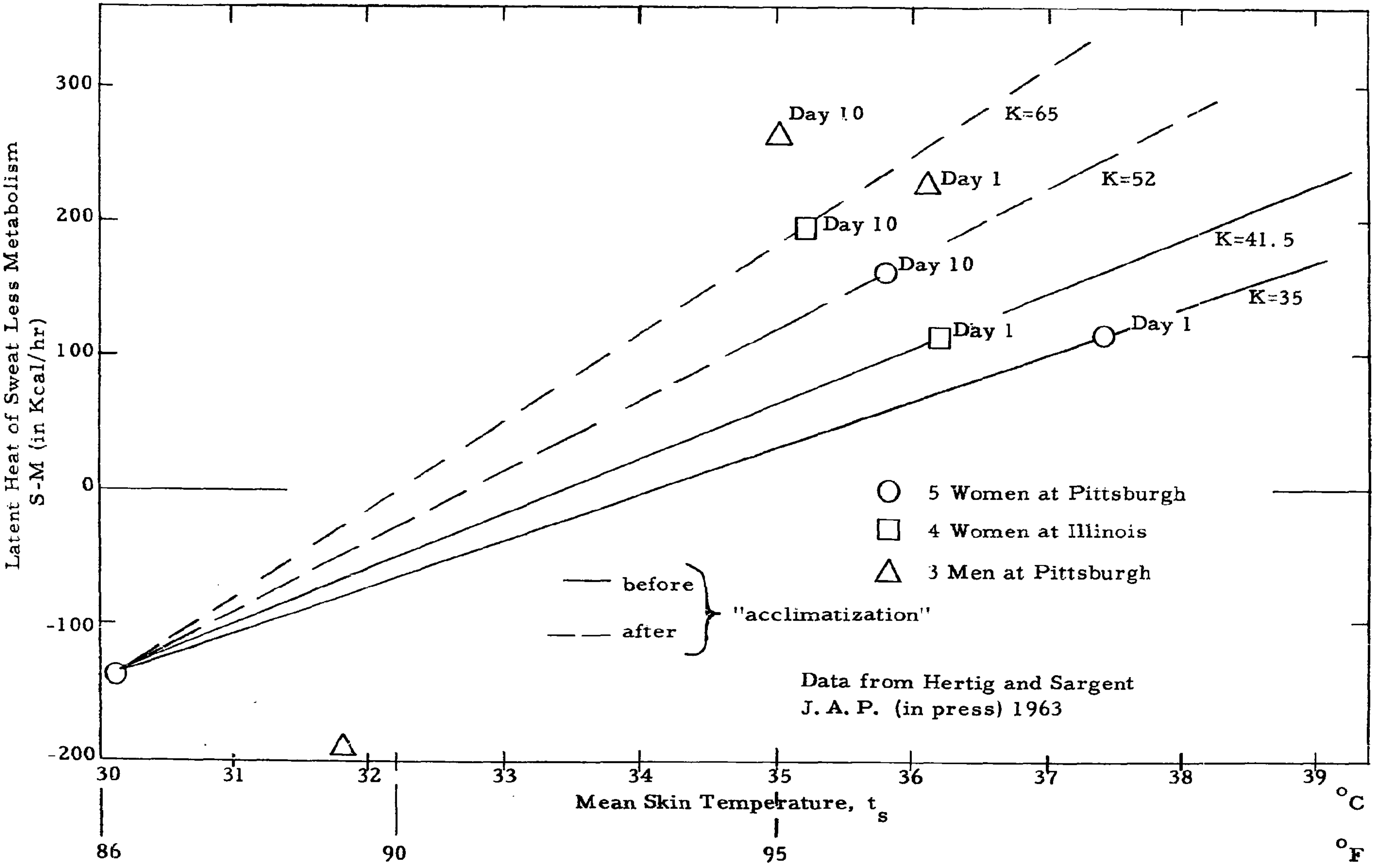


Figure III-20 Change in sweat response of two groups of women, compared with a group of men.

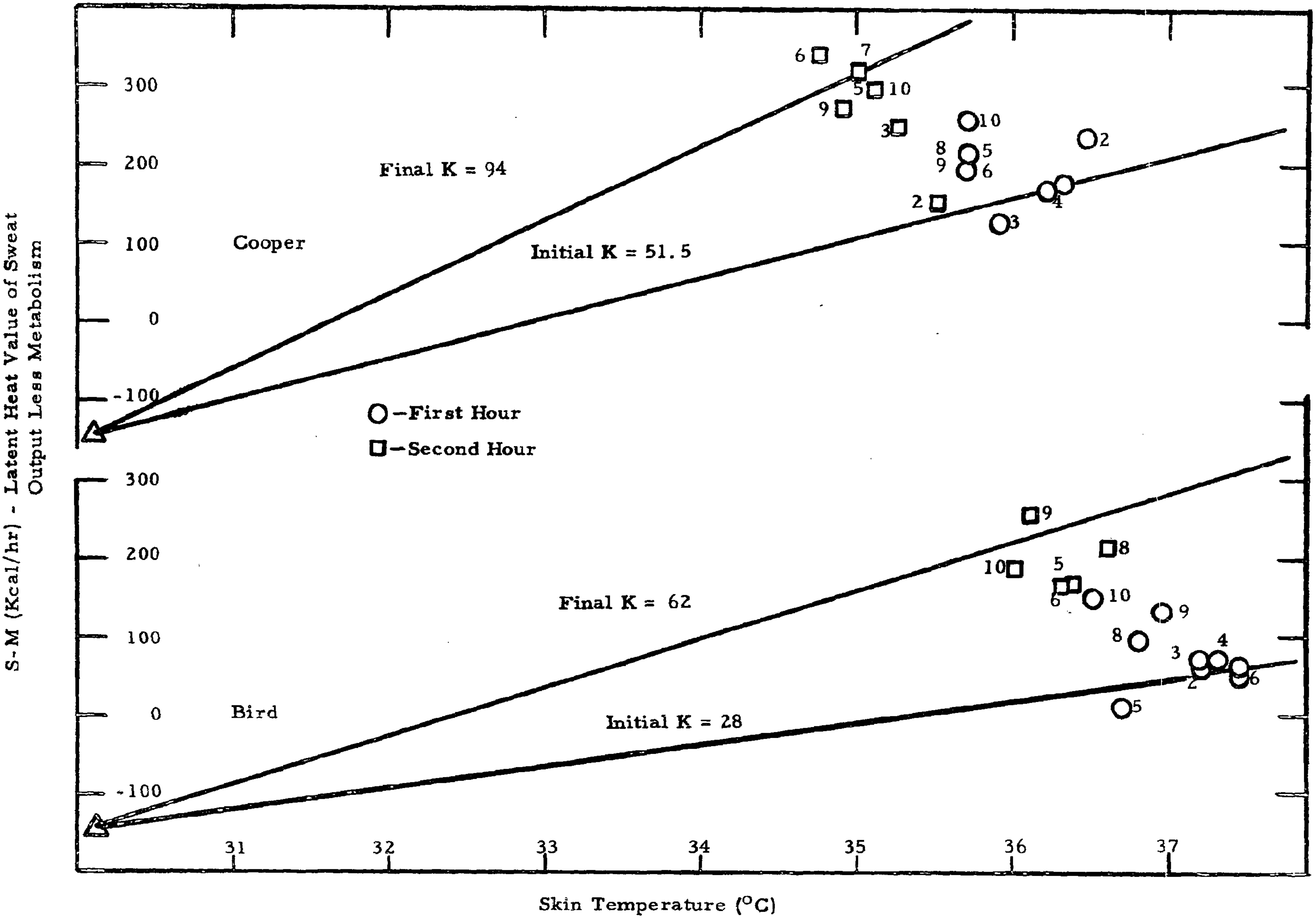


Figure III-21 Sweat Response During Acclimatization as a Function of Day Number - 4 Women

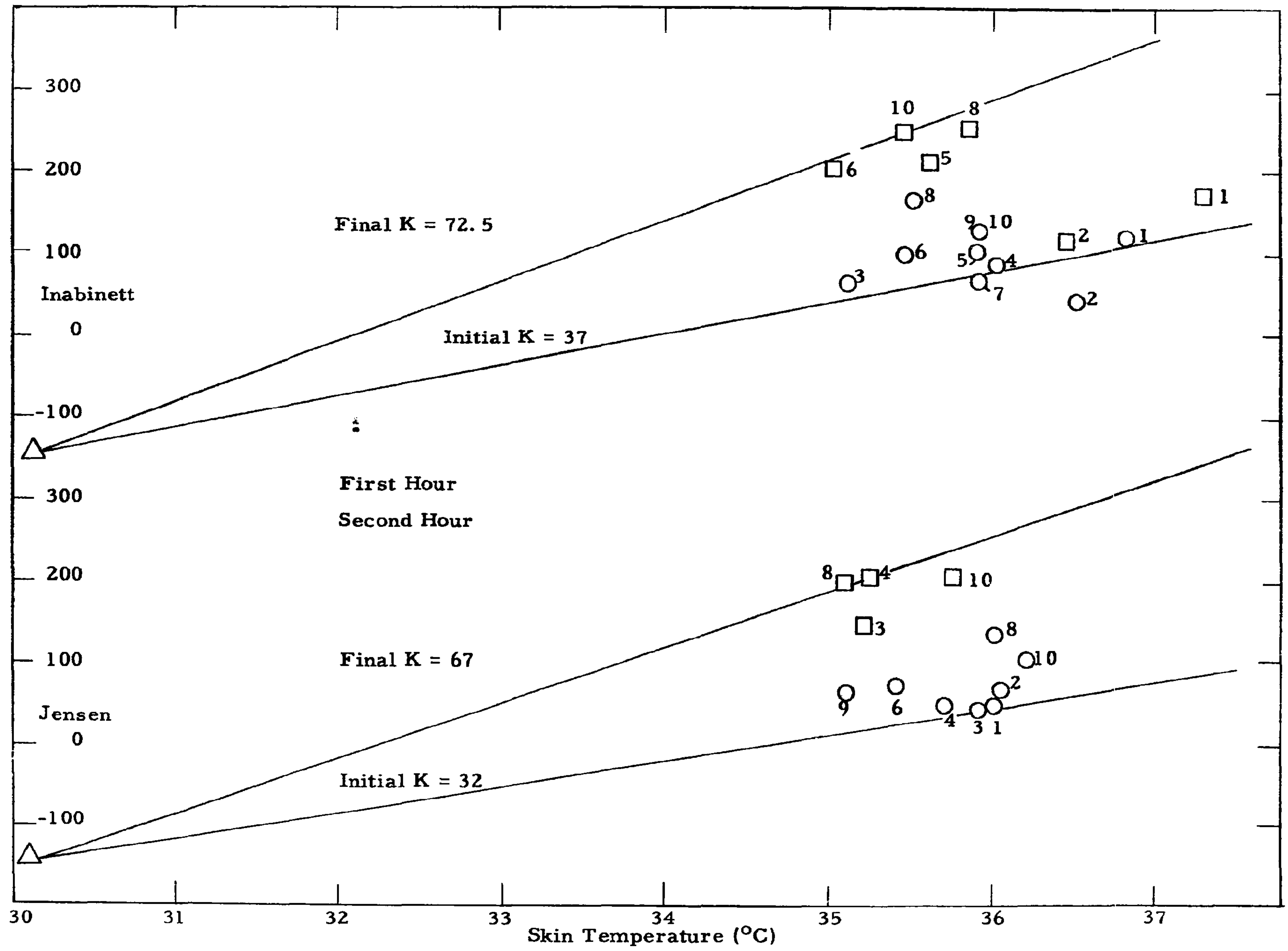


Figure III-21 (Con't) Sweat response during acclimatization as a function of day number - 4 women.

Changes in Sweat Response From Day to Day and From the First to the Second Hour During Acclimatization. (Average Data for Four Women)*

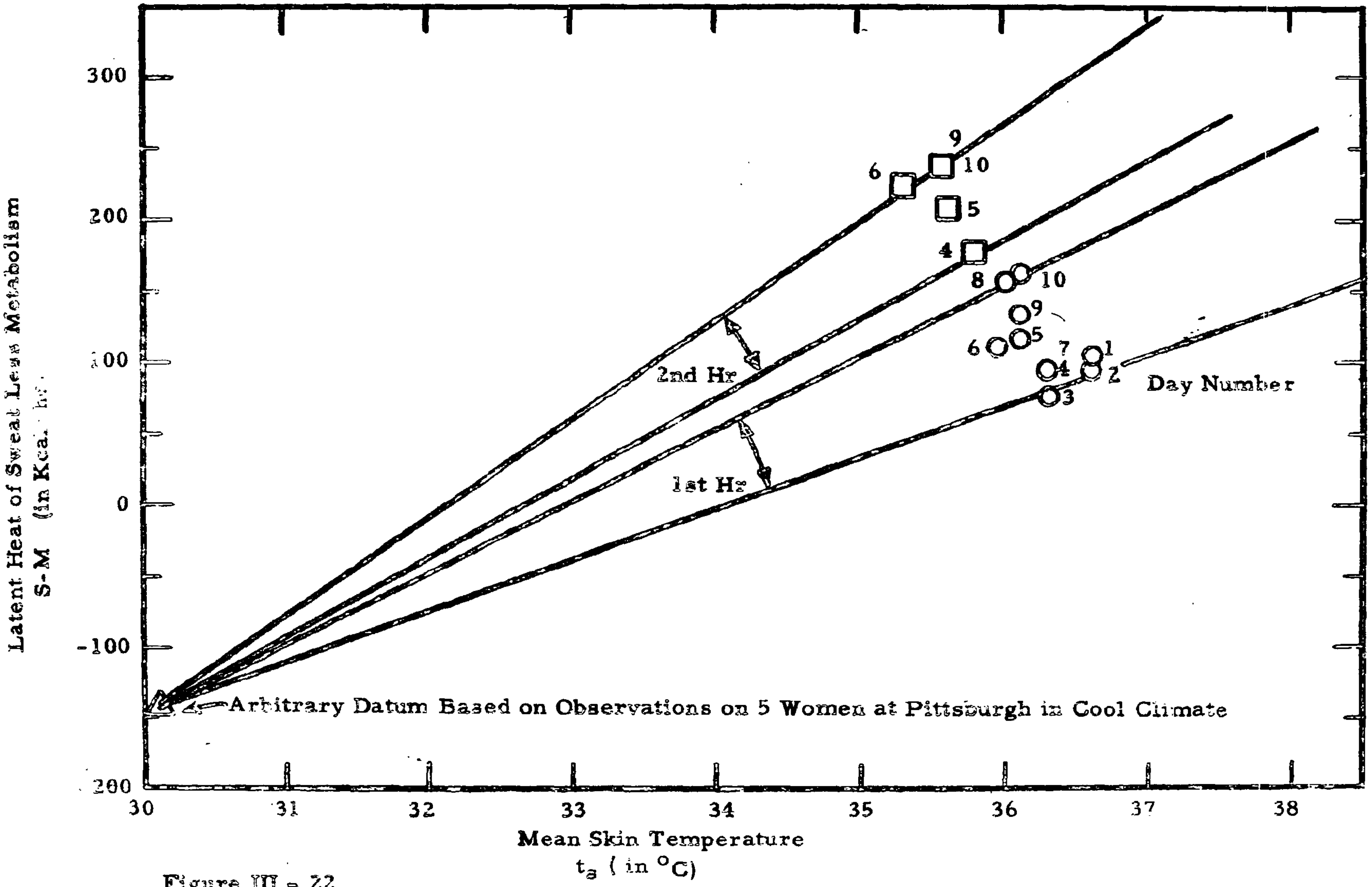


Figure III - 22

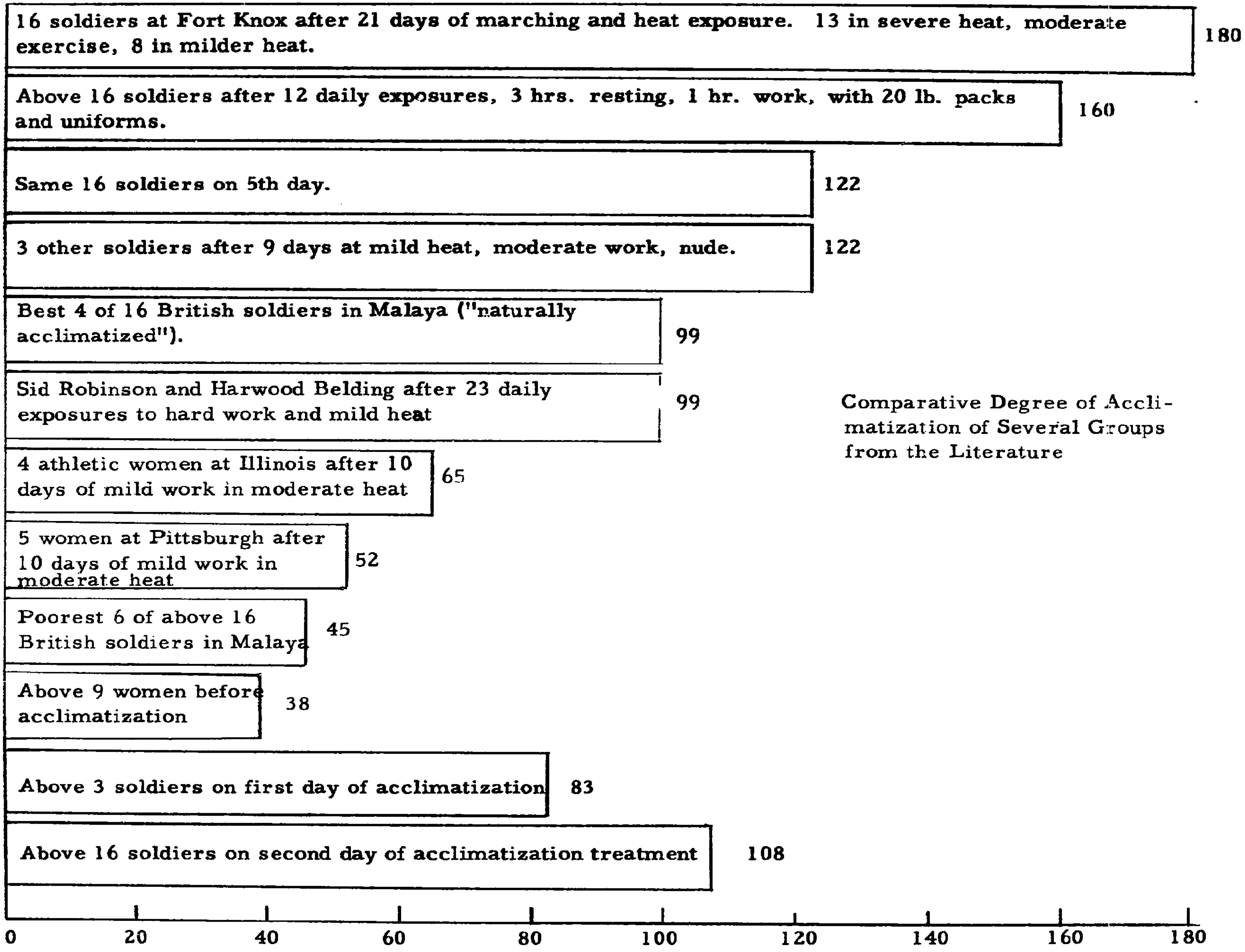
*Data Provided by F. Sargent II, Personal Communication.

(8) Summary of findings regarding individual differences in acclimatization

We have been able to uncover data on which to base estimates of sweat response K factor (which we propose as a measure of resistance to heat stress and "acclimatization" to heat) for six different groups of adults, at several different stages of acclimatization. Those data are assembled for easy inter-comparison in Figure III-23.

It must be pointed out that there is no reason to suppose that 180 Kcal/hr, °C is the highest value that has been observed in thermal tolerance research. As a matter of fact, the values quoted by Hatch for three wartime subjects at Fort Knox are considerably higher - up to 246 Kcal/hr, °C. Of more practical significance in the present context is the startlingly <u>low</u> value exhibited by the women - especially worrisome in that these were relatively active, athletic women. From the poorest individual reported in the literature we have covered, to the most heat resistant so far encountered, is a range of almost ten times in K factor. Accepting for the sake of argument the hypothesis advanced in this report, that the K factor does in fact reflect numerically the relative resistance to heat stress of an individual, it is not surprising that the prediction of the incidence of heat casualties in a large mixed population is so difficult a task.

In Figure III-24 we present some of the enormous collection of statistical data on heat casualties in the Marine Corps, gathered and reported by Yaglou and Minard (1957). It will be immediately apparent that there is no sensible answer to the question: at what environmental temperature will heat casualties reach a particular value? Notice the similarity in the shape of these curves to that of the Lind diagrams presented earlier (see Figures III-5 and III-6). For comparison, Figure III-25 is presented as a reminder of the characteristics of the "Lind diagram" which illustrates the Neutral Boundary Concept. In Figure III-25 we have taken data obtained on two individuals studied in Singapore, and thought to be at a more or less consistent level of acclimatization throughout the study. We have simply plotted the tabulated data for the rectal temperature at the end of their period of four hours rest in the heat against the effective temperature to which they were exposed. It must be borne in mind that other individuals of other physical and anthropological characteristics would yield



Comparative Degree of Acclimatization of Several Groups from the Literature

Figure III-23 "K" Factor, Measure of Acclimatization (Kcal/hr, °C)

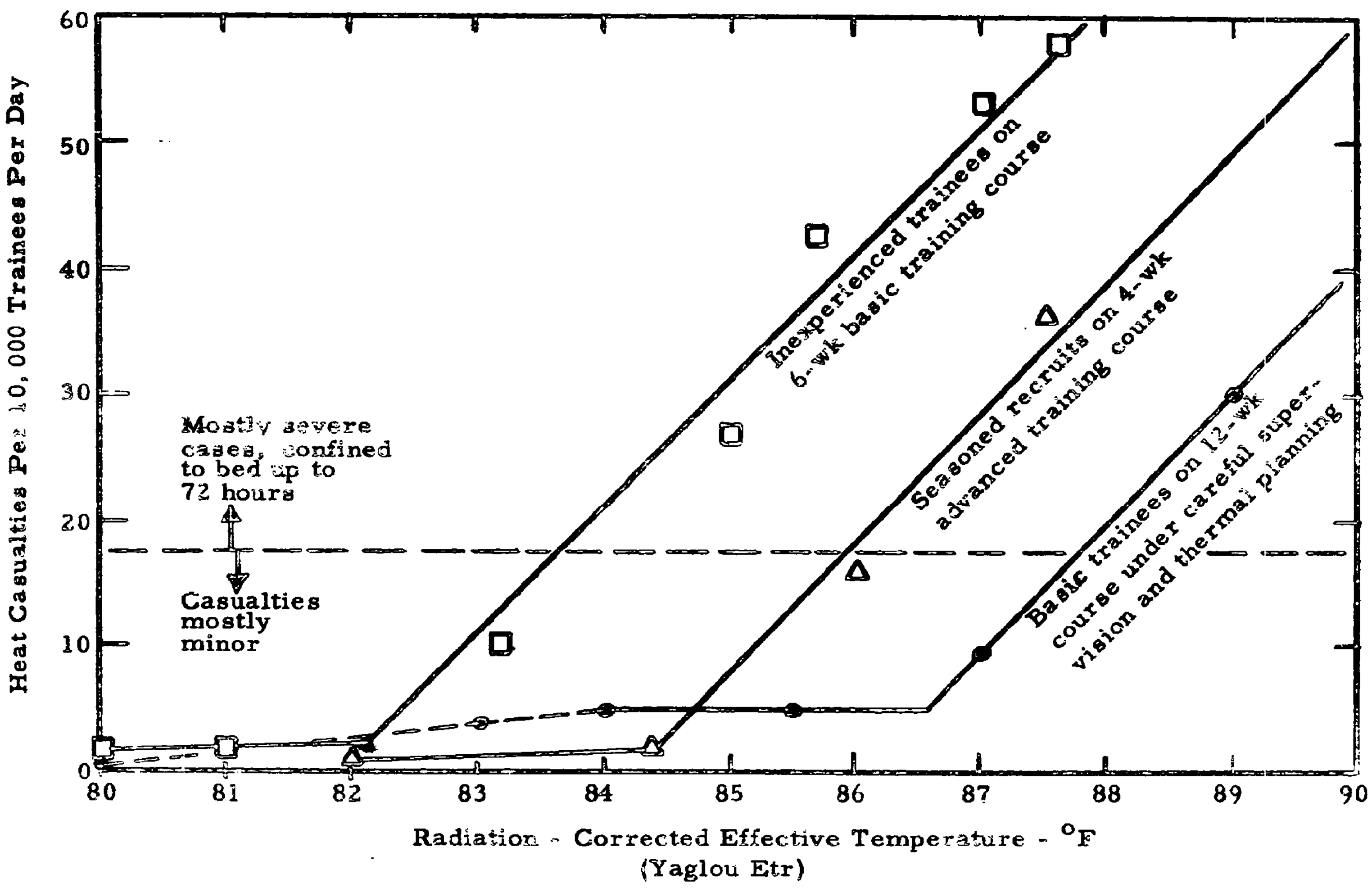


Figure III - 24 Heat casualty rates as a function of climate and acclimatization. Data from Yaglou and Minard (1957)

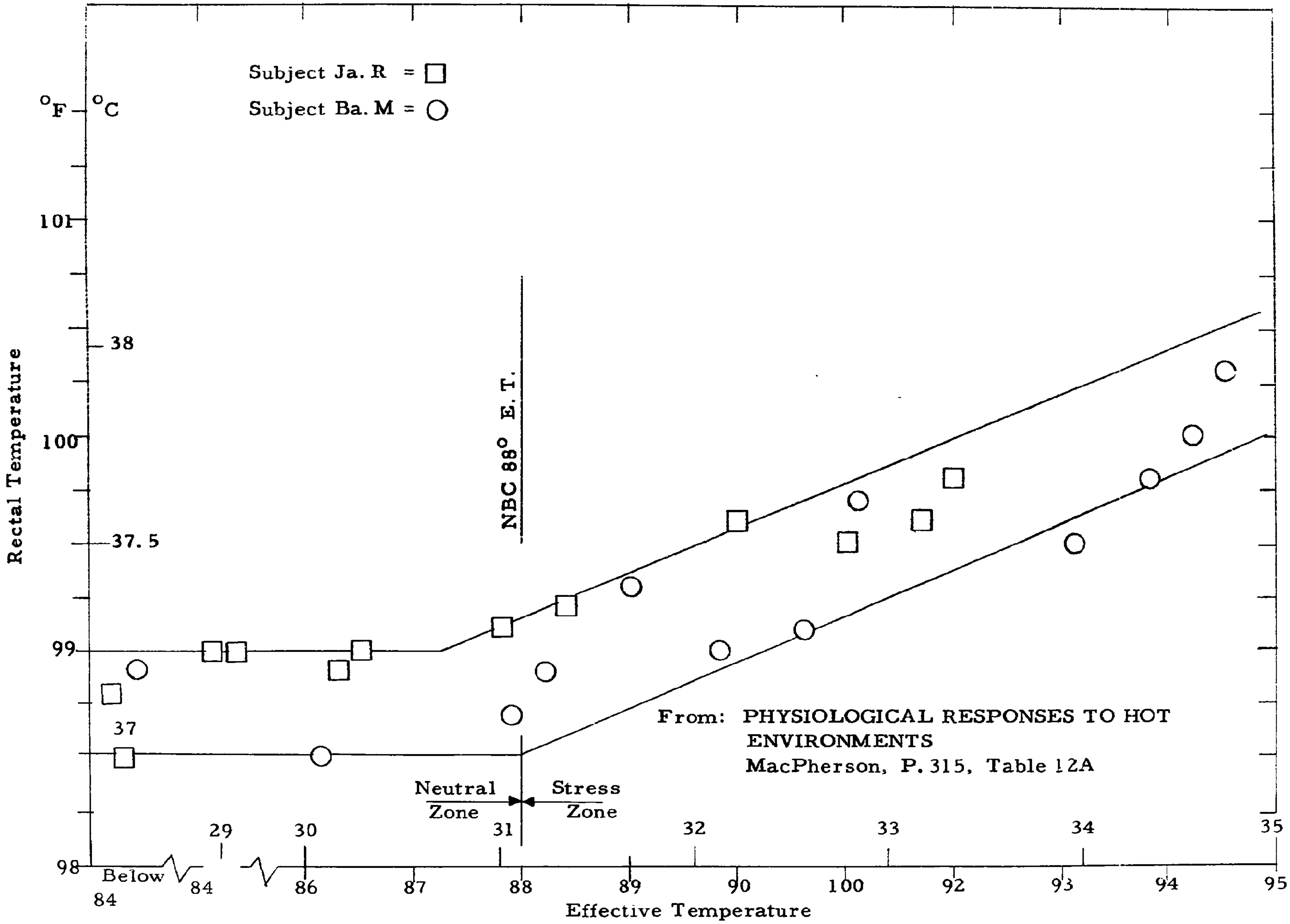


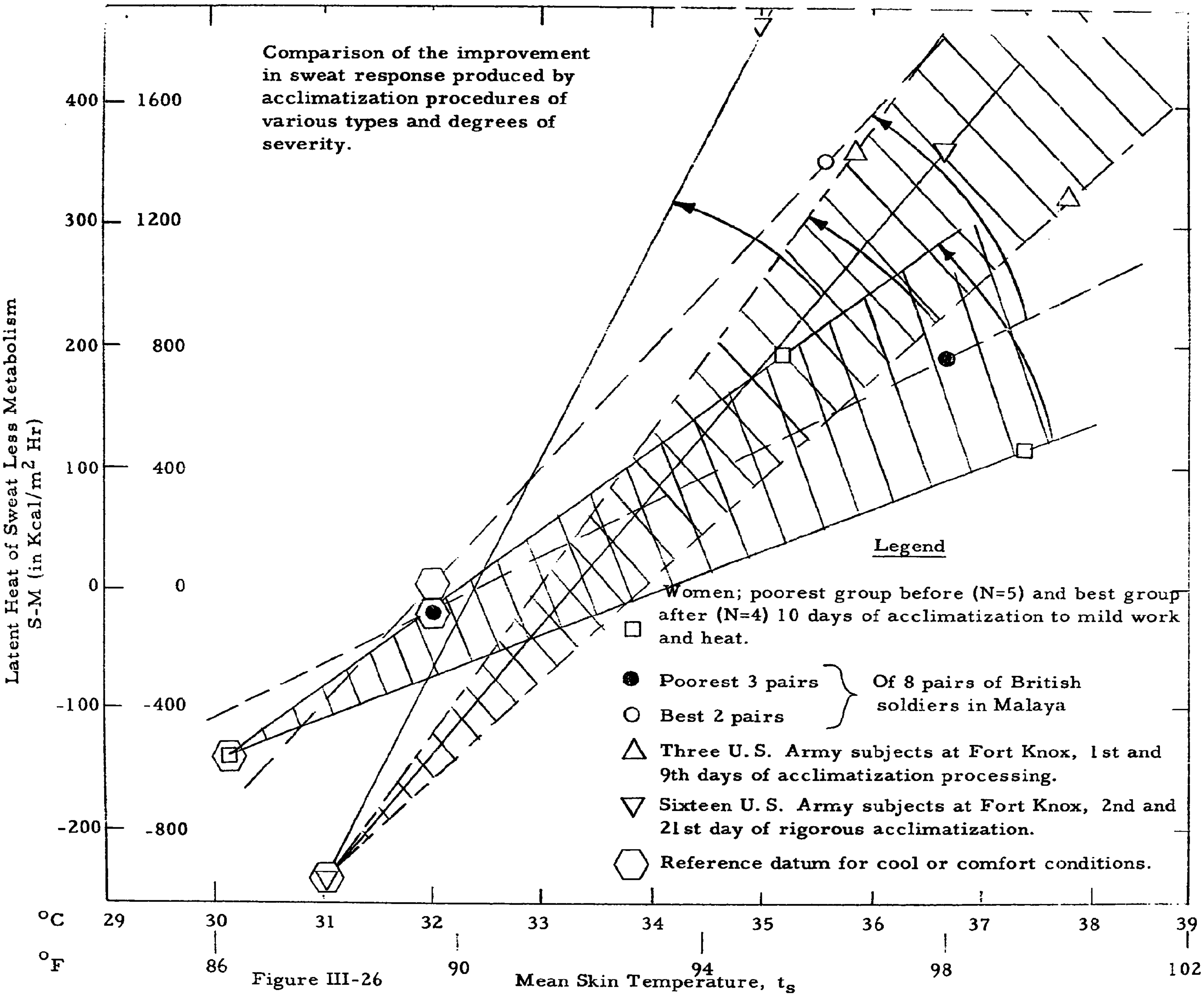
Figure III-25 Data of Dunham, et al. The effects of different airspeeds at dry-bulb temperatures 90°, 100° & 120°F and wet-bulb temperatures 83° and 88°F on men sitting throughout the four-hour experiments and wearing overalls.

data differing from those shown in the figure, both in the absolute level of the horizontal portion of the curve and in location of the discontinuity, or NBC. Only in the context of a large statistical sample of a population which is homogeneous in acclimatization can one generalize from a graph of this type.

Referring back again to Figure III-24, the differences between the three curves presented are primarily due to differences in the acclimatization status of the quite different populations concerned. Those differences emanate from the way in which the work activities of the individuals were scheduled as a function of the climatic temperature at the particular camps concerned. It is of interest to note that the method of analysis used by the authors of the original source of those data did not include that which lies behind Figure III-24; the very clear information which is derivable from Figure III-24 was completely obscured by the more conventional way in which the data were organized originally. Since our concern in this report is not with Marine trainees on the parade ground, we will defer any further discussion of Figure III-24.

In Figure III-26 we have selected certain of the data presented previously and displayed them in a manner designed to emphasize the alteration in the parameter K, which we have identified as synonymous with the "state of heat resistance," or "state of heat acclimatization." It is immediately apparent that one individual or group may be far more heat-resistant before acclimatization than another individual or group after they have been "acclimatized." The problem, of course, is the difficulty of defining what <u>degree</u> of acclimatization has been achieved.

By measuring the factor K on any individual, or any group, their relative position in the total heirarchy of heat stress resistance can be expressed numerically. The effectiveness of various routines of processing, by exposure to heat, with or without work, can be expressed by plotting the change in K factor achieved by the routine against some combination parameter which expresses the relative severity of the stress imposed during the process. In Figure III-27 various of the blocks of data presented in this report have been related in that way, using the very simplest conceivable index of acclimatization treatment severity - the product of the number of exposure days, elevation of metabolic rate above the resting level, and elevation of



Comparison of the improvement in sweat response produced by acclimatization procedures of various types and degrees of severity.

Figure III-26

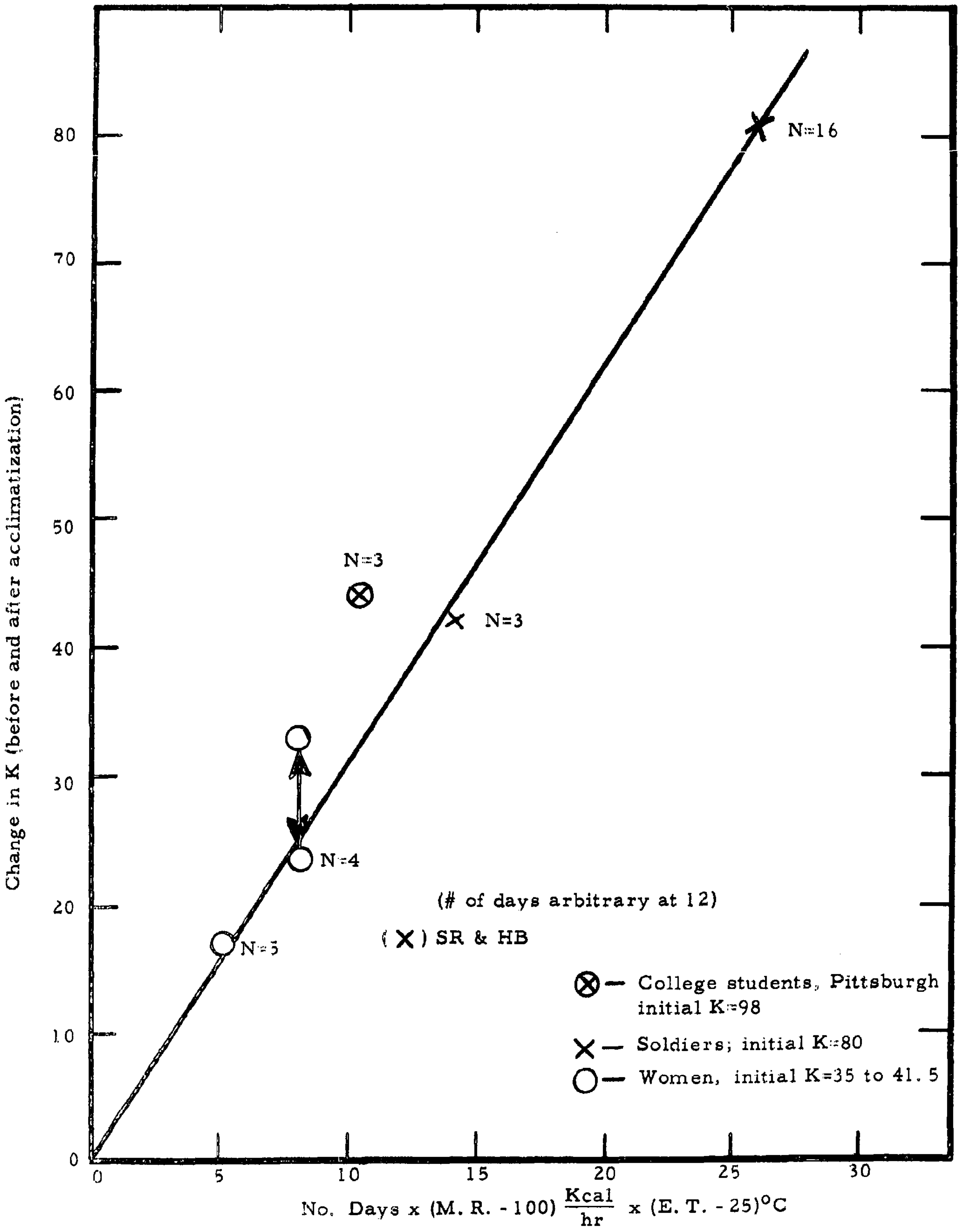


Figure II-27 Improvement in acclimatization (expressed as change in sweat response slope) as a function of treatment regime.

the effective temperature of the environment above a comfortably warm level for a resting man. It is somewhat astonishing to see the degree of linearity which this quite arbitrary relationship appears to possess. Considering that the groups of individuals involved in this analysis are extremely diverse in their characteristics, that a great variety of philosophies lay behind the designing of the various treatments, and that there was a factor of four separating the least group-average improvement and the greatest such improvement which we happened to come upon in our relatively restricted and accelerated review of the literature, the natural conclusion from an examination of Figure III-27 is an extremely powerful one. This is that there appears to be no upper limit in sight to the amount of improvement in resistance to heat stress which is achievable, providing we are able to conceive and define the ultimate, optimum "acclimatization" procedure.

In general terms, one can readily state that the optimum procedure is one which produces the desired state of acclimatization or resistance to heat stress in a minimum length of time, with a minimum of discomfort to the individual, and with the minimum risk of heat collapse in any individual. One of the more significant consequences of the present analysis will be the designing of an experimental investigation to determine optimal procedures for various classes of acclimatization requirement, including that of the overloaded shelter case; in the same investigation, the feasibility of using the K factor as the criterion for monitoring and controlling the rate of progress of a particular individual through the acclimatization process, will be established.

(9) Indices of environmental warmth

In the words of R. K. MacPherson (MacPherson, 1962):

"... The assessment of the thermal environment is not primarily a matter of the selection of some thermal index in which to express the results. Expressing the results in the form of an index may be a convenience, but the assessment of the environment is essentially the measurement of all the factors concerned, whether they are attributes of the environment, such as air temperature and humidity, or attributes of those exposed, such as their clothing, rate of working, and length of exposure. Remedial measures cannot be undertaken unless all these measurements have been made and the situation analyzed in the light of the findings. A suitable index may then be of help in determining the effect of the proposed remedial measures.

"Indices of thermal stress do not provide a substitute for a sound knowledge of the mechanisms of heat exchange and the physiological adjustments to a thermal environment."

In this most thorough review by MacPherson, no less than 19 indices for assessment of the thermal environment have been listed and described. They fall into three main classes: those based on the measurement of the physical factors in the environment, those based on a measurement of the physiological strain produced by the environment, and those based on the calculation of the heat exchange between the body and its environment. Obviously, it is important that the right selection be made when choosing an index for the purpose of co-relating environmental factors in a particular type of situation.

The oldest and in some ways perhaps the most respectable of the heat stress indices is the "Effective Temperature," which was developed from the research work of McConnell, Houghten, and Yaglou in the 1920's, supported by the American Society of Heating and Ventilating Engineers. While this venerable device for the combining of air temperature, humidity, and air velocity into a single number was originally based on the sensations of comfort or discomfort experienced by people within the first few minutes of exposure to various combinations of these three factors, the originators later presented evidence to indicate that equal effective temperatures in general produced similar physiological results. Unfortunately, however, the computational nomograms which were constructed cover a much wider range of conditions than the original research had explored in any thorough manner. In recent years there has been a rising tide of criticism of the assumption that the physiological effects of two combinations of environmental factors would be equal providing the Effective Temperatures for those environments were equal, and before his recent death, Yaglou himself had found that lines of equal skin temperature had a very different slope on the psychrometric chart from the lines of equal Effective Temperature.

The classical Effective Temperature scales are shown in nomograph form in Figures III-28 and III-29. Actually, although the concept is classical, these particular charts are somewhat more modern, originating as they do from the set of charts for the prediction of environmental warmth prepared for the Royal Navy by the late Tom Bedford. Bedford proposed the term "Corrected Effective Temperature" for an index in which the globe temperature was substituted for the dry bulb temperature as a means for adding the effect of the radiant temperature to those of the other three parameters normally combined in the Effective Temperature number. Bedford's concept assumed the use of a blackened globe, whose emissivity for the long wave radiation associated with moderate temperatures would be close to one; however, there is no theoretical barrier to the use of a globe with any other surface emissivity characteristics to produce a globe temperature, therefore providing a "Corrected Effective Temperature" appropriate to some specific situation.

For example, Yaglou and Minard (1957), in their "ETR" used a globe temperature obtained by covering the six-inch copper sphere with the fabric from which the uniforms of their test subjects were made. The rationale for this modification of Bedford's black globe is simply that Yaglou was dealing with an outdoor environment where the effect of solar radiation is crucial, and the <u>color</u> of the outer garments may be highly important, even though the long wave infra-red emissivity does not vary significantly from one fabric to another. In any indoor situation such as the one we are dealing with in the shelter problem, the normal blackened globe is perfectly adequate for determining globe temperature and "Corrected Effective Temperature."

Just as the Effective Temperature scale is probably the best index for convenient comparison of environments bordering on the zone of comfort, a quite different index, devised in the 1940's and exhaustively examined and evaluated in the 50's, is probably the most reliable means of comparing severe environments in which high humidities, and temperatures up to 110°F or so, cause people to sweat at substantial rates of between 0.1 and 6 kilograms per four hours. This is the P4SR (which stands for Predicted 4-Hour Sweat Rate) of McArdle, <u>et al.</u>, (1947).

Figure III-30 presents the nomogram by which the P4SR can be computed if one has a knowledge of the dry bulb and

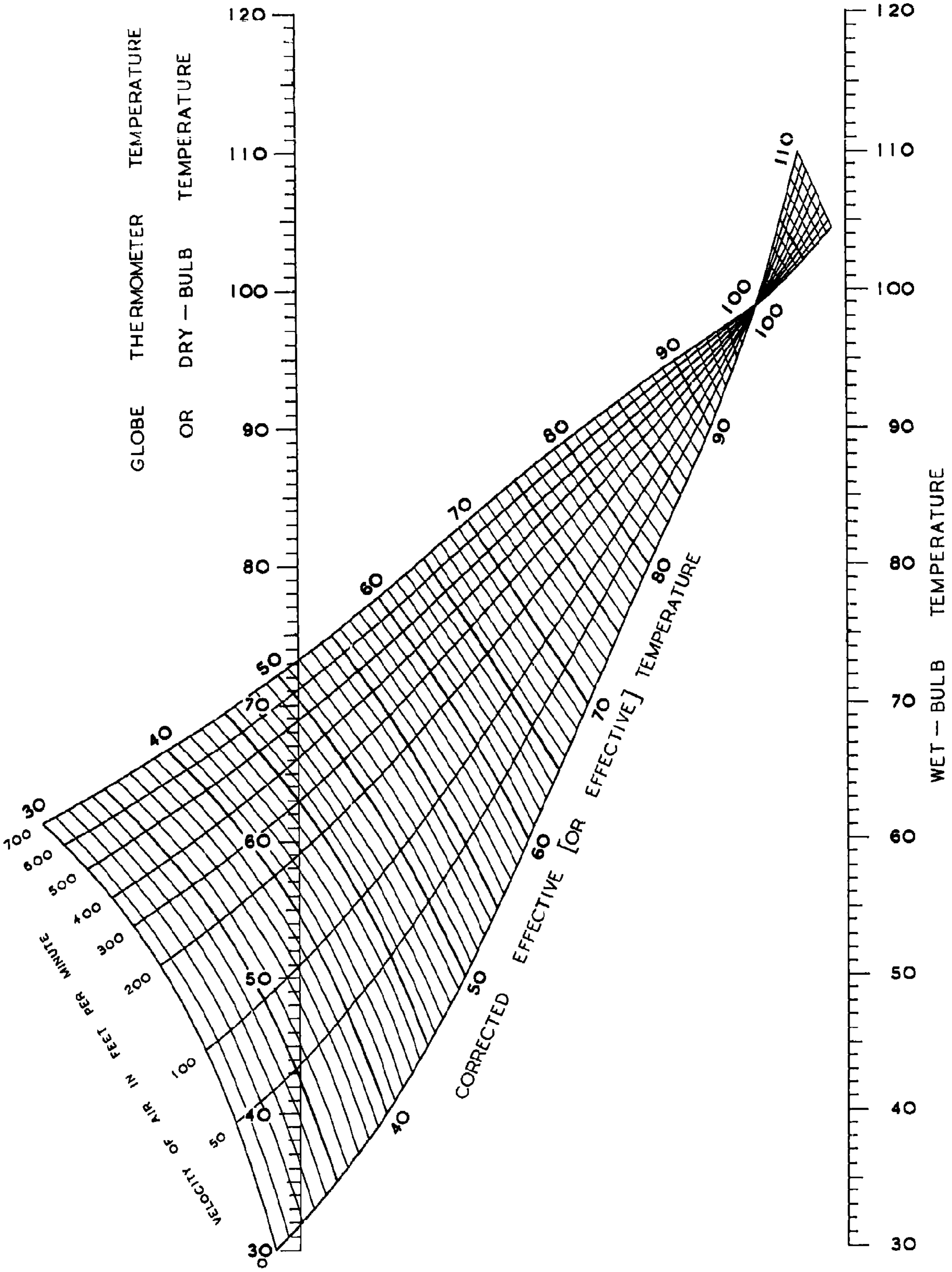


CHART SHOWING BASIC SCALE OF CORRECTED EFFECTIVE [OR EFFECTIVE] TEMPERATURE

NAKED TO WAIST

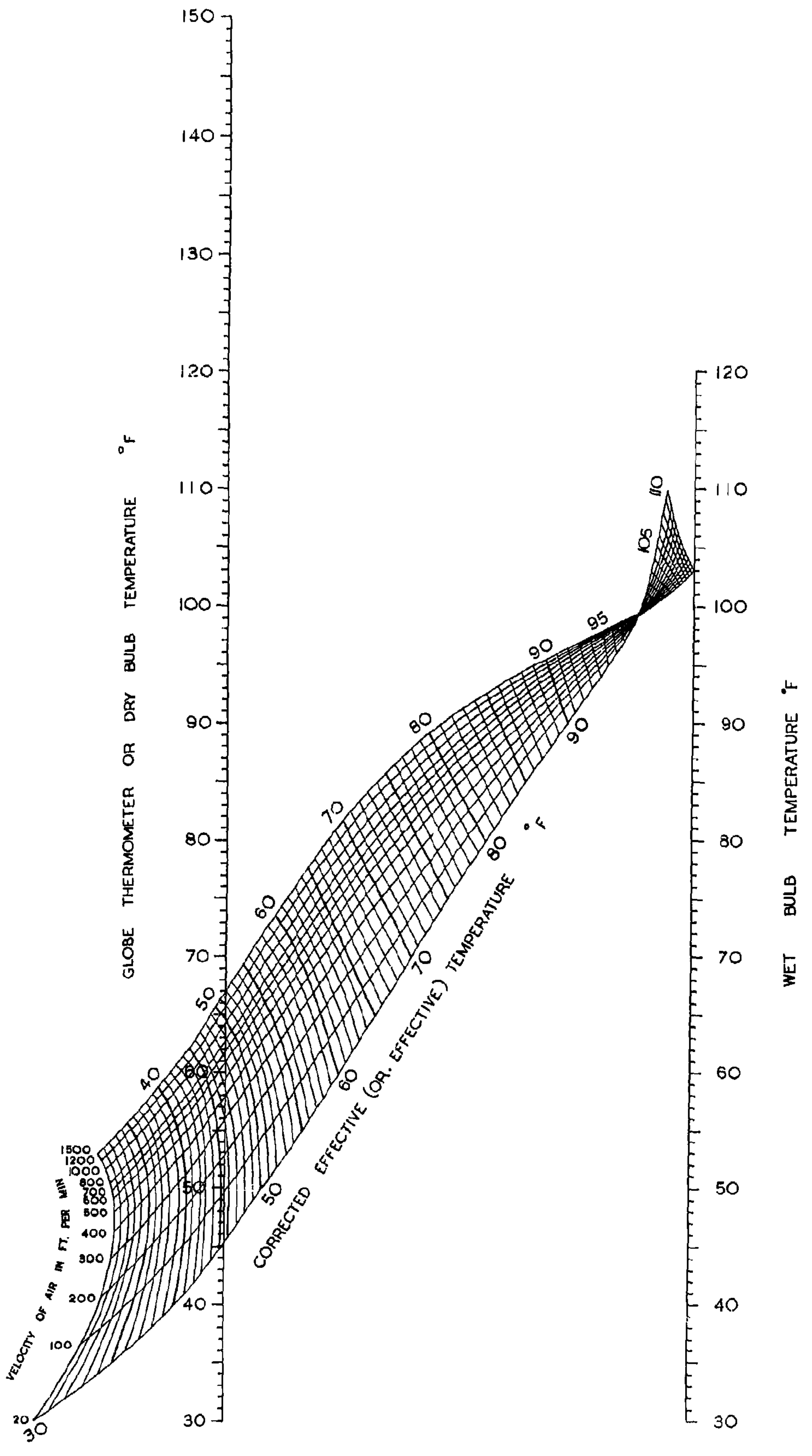


CHART SHOWING NORMAL SCALE OF CORRECTED EFFECTIVE (OR EFFECTIVE) TEMPERATURE

LIGHT INDOOR CLOTHING

wet bulb temperatures, the air movement, the metabolic rate, and the kind of clothing worn. The nomogram itself does not handle completely the full range of all these parameters; for persons sitting at rest wearing shorts only, the quantity yielded by the nomogram is the P4SR. For all other conditions the end result of computation with the nomogram is referred to as the "Basic 4-Hour Sweat Rate," or B4SR. In such a case an increment to be added to the actual or measured wet bulb must be determined by use of the inset graph in order to get the B4SR for a working man; then a further increment to be added to the B4SR must be computed by means of the following two formulae which pertain to men wearing shorts and coveralls respectively:

Shorts: $P4SR = B4SR + 0.014\ (M-54)$

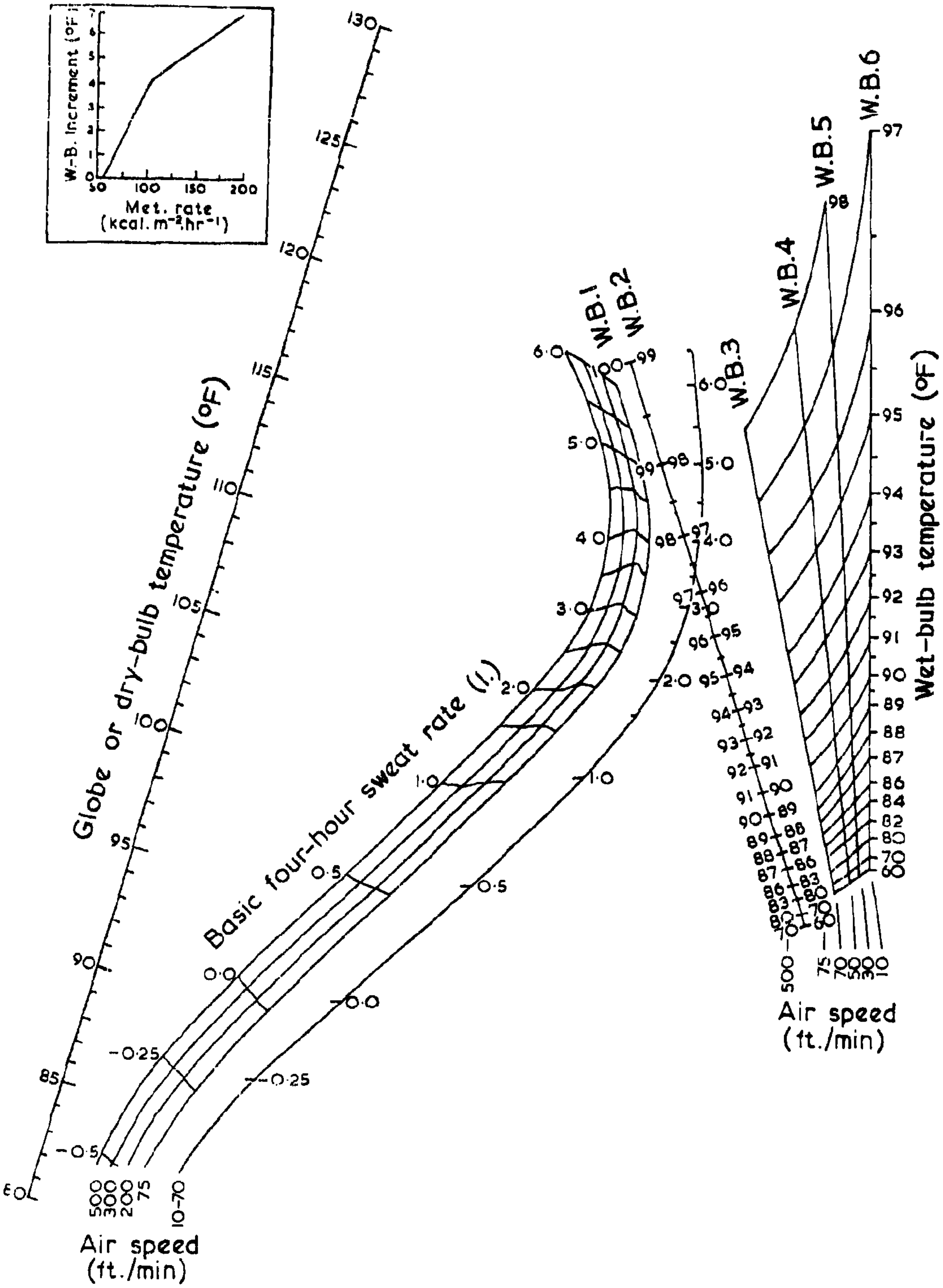
Coveralls: $P4SR = B4SR + 0.25 + 0.02\ (M-54)$

where M = metabolic rate in $Kcal/m^2$ hr.

(If heavier clothing is worn an appropriate further factor must be added.)

In Figures III-31 and III-32 families of curves have been presented to assist the reader in visualizing the direction and magnitude of the effects of work and air velocity under maximal humidity conditions such as we may expect to obtain in the shelter environment. Remembering that the P4SR index system is based on the most painstaking and intensive study of "acclimatized" naval ratings and soldiers, and was checked and re-checked on similar personnel living and working in the tropical regions of Singapore and Malaya, one cannot fail to be impressed by the very strong effect of air movement on the one hand and of metabolism on the other to change the magnitude of the index, representing the severity of the stress, at equal temperature. In contrast to the picture presented by these charts, we have the anomaly, illustrated in Figure III-33 of no consistent change in the P4SR index for a shift of Effective Temperature from about 84 to about 90°F.

The tentative conclusion drawn from this comparison of ET and P4SR is this: it will be necessary to explore much more intensively the specially limited range of conditions pertinent to our concern for the upper allowable limits of shelter overloading, before we will be able to establish with any degree of certainty the relative reliability of these two types of



Nomogram for the calculation of the P4SR. The inset chart gives the increment to be added to the wet-bulb temperature for metabolic rates between 50 and 200 kcal.m⁻².hr⁻¹.

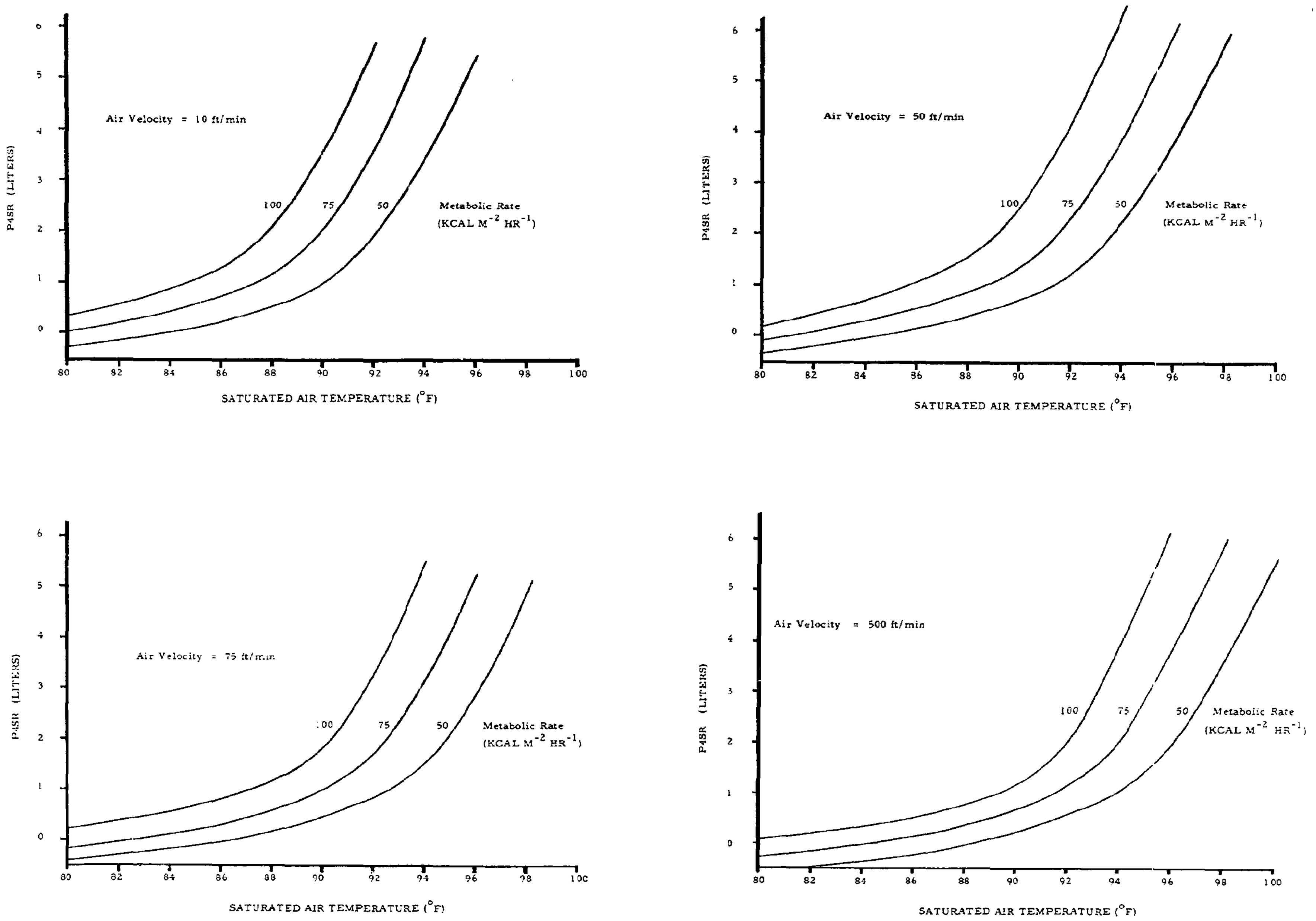


FIGURE III - 31. PREDICTED FOUR-HOUR SWEAT RATE

FIT, ACCLIMATIZED YOUNG MEN WORKING IN SHORTS

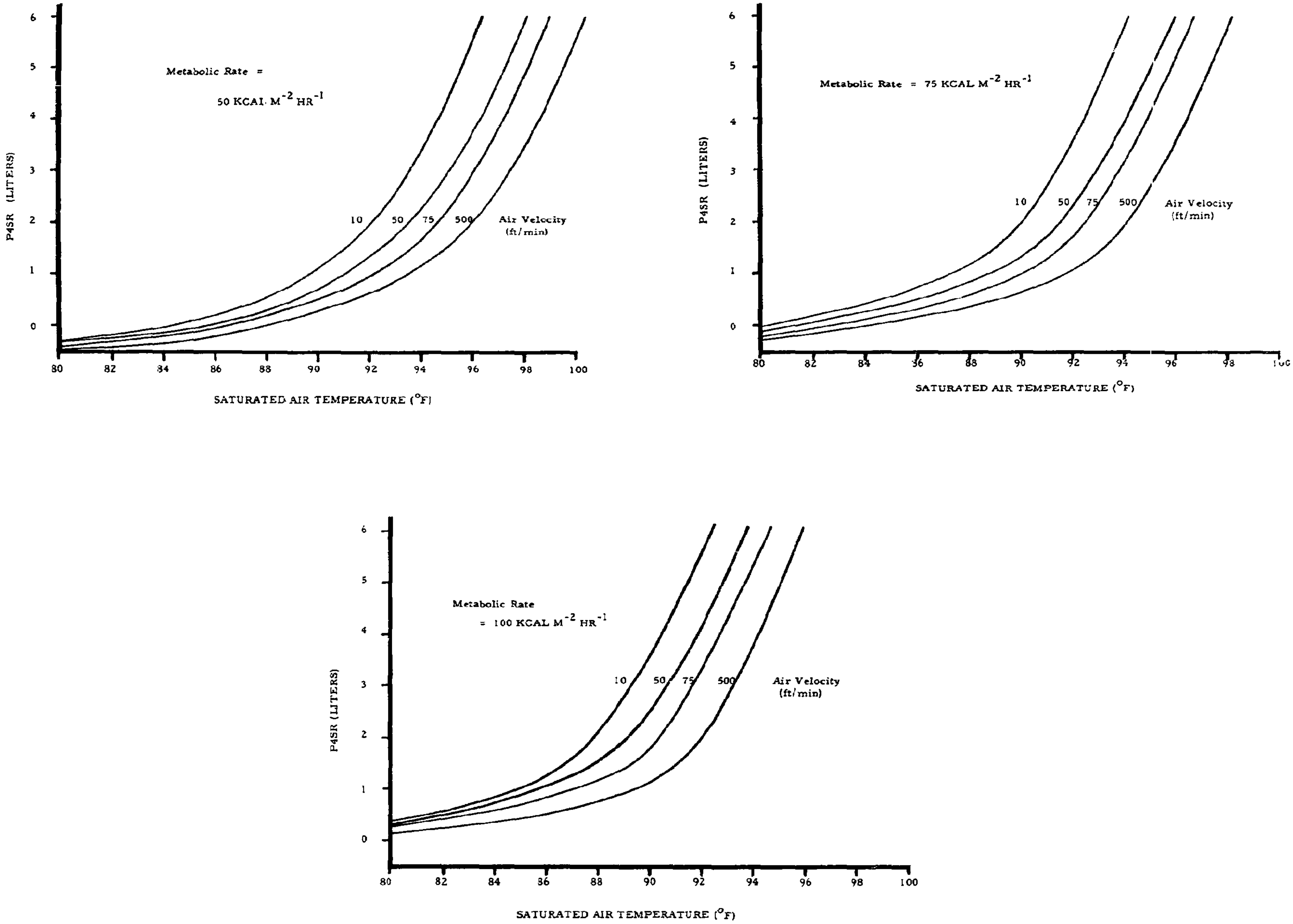


FIGURE III - 32. <u>PREDICTED FOUR-HOUR SWEAT RATE</u>

FIT, ACCLIMATIZED YOUNG MEN WORKING IN SHORTS

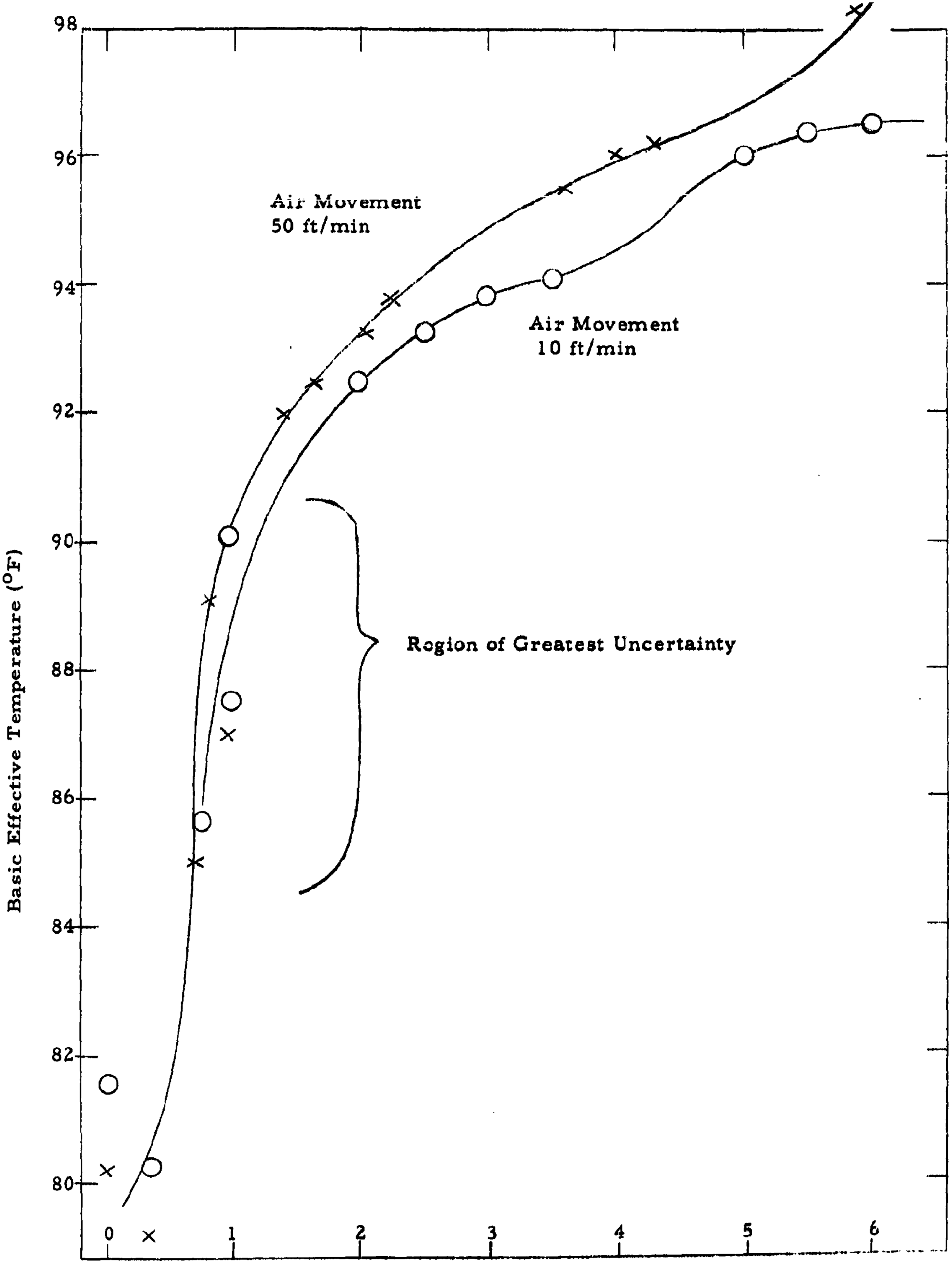


Figure III-33 P_4SR of Resting Men, in Shorts (Globe temperature equal to air temperature) index. A more immediate consequence of this comparison is the illustration of the fact that, while 4.5 may be the P4SR index value which marks the threshold between generally acceptable conditions and those in which an increasing number of "acclimatized" naval ratings will have difficulty in completing a 4-hour period of exposure, an index value of P4SR = 1 will probably produce one or two casualties per hundred persons after a week or so of continuous, unrelieved exposure (Navy advance report on 1961 shelter tests).

At this point, it should be emphasized that the two indices, ET and P4SR, are quite different in concept, approach, and interpretation. First of all, the P4SR value which characterizes a particular combination of environmental variables, clothing and work level, is supposed to be equivalent to an equal P4SR value which may have been obtained for a different combination of environmental variables, activity levels and clothing. That is to say that a man subjected to a P4SR of 5 when working hard is theoretically no more likely to collapse within a 4-hour exposure period than a man exposed to the same P4SR while sitting quietly in shorts. This is in contrast to the situation relating to the use of Effective Temperature, which does not distinguish among different metabolic rates.

Parenthetically, in addition to its superior integrative capability, the P4SR index is useful as a rough index of water requirement - division by four provides an estimate of the hourly sweat output. If to that quantity is added a value for average hourly urine production and water content of feces or other avenues of water loss, the total water output is derived. To avoid dehydration, water intake (including water of oxidation) must equal water output. The following equation defines the terms which should be accounted for in determining water requirements:

$$\begin{aligned} H_2O_{req} = {} & \text{Sweat loss (P4SR)} + \text{Urine } H_2O \text{ loss} \\ & + \text{fecal } H_2O \text{ loss} + \text{other sources of } H_2O \text{ loss} \\ & - \text{gain from } H_2O \text{ of oxidation} \end{aligned}$$

In planning for hot environments, it is usually sufficiently accurate if water requirement is computed by determining the P4SR and adding a constant estimate for all the remaining terms.

In view of the foregoing discussion we may conclude that the P4SR constitutes the best available integrative thermal index for our purpose. Having said this, we must not lose sight of the fact that there is no substitute for the precise description of the heat transfer between the human body and its surroundings as a means of determining the physiological state which is called forth by the environment.

It might be well at this point to explain the reason why the newly-developed parameter, the Oxford Index, has been dropped from consideration in this discussion. The primary reason is the absence of an air velocity term in the equation for determining the Oxford Index, and the obviously crucial importance of this factor in the shelter context. A further factor in the decision was the realization that the agreement between Sid Robinson's upper limit for the maintenance of equilibrium at rest, and the asymptote of the predictive equation for tolerance time as a function of Oxford Index, is apparently fortuitous, in view of the fact that Robinson's subjects were highly acclimatized, while those involved in the various tolerance experiments were practically unacclimatized.

(10) A prediction matrix based on the sweat response K factor and the P4SR

The analysis reported in these pages has served to establish with little doubt that the present state of the available data relative to physiological response to heat, upper acceptable limits of stress, and duration of tolerable exposure, is not adequate for the task of constructing a meaningful, flexible prediction tool of reasonably significant reliability. On the other hand, it is felt that the analysis has opened the way to the methodical collection of experimental data on a highly efficient and effective basis insofar as its applicability to future prediction is concerned. The prospect of the advance which could very well be made in the science of predicting thermal stress and physiological strain, is a breathtaking one; the unifying theory that has been developed under this program may well permit the attainment of truly important forward steps in the next year to 18 months, both in terms of thermal physiology and in terms of shelter stress prediction.

For the immediate future, it appears feasible and desirable to marry two elements of the problem - represented by two tasks.

The first task is to establish firmly the relationship between the K factor and other characteristics of the shelter population. A preliminary start on this task can be made by means of an intensified search of the raw experimental data which lies in the files of experimental scientists around the world, in the specialized archives of the U. S. Government, and at the Auxiliary Documentation Institute activity of the Library of Congress. However, the biggest advance on this front will come from the measurement of the K factor on a carefully selected sample chosen to match the distribution of various characteristics in the population as a whole. One of the charms of the theory which has been developed is the utter simplicity of the field measurement which is required - skin temperature and weight loss. Skin temperature can be measured by radiometer without requiring contact with the skin of the subject; weight can be determined before and after a period of exposure to a controlled environment, utilizing a high precision balance, which can be made completely portable and rugged. A traveling mobile environment laboratory for gathering such data in numerous urban and rural centers throughout the country is one concept which should be considered for gathering information about the distribution of the K factor in the general population - information which is badly needed if we are to predict shelteree response to heat stress with reasonable reliability.

Concurrent with the collection of data on the existing K factor in the general population, there should be an intensive experimental investigation utilizing a small group of subjects whose K factor is deliberately kept at a constant value from one experiment to another, to determine the exact nature of the relationship between skin temperature and air and wall temperature on the one hand and humidity on the other - a critical "refinement" which had never, to our knowledge, been introduced into the otherwise similar experiments of the past. One important parameter which needs to be established more firmly than is possible now, is the point at which the skin becomes "totally" wet. If one visualizes a line of constant sweat rate plotted upon a psychrometric chart (with dry bulb temperature as the abscissa and vapor pressure as the major ordinate), we would expect the line to follow a constant dry bulb temperature until it approaches the condition of 100 percent wetted area, whereas coming the other way from its origin on the saturation line, the line of constant sweat rate would follow a fixed slope until it approached the same "drip point." The goal would be to determine experimentally a family of constant sweat rate lines, one set for each of several activity levels, air velocities, and K factor intervals.

Having obtained the foregoing data, it would then be desirable to relate them to the thermal tolerance data of the past (wherever possible) and more particularly to measures of physiological strain. Having determined the variation of K within the population, and having more accurately defined the quantitative aspects of the biophysical mechanisms as they relate to the K factor, it should then be quite feasible - and extremely useful - to construct a thermal tolerance prediction matrix for the general population (or for special groups within it) based on the sweat response K factor and the P4SR. Given a definable median, mean, and distribution of the K factor in the population at risk in a particular shelter, the proposed technique would make it possible to predict the range of skin temperature and sweat rate to be expected as a function of environmental load (or index of heat stress).

By reference to a series of psychrometric charts bearing parametric curves of equal skin temperature, the probable boundary condition separating the dripping sweat region from that where all the sweat is evaporated, can be estimated. If the predictive material is suitably arranged, it should be possible to prescribe the minimum rate of air movement which is required at any combination of wet bulb and dry bulb temperatures to prevent the wastage of sweat (i. e., dripping). This value for required air movement can then be compared with tabular or graphic material which indicates the energy cost to achieve such an air velocity, whether by manpower or in more conventional ways.

(11) An index of physiological strain, and prospects for its experimental determination

A theoretical rationale has been advanced by Hatch to justify the selection, as a measure or index of physiological strain due to thermal stress, the ratio:

skin blood flow/total cardiac output.

At the time Hatch made this suggestion, neither element in the ratio was amenable to direct measurement, and he offered the suggestion only for the value which it had in clarifying thoughts about the problem of quantifying thermal strain. With the rapid advance in the state-of-the-art of bio-instrumentation which has occurred in the past year or two, it can be anticipated that within six months of the date of writing this report it will be possible to estimate, if not to measure directly, cardiac output, and a means of quantifying the skin blood flow parameter should have been worked out. Research is currently under way to determine the feasibility of measuring cardiac output by an indicator dilution method without penetrating the skin in any manner.* The technique, the potential of which is being explored experimentally as well as analytically, is that of using heat as the indicator (in the same manner as dye or radioactive material might be used if one were willing to puncture the skin and vessels), with this heat being added in an extremity and detected in an artery on the other side of the body. The conclusion from another study performed by the same group was that the prospects are excellent for resolution of the final remaining problems to make the direct measurement of blood pressure by external arterial tonometry an accurate and reliable measurement on the relatively active man. Should this prediction be confirmed, the product of pulse rate and an integration of the arterial pressure curve could be used as a fairly reliable index of cardiac output.

Irrespective of the degree of reliance we are able to place upon our estimates of cardiac output and skin blood flow, the concept can be used to advantage in interpreting the meaning of experimental measurements taken in the course of moderate to severe heat stress experiments. When a heat collapse occurs, it seems to be due to a failure of the cardiovascular control system to adequately adjust the distribution of the flow of blood between the central nervous system, the metabolically active tissues, and the skin. As far as we have been able to determine, this is still true whether the collapse occurs at the end of several days of continuous exposure to a moderate stress (such as after seven or eight days in the two week 100-man shelter test conducted by the Navy) or the acute failure which occurs

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*Work being performed by Webb Associates under contract to NASA Manned Spacecraft Center as of the date of this writing.

at the end of about two hours when a man is exposed to 130°F air and wall temperature with a water vapor pressure of 10 millimeters of mercury.

It does not seem likely that a simple difference in the ability to sweat between acclimatized and unacclimatized people would be a sufficient explanation for both of those empirical facts; apparently, a great deal more is involved in the acclimatization process than that - and the skin-to-total blood flow ratio may well be the index which provides the needed correlation between strain and diverse thermal stresses. Suffice it to say that any effort expended toward the quantification of this parameter should be richly rewarding in improving our understanding of past and future experimental results pertaining to heat collapse.

(12) Conclusions

From the foregoing analysis, the rather startling conclusion can be reached that perhaps the best way to improve the habitability of shelters under oppressive circumstances is to improve the physiological characteristics of the shelterees. In large degree, arrival at this conclusion has been heavily influenced by the discovery that people in general differ so enormously in their heat stress resistance. Since we have found that this resistance is quantifiable by means of a parameter which relates sweat output, metabolism, and skin temperature, and that an increase in the numerical value of this parameter - the K factor - is associated with a vastly improved ability to tolerate heat in the individual, we have recommended that primary attention be given to the task of modifying this characteristic in the specific individuals who constitute the occupants of a given shelter.

A still more radical approach could be offered as an alternative, namely eliminating the need for sweating by maintaining a wet garment and thus a relatively cool skin. Thus the probability of encountering heat casualties will be vastly reduced if the operation of the sweating mechanism is made less onerous for the body or eliminated as a requirement altogether. The additional benefits to electrolyte balance, hydration, maintenance of sweating, and modesty, together with the beneficial effects on water economy, make this approach the distinctly favored one. More detailed comments on the various methods for increasing the thermal stress which can be survived, are offered in Section IV.

b. Atmospheric Variables

(1) Oxygen, carbon dioxide and respiration

The level of oxygen and carbon dioxide in the shelter atmosphere is intimately related to the rate of oxygen utilization and carbon dioxide production of the inhabitants and the rate of ventilation of the shelter. Oxygen utilization and carbon dioxide production, in turn, are functions of number, age, sex and state of health of the occupants; activity level; diet; environmental temperature, and other factors. Maintenance of an adequate respiratory environment in the shelter is vital to survival of the occupants, and requires that oxygen and carbon dioxide in inspired air be maintained reasonably close to their normal proportions in the atmosphere. To define the contribution of CO_2 and O_2 levels to the stresses present in an overloaded shelter, physiological background and tolerance limits for oxygen and carbon dioxide in relation to their expected concentrations in the shelter atmosphere are discussed in the following sections.

(a) Physiological background

In measuring tolerance limits in the human to decreased oxygen, the closer to the tissue level one measures the partial pressure of oxygen (pO_2), the less will be the variation in the observed pO_2's corresponding to given physiological changes. Thus, in specifying tolerance limits, the measure of choice would be tissue pO_2 and pCO_2. However, since such measures are generally difficult or impossible to make under practical conditions, blood gas measurements are usually made due to the relative ease with which blood is withdrawn. However, more variability exists in the correspondence between blood gas measures and physiological response than between tissue gaseous tensions and response.

Even easier, but introducing even more source of variability, is the measurement of exhaled gases - which, if properly taken, closely correspond to alveolar gases. And, of course, ambient gas tensions are easiest of all to measure, but are the least reliable of those mentioned as predictors of physiological response - even though the most popular in the general environmental literature. Although for many purposes standards based on external environmental measures are satisfactory, the analysis of effects of environments in which both oxygen and carbon dioxide vary outside normal limits requires physiological standards based on blood gas measures such as arterial pO_2, pCO_2 and O_2 content or saturation. Such blood gas predictions require a knowledge of alveolar partial pressures of O_2 and CO_2 as well as the gas combining properties of blood. For many toxicological predictions, pulmonary ventilation rate (minute volume) must be known as well. Therefore, a brief review of the methods for computing these values is given below. To provide a general idea of the magnitude of the gas pressures involved, Figure III-34 is included to show the normal values for pO_2 and pCO_2 at various points within the cardiorespiratory system beginning with ambient air and progressing to the tissue level.

(i) Alveolar and blood gas composition

Air brought into the lungs is saturated with water vapor and mixed with carbon dioxide to produce alveolar air. The partial pressure of oxygen in alveolar air for subjects in the steady state is given by the following equation (Fenn, et al., 1946; Hanifan, 1958):

$$p'0 = \frac{fO(P_B - 47)\,Q - p'C[1 - fO(1-Q)] + fC(P_B - 47)}{fC(1-Q) + Q} \qquad \text{Eq. 6}$$

which, in the absence of significant quantities of CO_2 in the inspired air, can be simplified to:

$$p'O = fO(P_B - 47) - p'C\left[\frac{1 - fO(1-Q)}{Q}\right] \qquad \text{Eq. 7}$$

where:

$p'O$ = alveolar pO_2, mm Hg

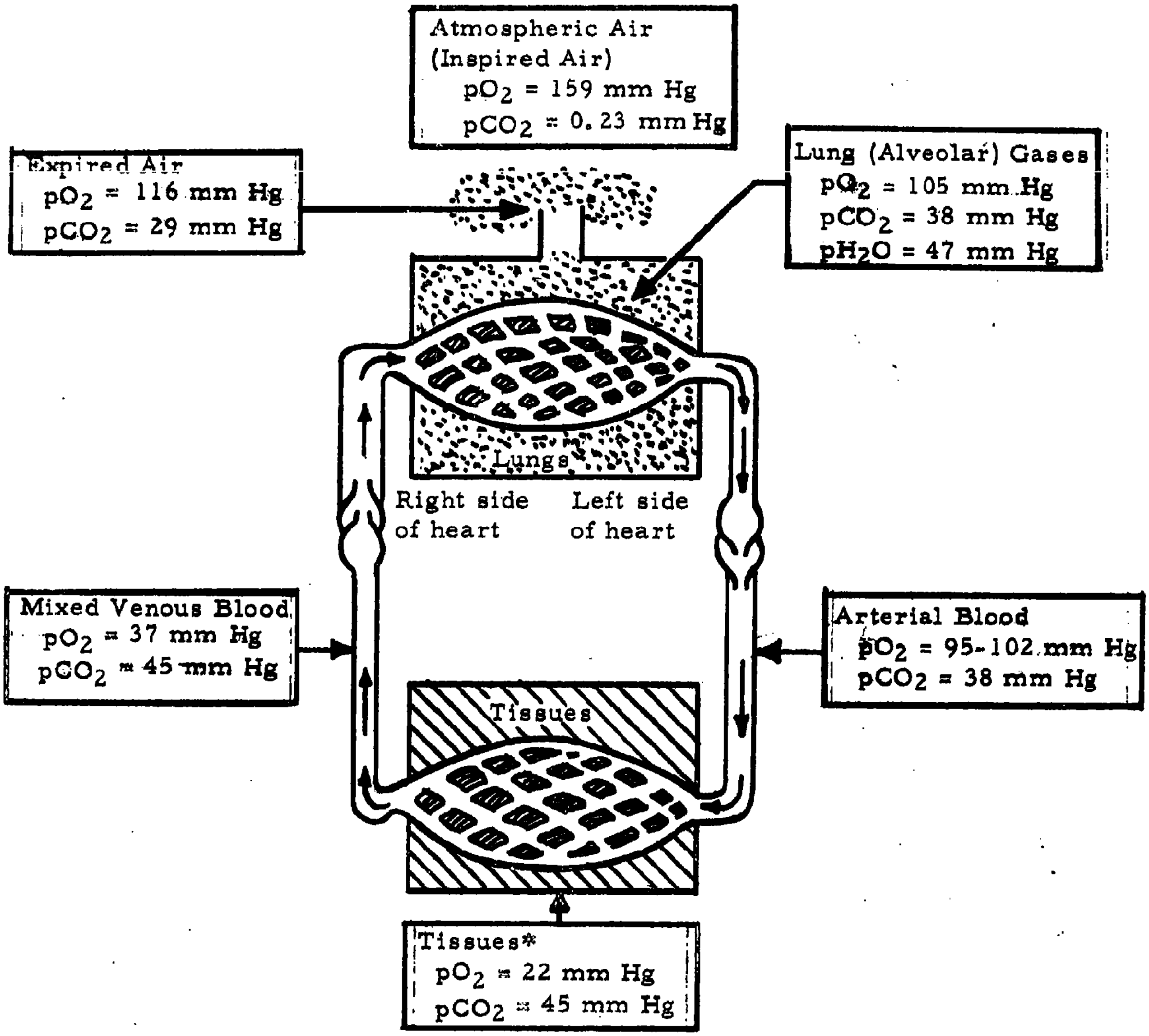
$p'C$ = alveolar pCO_2, mm Hg

fO = fraction of O_2 in inspired gas (0.2093 for normal atmospheric air)

P_B = barometric pressure, mm Hg

Q = respiratory exchange ratio (metabolic quotient for the steady state, 0.82 for normal diet, 0.90 for diet which is largely carbohydrate)

fC = fraction of CO_2 in inspired gas



*Other than brain, thyroid and kidney

Lungs: Normal volume = 4000 cc
Volume expired or inspired with each breath = 500 cc

Arterial Blood: Volume = 1500 cc

Venous Blood: Volume = 4500 cc

Tissues: Mass = 70 Kg

Circulation Time:
Through lungs = 0.75 sec.
Through total body = 60 sec.

Figure III - 34 Diagram of the Human Respiratory and Circulatory System Showing Normal Values of pO_2 and pCO_2 for Adults (Taken from Hanifan, 1958).

In addition to alveolar pO_2 and pCO_2 it is frequently desirable to compute pulmonary ventilation, a quantity which is dependent on the rate and depth of breathing. The physiological mechanisms which control rate and depth of breathing are not completely understood. Nevertheless, the effects on pulmonary ventilation of many conditions of the gaseous environment are well known. In particular, the effects of carbon dioxide in the inspired air, hypoxia, and exercise have been investigated. Such factors as anxiety are also recognized as affecting pulmonary ventilation but are difficult to quantify.

To a first approximation, pulmonary ventilation is regulated in such a manner that the alveolar carbon dioxide tends to be maintained at a more or less constant value of 5 percent at sea level (equivalent to a pCO_2 of 38 mm Hg). Normal resting pulmonary ventilation is on the order of 10 liters per minute BTPS (gas volume expressed at body temperature and pressure, saturated with water vapor). Addition of carbon dioxide to the inspired air increases the ventilation, which may reach 50 to 80 liters per minute when breathing CO_2 at a concentration of 8 to 10 percent at sea level pressure. (Experimental values are presented in Figure III-35). The increased ventilation may be ascribed to the effort of the regulatory mechanism to maintain a constant alveolar carbon dioxide partial pressure. However, increase in alveolar carbon dioxide cannot be avoided completely, but only minimized. At concentrations on the order of 10 to 12 percent carbon dioxide in the inspired air, pulmonary ventilation begins to be reduced due to the anesthetic effect of high concentrations.

In relatively short exposures (such as would be expected in the shelter during initial "button-up," ventilation system failure, etc.), reduction in oxygen content of inspired air will also increase pulmonary ventilation, although the concentration must be reduced to about 12 percent in acute exposures before significant increases occur. Consequently, in shelter exposures of concern here, the increase in pulmonary ventilation observed will be due primarily to increased carbon dioxide. Although the process

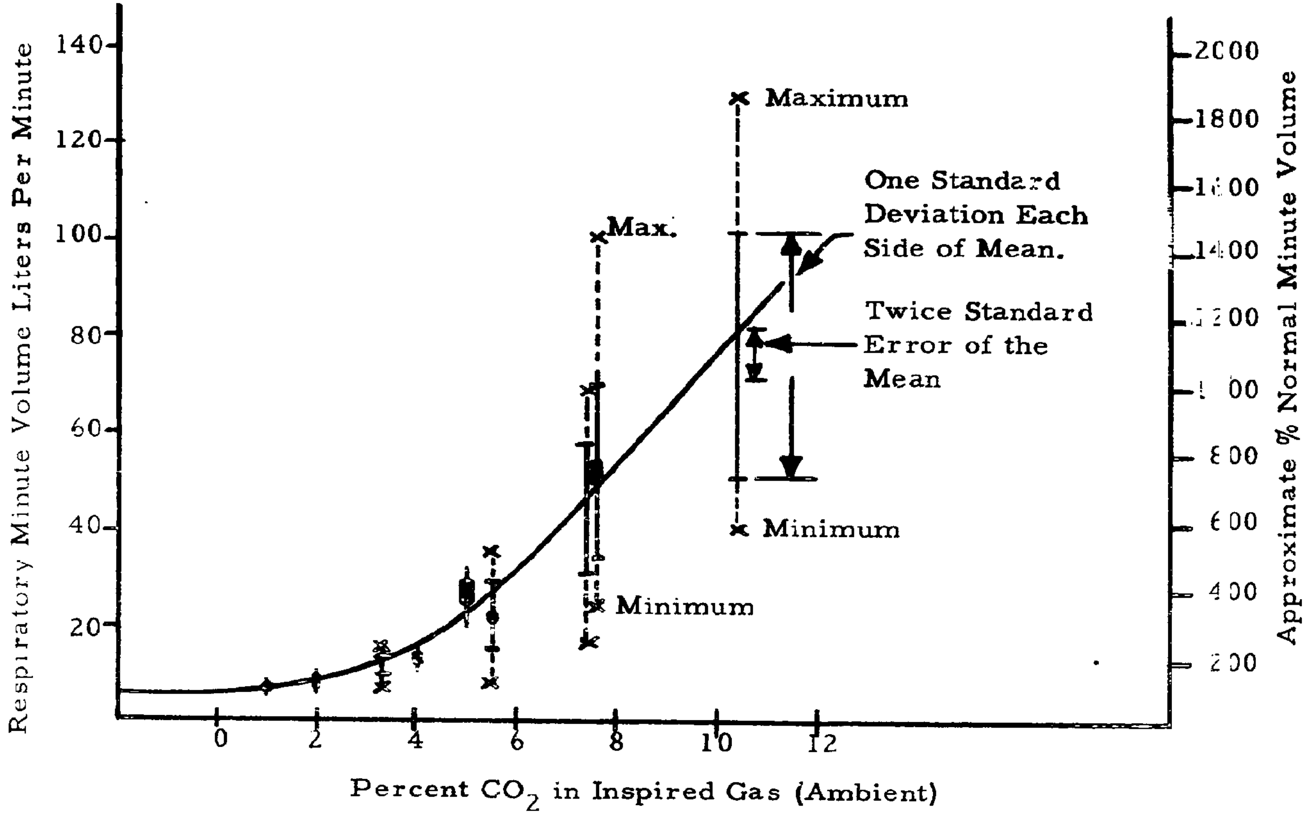


Figure III - 35 Respiratory Response to Various Concentrations of CC_2 in the Inspired Gas at Sea Level (White, 1954).

of acclimatization to lowered oxygen tension would change this picture significantly, it is not likely that lowered oxygen tensions will exist in the shelter for periods sufficiently long to bring such alterations about.

During muscular exercise both oxygen consumption and carbon dioxide production are increased. Thus, the increased demand of the body for oxygen, which calls for an increase in pulmonary ventilation to supply that demand, is accompanied by an increase in the rate at which carbon dioxide is built up in the blood and released to the alveoli. This, in turn, stimulates the breathing mechanism to increase the pulmonary ventilation to maintain the carbon dioxide at its normal level.

Equations for computing alveolar ventilation are as follows (Fenn, et al., 1946; Hanifan, 1958):

$$V'_a = \frac{0.863\, X_o\, [Q + fC(1-Q)]}{p'C - fC(P_B - 47)} \qquad \text{Eq. 8}$$

or

$$V'_a = \frac{0.863\, X_o\, [1 - fO(1-Q)]}{fO(P_B - 47) - p'O} \qquad \text{Eq. 9}$$

where the barometric pressure is 760 mm Hg, and:

V'_a = alveolar ventilation, liters/min BTPS (alveolar ventilation is that part of the total pulmonary ventilation which is effective at the alveolar level)

X_o = O_2 intake, cc/min STP

Q = respiratory exchange ratio

fC = fraction of CO_2 in inspired air

fO = fraction of O_2 in inspired air

pC = partial pressure of CO_2 in inspired air

pO = partial pressure of O_2 in inspired air

$p'C$ = partial pressure of CO_2 in alveolar air

$p'O$ = partial pressure of O_2 in alveolar air

Alveolar ventilation, V'_a, can be converted to total pulmonary ventilation, V'_t, if breathing frequency and deadspace ventilation are known. Deadspace ventilation is equal to frequency times deadspace volume. Thus

$$V'_t = V'_a + V'_d \quad \text{liters/min BTPS}$$

where V'_d = deadspace ventilation. For calculations involving shelter occupants, reasonable approximations for the non-environmental terms used in the above equations are as follows:

X_o = oxygen uptake (cc/min STP) computed as equivalent to heat output or metabolic rate, taking into account age, sex, activity, etc.

Q = 0.90 (largely carbohydrate diet)

$p'C$ = 38 mm Hg at $fC = O$; see Figure III-36 for values at fC greater than zero

$p'O$ = value computed by equation

V'_d = 150 cc

In the ideal case, blood which has passed through the lung capillaries is in gaseous equilibrium with the mixed alveolar air. However, due to the presence of shunts, unequal distribution of pO_2 among alveoli, and incomplete diffusion, this ideal is not achieved for oxygen (although equilibrium is very nearly achieved for carbon dioxide). According to Farhi and Rahn (1955), the alveolar-arterial difference in pO_2 can be related to alveolar pO_2, such that the arterial pO_2 is lower than alveolar pO_2 by 6 mm Hg at 60 mm Hg pO_2 alveolar, by 8 mm Hg at 100 mm Hg pO_2 alveolar and by 8 mm Hg at 48 mm Hg pO_2 alveolar. An average value of 7 mm Hg for the alveolar-arterial oxygen difference should be satisfactory for most computations involving shelter environments.

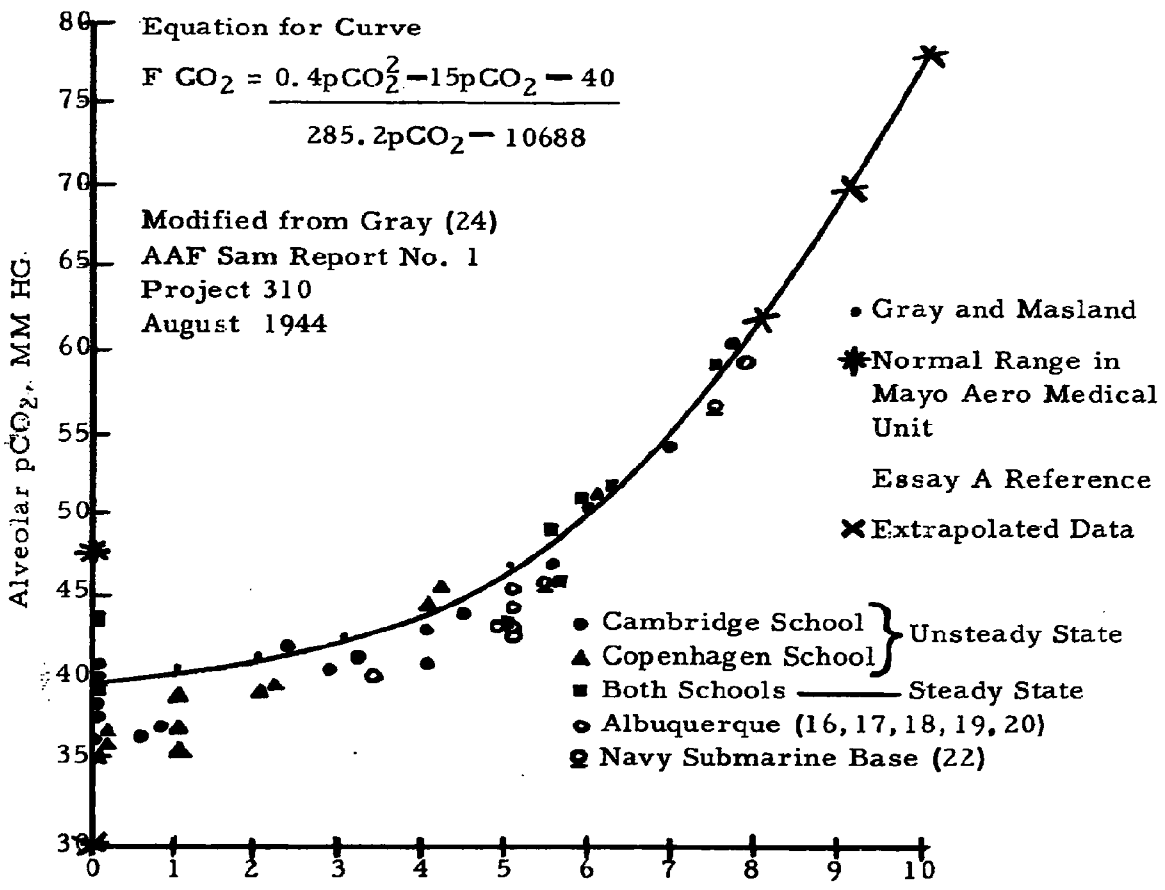


Figure III - 36 Alveolar pCO_2 as a Function of Percent CO_2 in Dry, Inspired Gas at Sea Level (White, 1954; See original article for references).

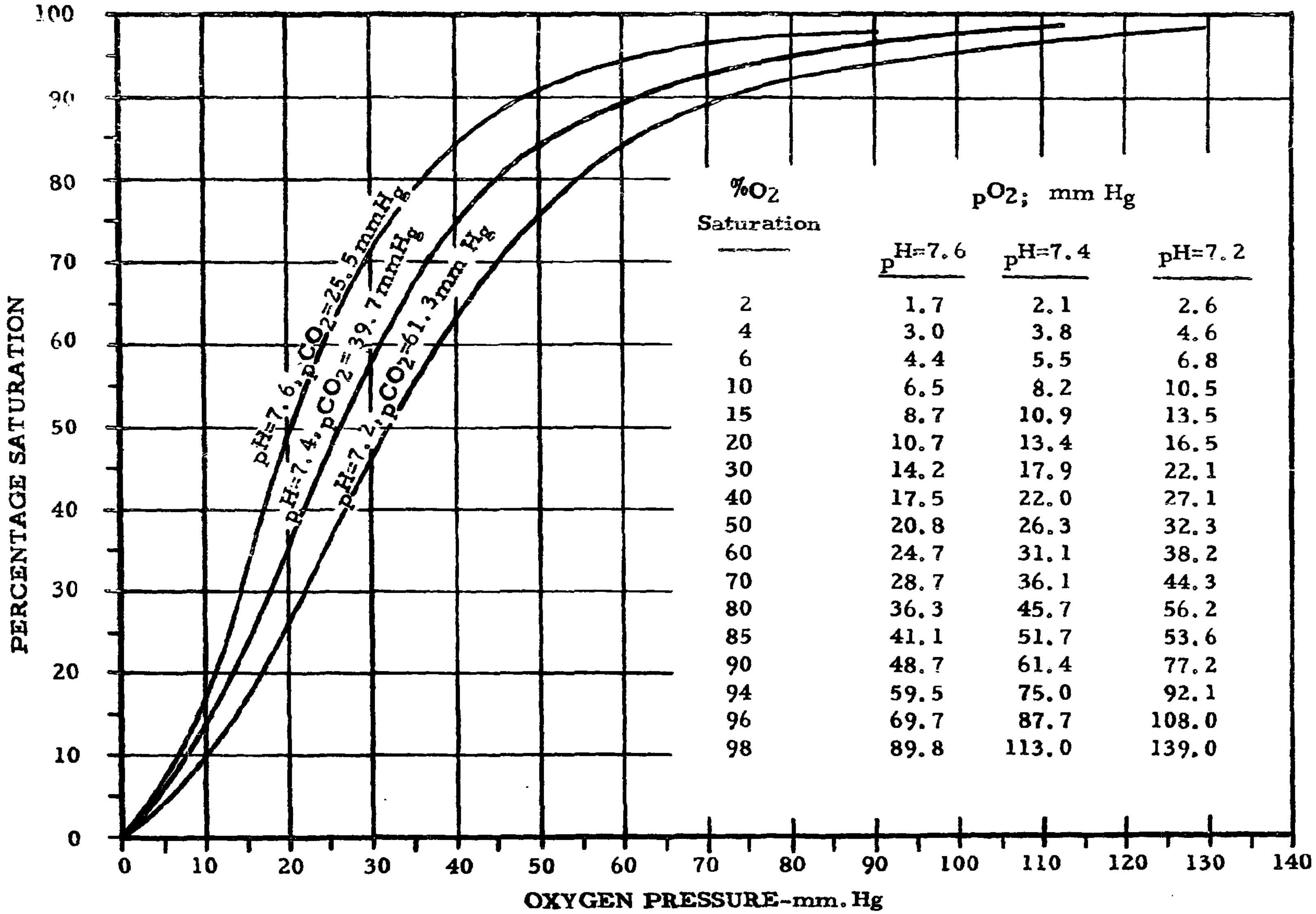
By using the foregoing equations and allowing for the alveolar-arterial oxygen difference, it is possible to predict the pO_2 and pCO_2 of arterial blood.

Most of the oxygen carried by blood is in the form of oxyhemoglobin, or hemoglobin combined with oxygen. Hemoglobin combines with oxygen at higher partial pressures and gives if off at lower partial pressures. The curve(s) relating the percent saturation with oxygen of hemoglobin in blood, and the partial pressure of oxygen in a gas in equilibrium with it is known as the oxyhemoglobin dissociation curve, and is given in Figure III-37 for various levels of pCO. A convenient form of the same relationships to be used for predicting $\%HbO_2$ is given in Figure III-38.

The oxyhemoglobin dissociation curve is useful to the present analysis because it enables the arterial blood oxygen saturation to be determined when arterial pO_2 and pCO_2 have been computed as described in the foregoing discussion. The importance of knowing $\%HbO_2$ is due to the fact that the difference between the blood oxygen saturation at arterial pO_2 and at tissue pO_2 (approximately that of venous blood) is proportional to the amount of oxygen which is available for tissue consumption, a quantity which is of prime significance. Of course the levels of tissue pO_2 and pCO_2 would be of greatest value since these determine the basic adequacy of the cellular environment as well as the potential against which oxyhemoglobin unloads oxygen and accepts carbon dioxide. However, for our purposes a knowledge of arterial blood oxygen saturation ($\%HbO_2$) and alveolar pO_2 and pCO_2 will be sufficient since $\%HbO_2$ and alveolar pO_2 and pCO_2 have been reasonably well correlated with levels of performance for various tasks and with various physiological and psychological changes.

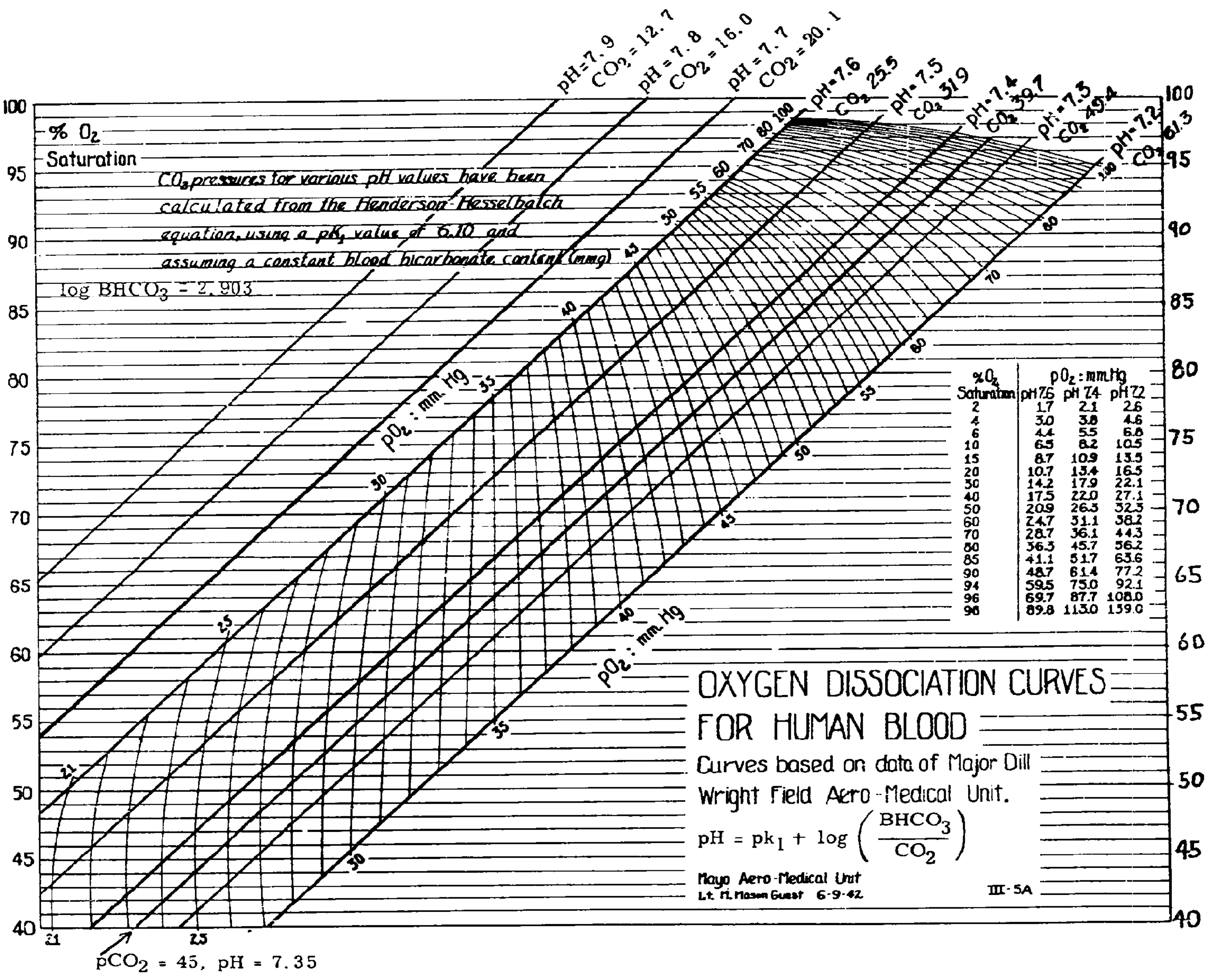
Utilization of blood oxygen saturation and alveolar pO_2 and pCO_2 instead of ambient oxygen and carbon dioxide concentrations has a number of advantages for analysis of shelter environments:

1. Effects of O_2 and CO_2 can be combined, a factor which is important since CO_2 tends to increase in cases where O_2 decreases in the shelter.



%O2 Saturation	pO2; mm Hg pH=7.6	pO2; mm Hg pH=7.4	pO2; mm Hg pH=7.2
2	1.7	2.1	2.6
4	3.0	3.8	4.6
6	4.4	5.5	6.8
10	6.5	8.2	10.5
15	8.7	10.9	13.5
20	10.7	13.4	16.5
30	14.2	17.9	22.1
40	17.5	22.0	27.1
50	20.8	26.3	32.3
60	24.7	31.1	38.2
70	28.7	36.1	44.3
80	36.3	45.7	56.2
85	41.1	51.7	53.6
90	48.7	61.4	77.2
94	59.5	75.0	92.1
96	69.7	87.7	108.0
98	89.8	113.0	139.0

Figure III - 37. Oxyhemoglobin dissociation curves for human blood (from Committee on Aviation Medicine, 1944).



%O2 Saturation	pO2 : mmHg pH 7.6	pH 7.4	pH 7.2
2	1.7	2.1	2.6
4	3.0	3.8	4.6
6	4.4	5.5	6.8
10	6.5	8.2	10.5
15	8.7	10.9	13.5
20	10.7	13.4	16.5
30	14.2	17.9	22.1
40	17.5	22.0	27.1
50	20.9	26.3	32.3
60	24.7	31.1	38.2
70	28.7	36.1	44.3
80	36.3	45.7	56.2
85	41.1	51.7	63.6
90	48.7	61.4	77.2
94	59.5	75.0	92.1
96	69.7	87.7	108.0
98	89.8	113.0	159.0

Figure III - 38 Chart for determing %HbO_2 from pO_2 and pCO_2 (Blockley and Hanifan, 1961; modified from Committee on Aviation Medicine, 1944)

2. To compute the combined effects of low pO_2 and pCO (carbon monixide), it is necessary to consider $\%HbO_2$ in conjunction with %HbCO (see section on CO).

3. Less variability is expected to exist in the correlations between blood and alveolar measures and physiological effect than between ambient oxygen concentration and physiological effect.

4. Population variability can be expressed conveniently in terms of alveolar or blood gases.

Unfortunately, the greatest share of the generally cited data on physiological and psychological response to decreased pO_2 and to increased pCO_2 have been taken from experiments on healthy, young men. For reference purposes, the more important of those data are included here. Figure III-36 provides a basis for estimating the alveolar pCO_2 which accompanies the breathing of CO_2 in shelter air. Along with the breathing of CO_2 there is also an increase in respiratory (pulmonary) minute volume, which is given in Figure III-35. These data provide a basis for choosing a value for p'C when computing alveolar pO_2 by Equation 6.

Given alveolar pO_2 and pCO_2 and adjusting pO_2 for the alveolar-arterial oxygen difference (usually about 7 mm Hg), arterial blood oxygen saturation ($\%HbO_2$) can be estimated by referring to the oxyhemoglobin dissociation curves given in Figure III-37 and in Figure III-38.

The values which are computed using the foregoing data will be most relevant to resting, healthy, young men. The computation of values for different ages and sexes and particularly for diseased states, requires adjustment of those data in many cases. Vigorous exercise will also impose a requirement for adjustment, but at the activity levels expected in the shelter, resting data appear to be sufficiently close.

Experimental values for alveolar pO_2 and pCO_2 and arterial blood oxygen saturation ($\%HbO_2$) at various levels of inspired oxygen concentration are given in Table III-10, which is a compilation of data for

TABLE III-10

COMPILATION OF MEASURED VALUES FOR ALVEOLAR AND ARTERIAL O_2 AND CO_2

Inspired Air O_2, %	Number of Observations (Alveolar only)	Alveolar Partial Pressure				Arterial % HbO_2				
		CO_2, mm Hg		O_2, mm Hg		(Henson et al, 1947)		(CAM, 1944)		
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	N
20.1	186	36.7	2.7	102.3	5.5			97-98		
19.4	8	38.1		95.5						
18.7	45	36.2	2.9	80.2	5.2	95.5	2.2			
18.0	8	38.5		84.8						
17.3	62	36.5	2.8	81.6	4.5	91.0	2.0			
16.6	54	36.2	3.1	74.2	5.2					
16.0	3	40.0		67.0		91.0	2.0			
15.3	10	37.4		64.8		89.0	2.0			
14.7	50	35.4	3.2	61.2	5.8	85.5	2.0			
14.1	92	35.8	2.6	60.9	4.6	85.5	3.0			
13.5	12	36.8		53.3		82.0	4.0			
12.9	61	34.8	3.2	50.7	5.4	85.0	3.5			
12.4	15	36.5		44.9		78.0	3.5			
11.8	26	35.4		44.0		79.0	4.0	77.1	5.5	7
11.3	145	32.9	2.8	44.2	5.1	74.5	4.0	78.5	3.6	12
10.8	9	33.8		38.8		76.0	6.0	75.5	5.5	11
10.3	37	30.7		38.1		70.0	4.5	74.5	6.1	12
9.8	55	31.8	2.5	37.9	3.8	71.0	6.0	68.0	6.2	12
9.4	11	29.4		36.5		67.5	7.0	64.7	7.2	6
8.9	81	29.4	2.6	35.3	4.6	71.0	6.0			

*Most of the data were taken from studies on healty, young men made in low pressure chambers and reported in terms of equivalent pressure altitude or pressure. Pressure was converted to physiologically equivalent oxygen percentages at 760 mm Hg barometric pressure by using the altitude - oxygen mixture equivalence chart given in Committee on Aviation Medicine (1944). The basic data on alveolar pO_2 and pCO_2 were taken from Committee on Aviation Medicine (1944).

relatively short exposures of half an hour or less. For longer exposures and a greater range of ages, one of the most comprehensive studies of the effects of exposure to oxygen concentrations from 14 percent to about 11 percent was reported by McFarland (1938), who observed responses of over 200 male subjects between the ages of 18 and 72 years. He made many physiological and psychological measurements during exposure durations of two hours (plus time of onset). Observed values for alveolar pO_2 and pCO_2 at ten levels of percent oxygen in inspired air are given in Table III-11. It should be noted, however, that carbon dioxide was present in greater than normal concentrations (0.36 to 0.90, mean 0.53%). However, the presence of carbon dioxide does not invalidate the results for our purposes, since greater than normal concentrations of carbon dioxide are expected in the shelter as well.

(ii) Response to O_2 and CO_2 concentrations

A feature of particular interest in McFarland's investigation was the observation that slowly reducing the oxygen concentration was more tolerable than rapidly reducing the concentration even though the terminal concentrations were the same. For instance, a number of subjects who could be decreased to 11.2 percent oxygen in 75 minutes and stay for two hours would collapse if the decrease was made in 30 minutes. Apparently, a short term accommodation can take place if the oxygen concentration decreases slowly, a factor which is important in determining the tolerable limits of oxygen deficiency in the shelter. Tolerance limits to hypoxia have generally been derived from data in which the onset of hypoxia was sudden rather than gradual. Consequently, lower concentrations of oxygen can be tolerated than has generally been supposed for the shelter situation, and the use of most tolerance data provides a built-in safety factor. In addition to that factor, small concentrations of carbon dioxide seem to result in an elevation of alveolar pO_2 due, in part, to increased pulmonary ventilation. In McFarland's experiments, chamber carbon dioxide concentrations were higher for slow onset than for rapid onset (see Table III-11) a factor which may also have contributed to the greater tolerance for slow onsets.

TABLE III-11

MEANS OF ALVEOLAR pCO_2 AND pO_2 FOR VARIOUS CHAMBER CONCENTRATIONS OF OXYGEN

Average % O_2, Inspired Air	Number of Subjects	Control Alveolar Gases		First Hour				Second Hour			
				Alveolar Gases		Inspired Gases (Chamber)		Alveolar Gases		Inspired Gases (Chamber)	
		pCO_2 mm Hg	pO_2 mm Hg	pCO_2 mm Hg	pO_2 mmHg	$\%CO_2$	$\%O_2$	pCO_2 mm Hg	pO_2 mm Hg	$\%CO_2$	$\%O_2$
14.06 rapid (15 min)*	18	40.4	99.0	38.1	54.3	0.36	13.95	44.2	54.8	0.65	14.16
14.06 slow (40 min)	14	39.2	103.0	37.6	59.3	.43	14.06	----	----	----	-----
13.04 rapid (20 min)	14	38.2	105.5	36.1	56.8	.36	13.13	34.5	56.5	.51	12.94
13.31 slow (45 min)	12	40.5	100.1	37.7	53.7	.49	13.25	40.3	50.5	.72	13.36
12.13 rapid (20 min) (17-30 yrs.)	50	39.9	98.5	39.4	43.58	.38	12.06	37.0	44.4	.69	12.20
12.09 rapid (20 min) (30-45 yrs.)	15	37.5	101.9	35.5	43.2	.39	12.04	34.3	45.0	.90	12.14
12.31 rapid (20 min) (45 yrs. & over)	16	38.03	100.3	36.2	47.6	.45	12.42	35.5	54.6	.63	12.19
12.09 slow (45 min)	13	38.8	100.9	38.8	43.9	.46	12.16	38.5**	38.5**	.55	12.02**
11.17 rapid (30 min)	27	38.5	101.1	35.3	38.6	.37	11.16	34.9	38.4	.63	11.18
11.20 slow (75 min)	19	38.5	101.3	34.6	43.2	.47	11.10	34.3	39.4	.66	11.30

*Time spent in reducing $\%O_2$ from about 21 percent to nominal value.
**One subject

Adapted from: McFarland, R. A.: "The Effects of Oxygen Deprivation (High Altitude) on the Human Organism." Technical Development Report No. 11 (May 1938). Civil Aeronautics Authority, Washington, D. C.

It is known that a well-controlled rise in pulse rate is a favorable response to lowered oxygen tension and that many persons in poor physical condition respond with either an unusually large increase in pulse rate or with no change at all. For normal subjects the picture of increasing pulse rate with decreasing oxygen concentration is particularly clear-cut for the faster onsets. The average blood pressure records do not show definite trends although at moderate concentrations of around 12 to 13 percent most subjects react with an initial increase in either the systolic or diastolic blood pressure, or both, followed by a well-controlled fall to normal values. A more reliable objective indication of the physiological state is the level of hypoxia as measured by the alveolar oxygen and carbon dioxide pressures.

Objective physiological measurements are difficult to interpret unless they are accompanied by some measure of performance. In the shelter, measures of general discomfort and well-being are particularly relevant. In an effort to measure the "general discomfort" accompanying prolonged exposure to reduced oxygen concentrations, McFarland asked each subject to write a running account of his subjective reactions. The most frequent complaints recorded voluntarily by each subject are shown in rank order as to frequency in Table III-12.

TABLE III-12

MOST FREQUENT COMPLAINTS NOTED VOLUNTARILY BY SUBJECTS AT THE OXYGEN CONCENTRATIONS SHOWN FOLLOWING RAPID ONSETS

	O_2 Concentration			
Complaints	14%	13%	12%	11.2%
Headache	10.5	33.3	62.4	66.7
Respiratory changes or difficulties	26.3	16.7	42.5	60.0
Excessive sleepiness	21.1	50.0	37.5	30.0
Vertigo or dizziness	5.3	0	32.5	53.3
Difficulty in concentrating	21.1	16.7	5.0	46.7
Sensory impairment	5.3	16.7	30.0	33.3
Lassitude, Indifference	21.1	16.7	25.0	13.3
Fatigue	5.3	0	27.5	33.3

Adapted from: McFarland, (1938).

McFarland's objective tests showed significant impairment of performance at oxygen concentrations only at 12 percent or below on the average. For instance, handwriting tests showed significant deterioration in motor control at 12 percent and less, being fairly great at 11 percent following rapid onset. Heterophoria tests in which the amount of ocular muscle imbalance was measured showed a significant difference from controls only when concentrations fell below 12 percent. Likewise, choice reaction times were not significantly lowered until concentrations lower than 12 percent were used. Color naming tests, code transliteration tests, and memory for paired associates tended to show impairment at concentrations between 14 and 12 percent.

McFarland's results indicate that reasonably healthy shelterees from the ages of 18 to 72 can be subjected to oxygen concentrations as low as 12 percent for at least two hours without significantly deteriorated performance except for memory and concentration. However, at only 14 percent oxygen as many as 10 percent may complain of headache and over 20 percent may complain of respiratory difficulties, excessive sleepiness, difficulty in concentrating and lassitude and indifference (Table III-12).

Otis, et al., (1946) studied the effect of varying alveolar pO_2 and pCO_2 on performance as judged by a steadiness test and a test of contrast discrimination. Figure III-39 summarizes their data. In comparing the data of McFarland with those of Otis, et al., it is interesting to note that McFarland's alveolar gas observations at 14 and 13 percent inspired oxygen fall within the Otis, et al., "Region of Normal Performance," and that the observations at 12 and 11 percent fall within the region of "Impaired Performance," thus demonstrating a good general agreement between the two bodies of data within the range of 11 to 14 percent oxygen in inspired air.

Correlations have also been made between arterial oxyhemoglobin saturation and performance measures. Values given by the Committee on Aviation Medicine (1944), are as follows:

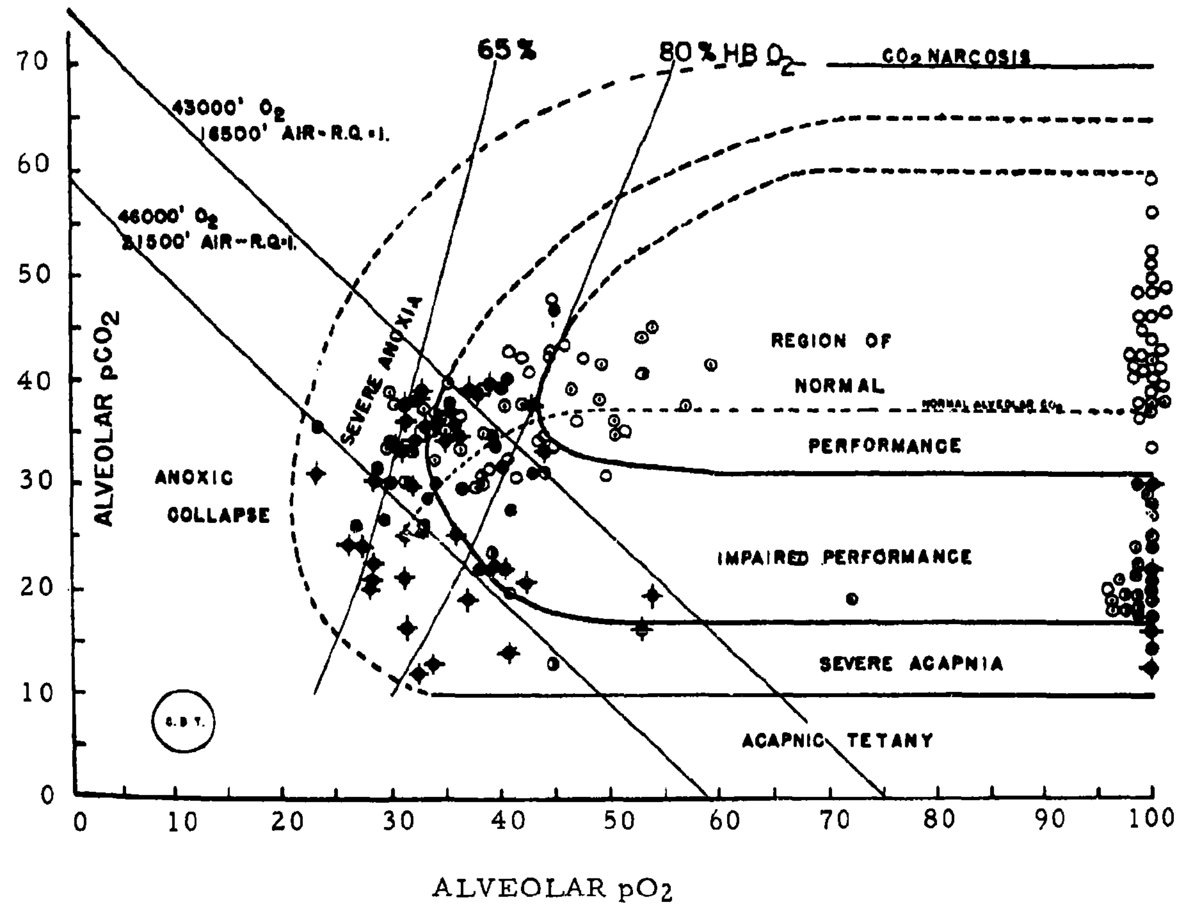


Figure III - 39 Relationship of alveolar gas composition to steadiness test performance. Alveolar pCO_2 and pO_2 expressed in mm. Hg (BTPS). Each type of symbol represents a probability (P) that a subject's experimental score was not different from his control score. The blacker the symbol, the lower the probability and the greater the certainty of abnormality. Solid circle with cross, $P < 0.01$; solid circle, $P = 0.01$ to 0.05; half solid circle, $P = 0.05$ to 0.1; open circle with dot, $P = 0.1$ to 0.5; open circle, $P > 0.5$. (Taken from White, 1954; after Otis et al, 1946.)

$\%HbO_2$	General condition of subject
85	Appreciable handicap
75	Considerable handicap
70	Serious handicap
60-65	Imminent collapse

To determine the degree of general agreement between McFarland's data and the above scale, four of McFarland's sets of mean values for alveolar pO_2 and pCO_2 (first hour, slow onset) were converted to $\%HbO_2$ assuming a 7 mm Hg oxygen difference. The results are tabulated below:

	Alveolar gases		Assumed arterial gases		Predicted
$\%O_2$, chamber	pO_2	pCO_2	pO_2	pCO_2	$\%HbO_2$
14.06	59.3	37.6	52.3	37.6	85
13.25	53.7	37.7	46.7	37.7	82
12.16	43.9	38.8	31.8	38.8	63(72w/o O_2-diff)
11.10	43.2	34.6	31.2	34.6	64(72w/o O_2-diff)

In general, the agreement is reasonably close. On the basis of predicted $\%HbO_2$ for McFarland's data, the values at 14 and 13 percent (85 and 82 $\%HbO_2$) correspond to appreciable (just noticeable) handicap and the values at 12 and 11 percent correspond to a state of serious handicap or imminent collapse, depending on the assumption one makes about alveolar-arterial oxygen difference.

Short exposures to CO_2 of up to an hour and a half or so have been fairly well explored and tolerance times at various concentrations of up to 10 percent or more have been well reported. Figure III-40 is one of the generally accepted curves. Note that up to one percent can be tolerated for at least 100 minutes without noticeable symptoms, and that about two percent is the threshold for distracting discomfort. Six percent for 100 minutes is the concentration which leads to dizziness, stupor and unconsciousness.

Nuclear submarines operate at a concentration of about one percent CO_2. In "Operation Hideout," 20

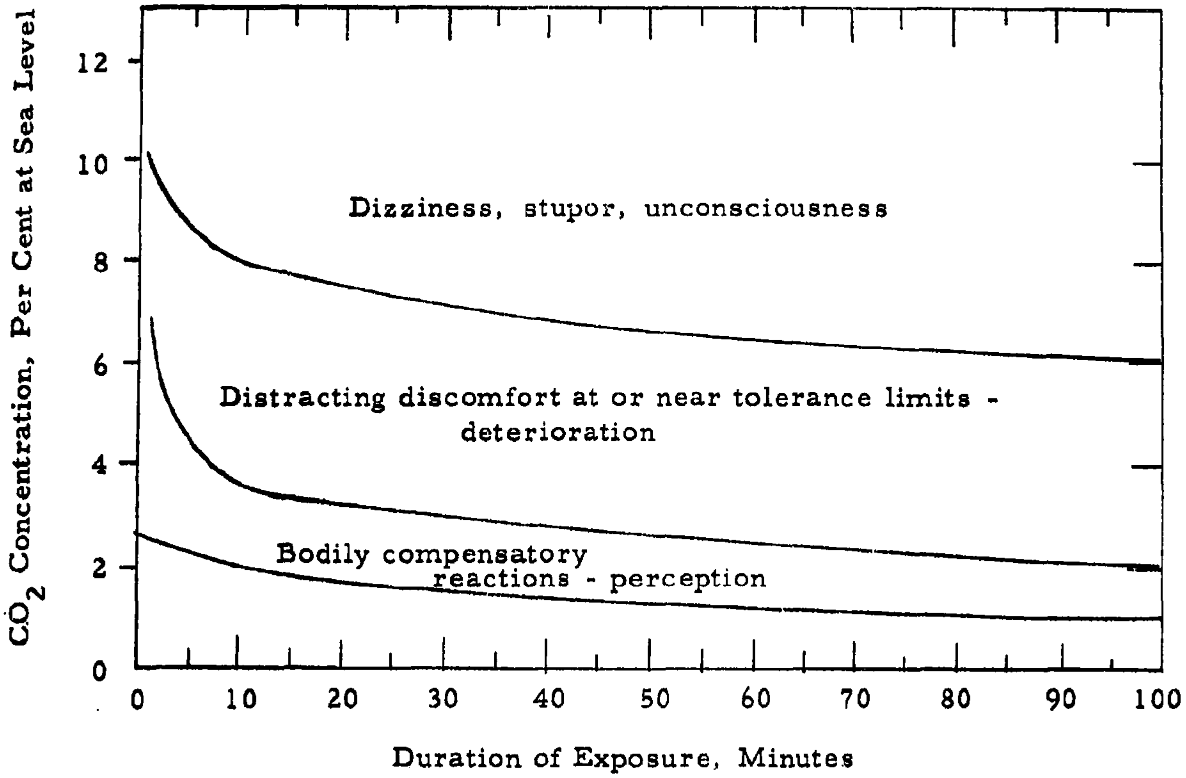


Figure III-40 Time concentration curves for reaction to carbon dioxide in inspired air. Curves based on an analysis by King (1949).

young men were exposed to one and a half percent CO_2 for over 40 days with some shift in chemical balance, but no subjectively noticeable effects. At higher concentrations, hyperventilation, headaches and other effects may be produced (Gates, 1962; Schaefer, 1960). A summary of the findings of various researchers on effects of carbon dioxide at various concentrations is presented in Table III-13.

Schaefer (1960) proposes three levels of response which may be used as tolerance limits for chronic CO_2 exposure, as follows:

% Inspired CO_2	Response
3% and above	Level producing performance deterioration, alterations in basic physiological functions as expressed in changes of weight, blood pressure, pulse rate, metabolism and finally pathological changes.
1.5%	Level at which basic performance and physiological functions are not affected. Produces adaptive changes in electrolyte exchange and acid-base balance.
0.5 - 0.8 %	Level at which no significant physiological, psychological or adaptive changes occur.

(iii) Production and utilization of CO_2 and O_2

The concentration of oxygen and carbon dioxide in the shelter will depend on the rate at which shelterees utilize oxygen and produce carbon dioxide, and on the rate at which fresh air enters the shelter via the ventilation system. This section is concerned with the rate of utilization and production of oxygen and carbon dioxide under various conditions and for various segments of the population.

Table III-3, already presented in the section on population variables, shows the mean resting oxygen consumption and carbon dioxide production for age and sex groups in the general United States population.

TABLE III-13

REACTIONS TO CARBON DIOXIDE

No. of cases	Exposure pCO_2	Exposure Time min.	Observer	Effects
(Bodily compensatory reactions, below level of perception)				
1	6.0	?	Haldane & Priestly	11% increase of respiratory minute volume (R. M. V.)
16	7.6	17-32	Schneider & Truesdale	Slight increase of systolic and diastolic blood pressure, 24% increase R. M. V.
?	15.2	?	Brown	Unaware of increased breathing, dyspnea only on exertion
16	15.2	17-32	Schneider & Truesdale	Small increase of blood pressure, 50% increase of R. M. V.
(Bodily compensatory reactions, level for perception, distraction)				
--	22.8	--	Macleod	Depth of breathing doubled, increase is perceived
8	22.8	1	Spealman	Perceptible for most subjects
37 exp.	22.8-26.6	1-2	Gellhorn & Spiesman	Small loss in threshold of hearing at 128, 2048 and 4096 cps
(Bodily compensatory reactions, distracting discomfort)				
?	22.8-30.4	300-400	Brown	Mental depression, headache, dizziness, nausea; 1-3°F fall in rectal temperature
16	30.4-38.0	17-32	Schneider & Truesdale	"Breathing fails to satisfy intense longing for air"
16	38.0	17-32	Schneider & Truesdale	Headache, dizziness, hiccoughing
?	45.6	1-2	Gellhorn	Decrease in visual discrimination
?	53.2-60.8	60	Tomaszewski et al.	1 hour inhalation per day tolerated

TABLE III-13
(continued)

No. of cases	Exposure		Observer	Effects
	pCO_2	Time min.		
(Failure of compensatory reactions at or near limit of maximum voluntary tolerance)				
?	38.0	120	Davis, Haldane and Kennaway	Limit of tolerance
3	45.6	20-1/2 to 22	Brown	Much discomfort, severe symptoms impending
5	45.6	30 or more	Alexander et al.	5 headaches; 2 vomited (13% O_2)
6	57.0	3-1/2 to 6	Brown	"Symptoms urgent"
2	57.0	15	Barcroft & Margaria	"Highest quantity that could be endured over 15 minutes:
16	60.8	17-32	Schneider & Truesdale	Maximum tolerated
5	66.9	7-10	Brown	Very near tolerance limit
?	76.0	Few min.	Barcroft & Margaria	Maximum endured
(Marked deterioration, inability to take steps for self-preservation)				
42	57.8	2-1/2 to 10	Dripps & Comroe	13 dyspneic; 14 dizzy, 1 unconscious; headache, head fullness; sweating
7	79.0	1/2 to 2-1/4	Brown	Serious symptoms impending
31	79.0	2-1/2 to 10	Dripps & Comroe	Only 2 tolerated 5 min. exposure; 18 dizzy; 10 dyspneic; 7 faint
7	94.2	3/4 to 2	Brown	Severe dyspnea, dizziness, drowsiness; 1 collapse
2	141.0	2	Haldane & Smith	Imminent unconsciousness, dullness, cyanosis, throbbing in head
6	over 182	1-1/2 to 2	Air Transport Assoc.	3 groggy--escaped; 1 almost collapsed, escaped; 2 unconscious (flight trials)

(Webb Associates, 1962; after King, B.W.; J. Ind. Hyg. & Toxicol. 31:366, 1949)

These data form the basis for determining the general effect on oxygen consumption and carbon dioxide production of differing the composition of the population in the shelter. However, the values must be adjusted for activity level. This can be done in an approximate way by referring to Table III-14 which presents typical data on activity levels for men and women in terms of the percent increase in oxygen consumption over supine. These values can be used to arrive at approximate adjustments of the values given in Table III-3 for activity level. Although the percent increase over supine for adults may not be precisely the same as for children for the same activity due to different muscle efficiencies and body masses, the error introduced by use of the adult data for children will probably not be significant in the shelter context. Since oxygen consumption can be converted to heat production and vice versa, the percent increase over supine (resting or basal) can also be used to adjust the heat production values given in Table III-3 for different activity levels. The same is true for carbon dioxide production if one assumes a constant respiratory quotient (Table III-3 assumes 0.85).

(b) Computation of shelter atmospheric pO_2 and pCO_2 and resulting alveolar and blood gases

Using the equations derived in Appendix D the concentrations of oxygen and carbon dioxide in shelter air for various levels of overloading were predicted assuming (1) a shelter population in which age and sex are distributed in the same proportions as in the general United States population; (2) an average 24 hour activity level which results in oxygen consumption rates equal to 1.72 times basal; (3) ventilation of the shelter with fresh air at a rate of 3 cubic feet per minute per person for the planned number of occupants (ventilation rate does not increase with loading); and (4) a barometric pressure of 760 mm Hg and a temperature of 85°F. The results of the computations for overloading up to 10.0 times planned loading are presented in the first three columns of Table III-15.

Using the techniques and data presented in the section on physiological background, alveolar and arterial pO_2 and pCO_2, arterial $\%HbO_2$ and alveolar ventilation rate were

TABLE III-14

ADJUSTMENT FACTORS FOR OXYGEN CONSUMPTION, CARBON DIOXIDE PRODUCTION AND HEAT OUTPUT IN TERMS OF TYPICAL PERCENT INCREASE OVER SUPINE (BASAL OR RESTING) FOR VARIOUS ACTIVITIES*

Activity	% Increase Over Supine
Men	
Sitting at ease	54
Standing at ease	69
Dressing, washing, shaving	204
Walking (indoors), 2.4 mi/hr	268
Laboratory work	174
Washing dishes	182
Carpentry, joining floorboards	276
Carpentry, sawing soft wood	439
Women	
Sitting	11
Standing	13
Washing, dressing, undressing	237
Horizontal walking, 1.1 mi/hr	103
Horizontal walking, 2.2 mi/hr	190
Washing dishes, top of pan 42 in. from floor (ht of subject 66 in.)	40
Bedmaking, stripping	451
Typing, mechanical, 40 words/min	51

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*Values taken from Spector, 1956; Table 315, pg. 347.

TABLE III-15

COMPUTED EFFECT OF OVERLOADING ON SHELTER, ALVEOLAR AND BLOOD GASES: NORMAL VENTILATION*

Overload Factor	Shelter Air		Alveolar Air		Arterial Blood			Alveolar ventilation liters/min
	O_2 %	CO_2 %	pO_2 mm	pCO_2 mm	pO_2 mm	pCO_2 mm	HbO_2 %	
0	20.93	0.03						
1.0	20.5	.39	114.4	38.0	116.1	38.0	>97	6.8
1.5	20.3	.56	113.9	38.1	115.7	38.1	"	
2.0	20.1	.74	113.6	38.2	115.4	38.2	"	
2.5	19.9	.92	113.2	38.3	115.1	38.3	"	8.1
3.0	19.7	1.10	112.8	38.4	114.8	38.4	"	
3.5	19.5	1.27	112.4	38.5	114.4	38.5	"	
4.0	19.3	1.45	112.0	38.6	114.1	38.6	"	
4.5	19.1	1.63	111.7	38.7	113.8	38.7	"	
5.0	18.8	1.81	110.4	39.0	112.5	39.0	"	9.9
10.0	16.75	3.59	104.5	42.0	106.8	42.0	97	15.8

*Assuming ventilation by outside air is 3 cfm/person for the planned loading (1.0) and that total ventilation does not increase with loading.

predicted for each level of overloading and are presented in the last six columns of Table III-15.

In no case do alveolar or arterial gas values fall outside normal tolerance limits, although alveolar ventilation rates become unpleasantly high in the shelter loaded to ten times its planned occupancy - a loading which, however, seems highly unlikely. Carbon dioxide concentrations do not exceed one percent until overloading reaches 3.0.

In examining the predicted values for alveolar gases, it seems surprising at first glance that pO_2 is so high even at 16.75 percent oxygen in shelter air. However, inspection of the general alveolar equation and of the alveolar ventilation equation reveals that the high pO_2 is due largely to the presence of carbon dioxide in the inspired air, which stimulates alveolar ventilation. Since oxygen consumption does not increase as ventilation increases, less oxygen is removed from a unit volume of mixed gas than is the case for lower ventilation rates. Performing the computation for 16.75 percent oxygen in the absence of carbon dioxide, the predicted alveolar pO_2 is 77.9 mm Hg instead of 104.5 mm Hg which is obtained when 3.59 percent carbon dioxide is also present.

The worst case is one in which the shelter is closed tightly with no ventilation by outside air. For a 100 man shelter containing 6500 cubic feet air space, the computed time required for oxygen to decrease to 14 percent is only 35 minutes for a normally loaded shelter, at which time the carbon dioxide concentration has increased to almost 6 percent, a concentration which leads to unconsciousness if the exposure is prolonged for as much as an hour and a half. However, the build-up time must also add to the stress such that the hour and a half could not be achieved in practice.

It is of interest to note that in the foregoing illustration, alveolar pO_2 and pCO_2 would approach 80 and 50 mm Hg respectively and that arterial blood oxygen saturation would be 88 to 90 percent. It is clear that carbon dioxide toxicity will be the limiting factor during shelter "button-up" or ventilation failure.

(2) Trace atmospheric contaminants

While trace atmospheric contaminants do not appear to present a serious problem (except for odor) in normal shelter situations, they can become important in overloading with respect to their contribution to the overall stress. In particular, flatus, respiratory exhallants, volatile skin secretions, volatile constituents of fecal matter and vomitus, and products of smoking, will have important physiological effects if present in sufficiently high concentrations for long periods of time. To assess the importance of trace atmospheric contaminants, their sources and probable amounts are discussed below.

(a) Flatus (bowel gases)

The quantity and composition of flatus principally depend on the amount and kinds of food consumed, the bacterial flora of the bowel and individual variation in digestive processes. Consequently, considerable variation in flatus production exists.

In the absence of specific data on flatus production of subjects subsisting on the shelter rations, data on individuals living on a normal diet were used. Various estimates of average flatus volume vary from 500 ml per day (Beazell and Ivy, 1941) to over two liters per day (Kirk, 1949, cites values as high as 1.84 ml/min).

The average composition of human colonic flatus for 45 individuals, 25 of whom were on a milk-free diet, is shown in Table III-16. According to Table III-16 the average rate of production of flatus for the sample of 45 persons was 1.46 ml/min, which is slightly greater than two liters per day per person or about 88 ml per hr per person.

Although an increase in flatulence has been observed in natural starvation during famines, no increase in flatulence was observed during the extensive series of semi-starvation experiments carried out at the University of Minnesota (Keys, et al., 1950; pg. 595, Vol. I). Shelter conditions will more nearly be simulated by Keys' laboratory conditions than by natural starvation conditions. Therefore, a normal rate of flatus production of 1.46 ml per minute per person or about 88 ml per hour per person seems reasonable for computation of shelter atmosphere contamination.

TABLE III-16

COMPOSITION OF HUMAN COLONIC FLATUS*

Ml/min	%CO_2	%O_2	%CH_4	%H_2	%N_2	%H_2S
1.46	9.4	4.8	4.9	16.0	65.1	0.0002

*Weighted average of two samples, one on 20 persons taken during the 1943-44 period, and one on 25 persons taken during the 1945-46 period. (After Webb Associates, 1962, who cite Kirk, 1949. Also see Clemedson, 1959.)

Using the values for composition given by Table III-16 and the rate of production of 88 ml per hour per person, the rate of production of each of the constituents of flatus would be as shown in Table III-17.

TABLE III-17

AVERAGE HOURLY RATE OF PRODUCTION OF CONSTITUENTS OF FLATUS (PER PERSON)*

Constituent Gas	Rate of production per person liters/hr	 cu ft/hr
CO_2 (carbon dioxide)	0.00827	0.000292
O_2 (oxygen)	0.00422	0.000149
CH_4 (methane)	0.00431	0.000152
H_2 (hydrogen)	0.0141	0.000498
N_2 (nitrogen)	0.0573	0.00202
H_2S (hydrogen sulfide)	1.76×10^{-7}	6.16×10^{-11}

*Based on 88 ml/hr/person and composition given in Table III-16.

(b) Feces

In the normally loaded shelter, feces are not expected to be a serious problem since adequate, sealable storage facilities will be available. Release of unpleasant odors would be expected mainly for small children who have not been toilet trained. However, in severely overcrowded conditions it is quite possible that volatile constituents of feces may be released into shelter air due to difficulty in gaining access to toilet facilities, inadequate volume of storage, increased probability of epidemic diarrhea and the like.

The quantity of feces produced per day under the conditions of an average diet and under normal physical activity is 100 to 150 gm (Clemedson, 1959). Small variations in the diet have little or no effect on the nature of the feces. However, an exclusively vegetable diet tends to yield a larger bulk and softer consistency feces, while on a meat diet the feces are harder and the quantity is less. Feces are produced even during starvation, though the quantity is diminished (West and Todd, 1951; pg. 522). Under shelter conditions the quantity of feces may be somewhat diminished in the absence of diarrhea.

Normal feces is made up of 65 to 75 percent water, 3 to 5 percent nitrogen (mostly endogenous), various lipids such as lecithin, coprosterol, fatty acids, and a minute amount of neutral fats, also mostly endogenous. As much as 25-35 percent of the total feces may be dead and living bacteria. Feces also contains a variety of toxic and evil-smelling substances which are formed through the decomposition of various metabolites by gut bacteria. Various amines and organic acids are present as well as such products of bacterial action as hydrogen sulfide, carbon dioxide, hydrogen, methane, ammonia, phenols and mercaptans. Some of the evil-smelling substances such as indole, skatole, phenol, mercaptans and hydrogen sulfide are more or less toxic. Indole and skatole impart to the feces the characteristic fecal odor. Indole may be present in quantities amounting to 60 mgm per 100 gm.

A list of important products present in feces is given in Table III-18. Of those listed, indole, skatole, hydrogen sulfide, ammonia and methylmercaptan (methanethiol) are the substances of greatest concern with regard to atmospheric contamination.

TABLE III-18

IMPORTANT PRODUCTS PRESENT IN FECES

Indole (60 mgm/100 gm)	C_8H_7N	Odorous
Skatole	C_9H_9N	Odorous
Paracresol	C_7H_8O	
Phenols		Odorous
Para-Oxyphenyl-propionic acid		
Volatile fatty acids		Odorous
Hydrogen sulfide	H_2S	Odorous
Methane	CH_4	
Methylmercaptan	CH_3HS	Odorous
Carbon dioxide	CO_2	
Proteoses		
Peptones		
Peptides		
Ammonia	NH_3	Odorous
Amino acids		
Some raw vegetables, unchanged, such as radishes, cole slaw, pickles, onion, skin of fruit, nuts, berries		
Mucus		
Tissue remnants, epithelial cells, muscle fibers, connective tissue		
Detritus		
Fats, neutral, free fatty acids or soups, approx. 2 grams daily		
Starch granules		
Bacteria, a great variety		

(Modified from Webb Associates, 1962, who cite "Human Tolerances to Environmental Elements," Cornell Aeronautical Laboratory, 1960, based on Mangelsdorf, J. E., "Logistic Support to Man's Ecology in Space," lecture notes from Short Course On Human Engineering Concepts and Theory, University of Michigan, 1959.)

(c) Urine

As in the case of feces, urine is not expected to present a serious problem in the normally loaded shelter. Again, release of unpleasant odor from urine is expected mainly for small children who are not toilet trained. However, in severe overloading it may not be possible to confine urine such that odor is controlled.

The major odoriferous constituent of urine of interest toxicologically is ammonia, which will be produced at the rate of 3 - 13 mg per kilogram of body weight per day. Assuming a shelter population in which sex and age are distributed in accordance with Table III-3 the weighted mean body weight per occupant would be 52. 0 kg. Consequently, urine ammonia would be produced at a rate of 156 - 676 mg per person per day which, if all of it were volatilized, would amount to approximately 0. 2 - 0. 9 liters per person per day. For analytical purposes, it seems reasonable to choose a value of 0. 5 liters per person per day. The values to be used, then, are as follows:

> Average rate of production of urine ammonia in gaseous form = 0. 5 l/day/person = 0. 0208 l/hr/person = 0. 000735 cu ft/hr/person (where an average person weighs 52. 0 kg).

To arrive at the rate of atmospheric contamination by urine ammonia, it is necessary to estimate the proportion of total urine output which is likely to be spilled or otherwise exposed to shelter air.

Other odoriferous or potentially odoriferous substances are also present in urine. They are listed in Table III-19 together with their estimated amounts.

TABLE III-19

ODORIFEROUS SUBSTANCES IN URINE

Constituent	Rate of Production mg/kg body wt/day
Ethereal sulfates	0. 95
Ammonia	3-13
Phenol	0. 4 (0. 2-0. 6)
Lactic acid	3. 0 (2-5)

(Adapted from Webb Associates, 1962)

Assuming an average body weight of 52.0 kg, the rate of production per person of the urine substances listed in Table III-19 are as given in Table III-20.

TABLE III-20

RATE OF PRODUCTION OF SELECTED ODORIFEROUS SUBSTANCES IN URINE

Constituent	Rate of Production per 52 kg person per hr
Ethereal sulfates	2.06 mg
Ammonia	20.8 ml gas
Phenol	0.87 mg
Lactic acid	6.5 mg

(d) Respiratory and other sources of carbon monoxide

(i) CO in expired gases

Aside from carbon dioxide and water vapor, which are discussed in foregoing sections, the major atmospheric contaminant derived from expiratory gases is carbon monoxide.

Carbon monoxide is a highly toxic gas which is usually formed by incomplete thermal combustion of carbon containing compounds. However, it is also formed within the body through the breakdown of hemoglobin to bile pigments and, probably, through the breakdown of myoglobin (Sjöstrand, 1950, 1951a, 1951b, 1952a, 1952b, 1952c; Malmström and Sjöstrand, 1953; Metz and Sjöstrand, 1954).

The carbon monoxide formed in the body is excreted through the lungs. According to Sjöstrand (1951a) the rate of formation of CO is about 0.5-1.0 ml per hour at rest. That would be equivalent to about 12 - 24 ml per day.

According to Bogatkov et al., (1961), when three healthy subjects were enclosed in a hermetically sealed room of 24 cubic meters during a daily routine of physical and mental work for 9 to 10 days, the concentration of CO gradually increased to 0.023-0.027 mg/liter, which is equivalent to about 0.77-0.90 mg/hr/subject or 0.62-0.72 ml/hr/subject. The average value for nonsmokers was 0.016 mg/liter or 0.43 ml/hr/subject and the value for smokers was 0.038 mg/liter or 1.01 ml/hr/subject.

According to Russell (1962), breath analysis for three non-smokers gave an average CO of 0.330 ppm, and breath analysis for two smokers gave an average CO of 2.35 ppm for exhaled air. The equivalent rates are approximately 0.1 ml/hr/man for nonsmokers and 0.75 ml/hr/man for smokers.

Physical exercise increases the rate of CO formation in the body. An increase in inhaled CO_2 or decrease in inhaled O_2 also seems to be associated with an increased rate of CO production (Malström and Sjöstrand, 1953).

Considering the mechanism of CO formation in the body, it seems reasonable to predict its output on the basis of body weight. (Variation with activity level is not expected to be significant in shelter life.) Table III-21 includes a computation for output of CO per body weight assuming a 70 kg body weight for the male, adult subjects.

(ii) CO produced by tobacco smoking

Another possible source of carbon monoxide is through smoking. Carbon monoxide content of cigarette smoke depends on the brand and on the rate of smoking. Baumberger (1923) reported an average of 8.3 ml CO per gm of tobacco smoked. Tsumura (1937) found a CO production of ten brands of cigarettes from 13.4 to 37.6 ml per cigarette. De Voogd and van der Linden (1939) reported 300 ml of CO per cigarette and 750 ml per cigar. Saruta (1938), using a smoking machine, found the following average values for CO production: cigarette tobacco, 62.69 ml/gm; pipe tobacco, 119.98 ml/gm; and cigar tobacco, 126.75 ml/gm. On the average, a cigarette weighing about 0.71 gm yielded about 44.24 ml in the smoke, while a cigar yielded about 806.23 ml. With ordinary mouth smoking without inhalation, one cigarette yielded only about 13.12 ml CO. (See also Clemedson, 1959)

TABLE III-21

RATE OF CARBON MONOXIDE EXHALATION

Source	Type of Subject	Rate of CO Production Per Man ml/hr	Rate of CO Production Per Man cu ft/hr	Rate of CO Production ml/kg/hr	Rate of CO Production cu ft/kg/hr
Sjöstrand (1951a)	Healthy adult	0.5 - 1.0	$1.8 - 3.5 \times 10^{-5}$	.0071 -.014	$2.5 - 4.9 \times 10^{-7}$
Bogatkov, et al. (1961)*	Non-smokers	0.43	1.5×10^{-5}	.0061	2.2×10^{-7}
Bogatkov, et al.	Smokers	1.0	3.5×10^{-5}	.014	4.9×10^{-7}
Russell (1962)*	Non-smokers	0.1	0.35×10^{-5}	.0014	0.49×10^{-7}
Russell (1962)*	Smokers	0.75	2.6×10^{-5}	.011	3.9×10^{-7}
Average Non-smokers		0.265	0.935×10^{-5}	.00379	1.34×10^{-7}
Average Smokers		0.875	3.09×10^{-5}	.0125	4.41×10^{-7}
Average All Subjects		0.606	2.14×10^{-5}	.00866	3.06×10^{-7}

*Values reported were converted to ml/hr assuming, where appropriate (for Russell), pulmonary ventilation of approximately 3.2 liters per min (BTPS) per sq m of surface area (Spector, 1956; pg 268), and a surface area of 1.75 sq m.

For purposes of this report, the values of CO production given in Table III-22 will be used.

TABLE III-22

CARBON MONOXIDE PRODUCED BY TOBACCO SMOKING

Type of Smoking	CO Production* ml/cigarette, pipe or cigar
Cigarette	13.
Pipe (2 gm tobacco)	70.
Cigar	240.

*Based on Saruta (1938) smoking machine data multiplied by 0.3 to convert to probable values for mouth smoking. The values derived are probably minimal, and could likely vary upward by as much as a factor of three.

Assuming the occupants are granted restricted smoking privileges such that, out of 100 persons of a mixed population, 50 smoked three cigarettes per day and 5 smoked two pipes per day, the daily output of CO due to smoking would be a minimum of about 2700 ml (STP). Unrestricted smoking could result in daily CO production rates of as high as 27,000 ml until tobacco supplies were depleted.

(iii) CO produced by mass fires

Large amounts of carbon monoxide are produced by burning buildings and other combustible substances. Since CO is also released by smoldering remains long after flames have died down, in very special instances where ventilation inlets are located near such smoldering remains, CO can be a serious problem for shelter occupants. However, it is thought that the seriousness of the problem will usually be over in a few hours, during which it should be feasible to seal the shelter.

The findings of A. Broida (1962) are particularly relevant here (also Wilson, 1960). Following is a quotation from Broida's 1962 presentation at the Symposium on Survival Shelters at the 69th Annual Meeting of the

American Society of Heating, Refrigerating, and Air-Conditioning Engineers in June 1962:

> "The next argument is that large quantities of carbon monoxide will be produced and will be drawn into the shelter. Unfortunately, our experiments have shown that this is indeed possible. In fact, we have measured concentrations of carbon monoxide as high as 7 percent (a concentration above 1 percent can cause death in 1 to 3 minutes). However, I have already indicated that the amount of fuel available in any single location is consumed in a relatively short time, an hour or two of active burning at the most. I believe the other participants in this symposium can demonstrate that almost any shelter big enough to get into is habitable for an hour or two without any elaborate precautions. Thus, if you can just close down your ventilation system for an hour or so, you should have little difficulty surviving the flaming portion of the fire burning overhead and, provided your vent is located so that it will not be buried by rubble, any air you draw in subsequently should be relatively free of carbon monoxide."

It should be mentioned, however, that small residual concentrations of carbon monoxide will very likely be around for long periods of time, and that even such small amounts may be significant when added to sources within the shelter. It is quite possible for concentrations of CO as high as 0.01 to 0.02 percent to linger on for several hours or even days due to smoldering remains. According to Wilson (1960), "carbon monoxide concentrations sufficient to cause mild headaches lingered for several hours" after the "Briones" test (large-scale fire test involving trees and brush). Typical records of 0.02 - 0.04 percent CO were measured as late as two and a half hours after the test was begun.

(e) Miscellaneous sources of trace atmospheric contaminants

A number of other sources of trace atmospheric contaminants will be present in the shelter. Many of these, such as mildewing and fermenting organic materials, cooking odors and the like, are not of human origin and will not be analyzed in this section. Those substances in odors of human origin are listed in Table III-23. It will be our task, insofar as possible, to add up the contribution of those substances from their diverse sources to determine the extent of the problem which they may present to shelter habitability, particularly in the overloaded case where they are most likely to be present in significant quantities.

TABLE III-23

SUBSTANCES IN ODORS OF HUMAN ORIGIN

Butyric acid
Caprylic acid
Ethyl alcohol
Lactic acid
Valeric acid
Ethyl mercaptan
Methyl mercaptan
Propyl mercaptan
Methane
Hydrogen sulfide
Indole
Skatole
Phenol
Various volatile amines
Ethereal sulfates
Ammonia

(Adapted from Connor Engineering Corp., 1953)

(i) Sweat

Sweat will be produced by all occupants at the expected temperatures in the shelter. In general, sweat will contain on the order of 1.2 - 1.6 percent solids, the remainder being water. About 2.7 mg of CO_2 (H_2CO_3) is produced per Kg body weight per day. Of the solid constituents, a number will give rise to odor. They are listed in Table III-24 with their probable (mean) amounts per 100 ml of sweat.

TABLE III-24

ODORIFEROUS SUBSTANCES IN SWEAT

Constituent	Approximate Amount
Ammonia	3.45 mM/liter (equivalent to 7.73 cc gas/100 ml)
Phenol	5 mg/100 ml
Lactic acid	310 mg/100 ml

(Values are adapted from Webb Associates, 1962: Table II. C. 12)

Sweat rate will be quite variable. However, for adults at 85° E. T., metabolic rate of 75 kcal m^{-2} hr^{-1}, and air velocity of 10 ft/min (see Figure III-31), the P4SR (predicted four-hour sweat rate) is about 0.6 liters, or about 150 ml per hour. For a 100 man shelter, then, the constituents listed in Table III-24 would be produced at the rates shown in Table III-25 under the thermal conditions of the example.

TABLE III-25

A REPRESENTATIVE RATE OF PRODUCTION OF ODORIFEROUS CONSTITUENTS OF SWEAT AT 85° E. T. FOR 100 OCCUPANTS*

Constituent	Rate of Production per hour per 100 Occupants
Ammonia	1160 cc (STP)
Phenol	0.75 gm
Lactic acid	46.5 gm

*Air velocity, 10 ft/min; metabolic rate per occupant, 75 kcal m^{-2} hr^{-1} (assuming steady state thermal conditions).

(ii) Vomitus

Vomitus as a source of atmospheric contaminants is not expected to be important unless an epidemic outbreak of disease accompanied by vomiting should occur. However, it is felt that such outbreaks will increase in likelihood as the degree of overloading increases.

The composition of vomitus varies widely depending on the presence of food particles. However, after an initial clearing of stomach contents, the composition of vomitus will most closely resemble that of gastric juice, which normally consists of about 99.4 percent water plus hydrochloric acid, sodium chloride, potassium chloride, small amounts of phosphates, the enzymes pepsin and mucin, lactic acid, and traces of other enzymes and organic acids. After a meal particularly, peptides, amino acids and other products of the digestive process will be present as well as undigested food particles.

Although the material removed from the alimentary tract by vomiting is mainly of gastric origin, in severe and prolonged vomiting it may also contain appreciable amounts of intestinal material.

Although the most important implication of severe vomiting to the shelter problem is the accompanying dehydration, odoriferous substances may also be added to the shelter air thus adding to the stress of an already critical situation. The substances of particular concern are the organic acids and breakdown products of protein.

(f) Toxicity of trace contaminants

The toxicity to humans of most of the trace contaminants likely to be found in shelter air is not well understood, particularly for continuous exposure to low concentrations over extended periods of time. Even where toxicities for single substances are known, their effect in combination is usually difficult to predict. Both synergistic and antagonistic effects have been found.

Unfortunately, threshold limit values found in the toxicological literature ordinarily refer to a normal work-day and work-week for a normal working lifetime. Higher concentrations producing relatively rapid effects have also been defined. However, neither of those bodies of data provide limit values which are necessarily valid for a continuous fourteen day exposure, a fact which has been pointed out by Back and Sandage (1962). They state that space cabin engineers, "lacking better data, have been using highly speculative figures derived from Industrial Threshold Limit Values (TLV) for tolerable contaminant concentration levels. For example, values of 10 ppm (by volume) are being cited for carbon monoxide, hydrogen, methane and paracresol; 50 ppm for hydrogen sulfide, indole, skatole, ammonia, and methyl mercaptan. Statements to the effect that organic pollutants should not be allowed to rise above 100 ppm, inorganics above 10 ppm, heavy metals above 1 ppm, and halogenated compounds such as hydrogen fluoride and chloride above 3 ppm for periods of 24 hours or more are made and are being used as criteria for engineering purposes (Shaffer, 1961). Unfortunately, the Threshold Limit Value is only designed to be used for 8 hour exposures for a 5-day work week and 30 year or more work span. Any extrapolation of these values for 30, 60, 90 or more day continuous exposure is not necessarily valid even though the TLV-s may have large built-in safety factors."

Until further research is carried out on continuous exposure to trace contaminants both singly and in combinations, prediction of effects of shelter air contaminants will be more or less speculative. Nevertheless, a preliminary analysis of the effects of trace atmospheric contaminants on shelter inhabitants is warranted at this time to assess the order of magnitude of the problem. Even subthreshold concentrations, when combined with other stresses acting on the occupants, may be significant.

To provide a basis for examining the probable effects of shelter air contaminants, each of the more important contaminants listed in previous sections is discussed below.

(i) Ammonia (NH_3)

Ammonia is a colorless gas with a specific gravity 0.597 that of air. It is extremely soluble in water, with which it forms ammonium hydroxide, a fact that is important considering the high humidity and attendant water of condensation which may be present in shelters in certain instances. Not only is ammonia present in feces, urine and sweat, it is one of the products of putrefaction of nitrogenous substances, a factor which might become important if waste disposal facilities were inadequate (which seems likely in severe overcrowding). Near putrefying substances, the amount of ammonia may be of the order of 15 to 1,500 parts per million of air (Henderson and Haggard, 1943: pg. 125).

Fortunately, ammonia and carbon dioxide combine in air to produce ammonium carbonate, a fact which would tend to limit the accumulation of free ammonia in shelter air to relatively low concentrations (depending on the rate of reaction, among other factors). However, ammonium carbonate, while less toxic than ammonia due in part to its lower solubility, may have some systemic toxic effects upon absorption. Free ammonia has both upper respiratory irritant effects and systemic toxic effects.

According to Henderson and Haggard (1943), the physiological response to various concentrations (parts per million by volume of air) of ammonia is as follows:

Least detectable odor	53 ppm (.0053%)
Least amount causing immediate irritation of the throat	408 ppm (.0408%)

Least amount causing irritation of the eyes	698 ppm (.0698%)
Least amount causing coughing	1,720 ppm (.1720%)
Maximum concentration allowable for prolonged exposure	85-100 ppm (.0085%-.0100%)

A maximum permissible value recently derived for space cabin air contamination is 50 ppm (0.005%).

Ammonia (free and combined) may be present in shelter air in concentrations of the order of magnitude of 3 to 17 ppm (see Table III-34).

(ii) Hydrochloric acid (HCl)

Although hydrochloric acid is not expected to be a very important shelter air contaminant, trace amounts may be present from vomitus which is not disposed of properly. Fortunately, hydrochloric acid will be neutralized by the larger amounts of ammonia which will be present in the air, producing ammonium chloride.

Henderson and Haggard (1943) give the following values for physiological response to hydrochloric acid:

Causes irritation of throat on short exposures	35 ppm (.0035%)
Maximum concentration allowable for prolonged exposure	10 ppm (.0010%)

(iii) Methane (CH_4)

Methane is a colorless gas which is one of the constituents found in flatus and feces. Aside from the hazard of explosion with high concentrations, there are apparently no ill effects from remaining for several hours in an atmosphere containing methane in concentrations as high as 3 to 5 percent, or from repeated exposures (Henderson and Haggard, 1943). In higher concentrations, methane appears to act as a simple asphyxiant. The effect of long-term, continuous exposure apparently is not known, but it is not likely to be noticeable at the maximum concentrations of 2×10^{-4} to 9×10^{-4} percent (see Table III-34) which may be present in a shelter.

(iv) Hydrogen sulfide (H_2S)

Hydrogen sulfide is an odoriferous gas which is frequently evolved from the decomposition of organic material. Its sources in the shelter are flatus and feces. Hydrogen sulfide is both an irritant gas and a systemic poison. Even in low concentrations, it exerts a marked irritant action on the cornea of the eye. Free hydrogen sulfide in the blood acts upon the nervous system as a depressant in small amounts, as a stimulant in larger amounts, and as a paralytic agent in very large amounts.

Henderson and Haggard (1943) give the following response data:

Maximum allowable concentrations for prolonged exposure	20 ppm (.0020%)
Slight symptoms after exposure of several hours	70-150 ppm (.0070-.0150%)

According to Sandage (1961), in an experiment involving the effects of a mixture of hydrogen sulfide and methyl mercaptan,it was shown that more mice died than could be accounted for by either compound alone. A synergistic action between the two compounds was apparently responsible. In experiments in which ten monkeys, fifty rats and a hundred mice were exposed to 20 ppm (0.002%) hydrogen sulfide for up to ninety days, no monkeys died, 24 percent of the rats died as compared with 4 percent of the controls, and 26 percent of the mice died as compared with 19 percent of controls. Expired mice showed abscesses of the brain, liver and lung. Considering these experiments, it may be desirable to lower the limit value for prolonged, continuous exposure.

Fortunately, it does not appear likely that shelter concentrations of hydrogen sulfide will become as high as 20 ppm or 0.002%. A rough estimate (see Table III-34) makes it appear more likely that concentrations will probably be on the order of 8×10^{-9} to 40×10^{-9} percent if only flatus and fecal sources contribute.

(v) Indole (C_8H_7N)

Indole is a highly odoriferous compound with a melting point of 52.5°C and a boiling point of 254°C. It is present in feces in amounts as high as 60 milligrams per

100 grams. Together with skatole, indole imparts the characteristic odor to feces. It enters the gaseous phase directly from the solid by slow diffusion. A milligram of indole vaporized is equivalent to about 0.1915 ml (STP).

The Industrial Threshold Limit Value for indole is 10 ppm or 0.001 percent. Although relatively little is known about the effects of long-term, continuous exposure for humans, recent experimentation has demonstrated that continuous exposure to 10.5 ppm (0.00105%) for 90 days produced greater mortality in monkeys, rats and mice than in control groups (Sandage, 1961). Out of 10 monkeys, 50 rats and 100 mice, 20 percent of exposed monkeys died as compared with none of the controls, 10 percent of rats as compared with 4 percent of controls, and 22 percent of mice as compared with 16 percent of controls. According to the author, the presence of Heinz body formations in red blood cells of animals exposed to indole may be due to damage to reticulocytes (immature red blood cells).

Although the animal data are by no means conclusive on this point, it seems wise to not allow indole to exceed 10 ppm and, indeed, to reduce the level of concentration for long-term, continuous exposures. Fortunately, it does not appear likely that concentrations of indole in shelter air will exceed an order of magnitude of $.08 \times 10^{-9}$ to $.4 \times 10^{-9}$ percent (see Table III-34).

(vi) Skatole (C_9H_9N)

Skatole is a highly odoriferous constituent of feces which has a melting point of 95°C, at which its vapor pressure is 1 mm Hg, rising to a vapor pressure of 10 mm Hg at 140°C. Its rate of diffusion into the gaseous phase is expected to be small. A rough estimate of its presence in shelter air is of the order of magnitude of $.02 \times 10^{-9}$ percent to $.1 \times 10^{-9}$ percent (see Table III-34). The Industrial Threshold Limit Value for skatole is 3 ppm (0.0003%), which is well above its estimated concentration in shelter air.

(vii) Methyl mercaptan (CH_3HS)

Methyl mercaptan is an odoriferous constituent of feces with a boiling point of 5.8 or 7.6°C, consequently at shelter temperatures it is normally in the form of a gas slightly soluble in water.

The Industrial Threshold Limit Value for methyl mercaptan is 50 ppm (0.005%). However, recent experiments by Sandage (1961) have demonstrated a greater than control value mortality for animals at this concentration for continuous exposures of 90 days. Out of 10 monkeys, 50 rats and 100 mice, 40 percent of monkeys died as compared with none of the controls, 10 percent of rats as compared with 4 percent of controls, and 43 percent of mice as compared with 16 percent of controls. In the face of these results it would appear wise to reduce the permissible maximum concentration of methyl mercaptan for long-term, continuous exposure to a value somewhat below the current TLV of 50 ppm. Fortunately, a rough estimate of CH_3HS contamination in shelter air makes it appear unlikely that values will exceed an order of magnitude of $.03 \times 10^{-9}$ percent to $.1 \times 10^{-9}$ percent (see Table III-34).

(viii) <u>Combined exposure to indole, skatole, methyl mercaptan and hydrogen sulfide</u>

It is not sufficient to state that concentrations of each contaminant do not exceed limit values since combinations of substances will not only produce greater effects than any one singly, but apparently will produce greater results in combination than can be accounted for by the total of individual results. Sandage (1961) subjected 10 monkeys, 50 rats and 100 mice for 90 days to TLV values of a combination of indole (10.5 ppm), skatole (3.5 ppm), methyl mercaptan (50 ppm) and hydrogen sulfide (20 ppm). Eighty percent of the monkeys died as compared to none of the controls, 64 percent of the rats died as compared to 4 percent of controls, and 99 percent of the mice died as compared to 16 percent of controls. Death was rapid for many of the animals. There appeared to be low-grade hemolytic activity and all three species evidenced lung pathology, with rats showing additional liver and kidney pathology.

The experiment demonstrated a considerable degree of individual difference, a fact which is significant to us here. In the words of the author (Sandage, 1961):

"There are a number of reasons for suspecting that individual differences in response to simple chemical agents such as those used here are more significant than we might assume. In the first place, it was observed that the monkeys which did survive in Group A (the mixed gases referred to above) past the middle of the run appeared to have adapted to the environment. The single mouse in this group that survived (which is still living in the laboratory) did so, apparently none the worse for the experience, despite the fact that only one other mouse in that group had survived beyond the 35th day of the run, and it died on the 58th day. As a matter of fact, 70 mice died in the first five days. Now, if we ignore the statistical evaluation of weight data, and closely inspect instead the individual weight changes of the rats and monkeys surviving in Group A, we find a rather surprising picture. The monkeys were heavier than the average weight of those in any other group (exposure to single gases). Those rats that survived beyond 30 days had almost a normal rate of gain during the second 30 days, and during the last 30 days had a rate of gain higher than that of any other group of rats, including the control animals.

"Twice during this experiment, we introduced small groups of mice into the experimental groups. Of 12 mice introduced into Room A on the 30th day, two died in 24 hours, five died in the next 24 hours, and they were all dead in 72 hours. On the 75th day of the run, this was repeated, with a different shipment of mice. Again, no mouse survived more than 72 hours. Nevertheless, of the 100 mice originally placed in this room, 24 survived longer than a week, 13 longer than two weeks, five lived four weeks or more, and one survived the entire 90 days.

"These observations would seem to be entirely compatible with an assumption that there is a genuine adaptive process operating - or operable - and that there are quite serious and significant differences in individual tolerance for these toxic compounds."

The wide individual differences in tolerance to these compounds among animals may suggest a similar range of individual differences among humans, a fact which would dictate a considerable lowering of the limit values to provide protection for subjects with lower than normal tolerance. However, the phenomenon of adaptation might become an important alleviating factor, particularly for instances in which concentrations build up gradually (as in the shelter). More research needs to be carried out to elucidate the phenomenon of adaptation to these compounds.

The experiments discussed above indicate that tolerable gaseous concentrations of compounds such as indole, skatole, etc., should be based on a combined value for all those present rather than on individual values. Thus, it is not valid to add up individual tolerance values to obtain a total tolerance value. Nor does the proposal of Shaffer (1961) to limit organic pollutants to 100 ppm seem to be valid when one considers the drastic results obtained by Sandage (1961) for a total concentration of only 84.0 ppm of indole, skatole, methyl mercaptan and hydrogen sulfide combined. While Sandage's data on animals most likely do not apply directly to humans, in the absence of better human data it represents our most reasonable basis for setting upper limits for long-term, continuous exposures to these contaminants either singly or in combination.

Until further work is done to define the toxicity of trace contaminants for humans singly and in combination for long-term, continuous exposures, it might be well to reduce the individual limit values by at least 20 percent and, better, by even 50 percent; to limit combinations of similar-acting gaseous contaminants to a maximum combined total limit value which does not exceed that established for any one of the constituent gases - or perhaps to a value such as 20 ppm or 50 ppm; and in any event not to allow any constituent gas concentration to exceed its limit value taken singly.

A more valid approach might be to establish rules for combined concentrations of gases and vapors (in the absence of direct experimental evidence) on the basis of an analysis of their individual sites of action and their secondary and tertiary reactions, taking into account that limiting concentrations of toxic substances are ultimately based on the allowable extent of injury at the site of action.

The factors involved in such an analysis include: 1) physical state and concentration of the substance in air (gas, aerosol, dust, fume), 2) respiratory rate and/or rates of other processes controlling the rate of intake of toxic substances, 3) solubility in body fluids, 4) rate of transport within the body to site where damage will occur, 5) tissue predilection, 6) mode of action, 7) rate of detoxification and/or elimination, and 8) rate of replacement of damaged cells. Construction of a relatively simple mathematical model to define the above relations appears to be feasible for a number of toxic substances, and would make possible a much more satisfactory definition of the predicted response of shelter inhabitants to combinations of shelter atmosphere contaminants.

(ix) Phenol (C_6H_5OH)

Phenols as a class are represented by phenol which is a somewhat odoriferous compound (carbolic acid) with a melting point of 41°C and a boiling point of 182°C. Phenols are present in feces, urine and sweat and may be present in the atmosphere of overloaded shelters in concentrations of the order of magnitude of $.4 \times 10^{-7}$ percent to 2×10^{-7} percent (see Table III-34).

The Industrial Threshold Limit Value for phenol is 5 ppm (0.0005 percent). Acute poisoning in man is characterized by action on higher nervous centers causing collapse. Chronic poisoning results in severe systemic disorders with gastrointestinal disturbances such as dysphagia, ptyalism, diarrhea, and anorexia. Central nervous disorders are common and death usually occurs when there is extensive damage to the renal and hepatic apparatus (Arnest, 1961).

(x) Lactic acid ($CH_3CHOHCOOH$)

Lactic acid is a metabolizable organic acid which, while adding to the odor problem, is not expected to represent a toxicological hazard in the shelter. It is produced in urine, sweat and vomitus.

(xi) Carbon monoxide (CO)

Carbon monoxide is a gas with a slight garlic-like odor. Its specific gravity is 0.967 and its solubility in water at 40°C is 0.0178 (by volume). Carbon monoxide is produced in the body and exhaled in the breath, given off by burning tobacco, and may be present in air outside the shelter during and possibly for some time after a mass fire. Its probable concentration in shelter air is discussed in the next section.

Carbon monoxide exerts its toxic action entirely through its deleterious effect on the oxygen carrying ability of blood. Carbon monoxide competes with oxygen for union with hemoglobin and, since the affinity of hemoglobin for carbon monoxide is 200-300 times greater than its affinity for oxygen, small amounts of carbon monoxide can result in oxygen deficiency. The distribution of hemoglobin between oxygen and carbon monoxide tends to approach an equilibrium defined by the products of the tensions and affinities of the two gases. The equilibrium percentage of carboxyhemoglobin (hemoglobin combined with carbon monoxide) in blood at sea level and normal ambient pO_2's is given by the following equation:

$$\%HbCO = \frac{pCO \times 250}{pO_2 + (pCO \times 250)} \times 100 \qquad \text{Eq. 10}$$

where:

$\%HbCO$ = percent carboxyhemoglobin in arterial blood

pCO = partial pressure of carbon monoxide in the lungs (blood), mm Hg

pO_2 = partial pressure of oxygen in the lungs (blood), mm Hg

(In the normal case at near sea level where hyperventilation is not present and carbon dioxide and oxygen concentration in air are normal, pO_2 in the lungs is about 102 mm Hg. Although a proportional factor of 300 is given by Henderson and Haggard (1943), a more recent value closer to 250 is given by Roughton (1954).)

According to Henderson and Haggard (1943), the physiological effects of various levels of carboxyhemoglobin in the blood (at sea level, normal atmosphere) are as follows:

%HbCO	Physiological Effects
10	No appreciable effect except shortness of breath on vigorous muscular exertion.
20	No appreciable effect in most instances, except shortness of breath, even on moderate exertion; occasionally slight headache.
30	Decided headache; irritable; easily fatigued; judgment disturbed.
40-50	Headache; slight confusion; collapse and fainting on exertion.
60-70	Unconsciousness; respiratory failure and death if exposure is long continued.
80	Rapidly fatal.
over 80	Immediately fatal.

An increase of carbon dioxide in the blood decreases the affinity of hemoglobin for carbon monoxide compared with its affinity for oxygen and tends to aid in eliminating carbon monoxide from the blood (Henderson and Haggard, 1943). Thus, to a small extent the presence of carbon dioxide in the shelter may ameliorate some of the effect of carbon monoxide. However, this might possibly be offset by the increase in rate of production of CO in the body when inhaled CO_2 is increased as discussed earlier.

Assuming normal breathing in an atmosphere containing normal proportions of oxygen and carbon dioxide at a sea level barometric pressure of 760 mm Hg, the concentrations of CO required to produce various levels of HbCO in the blood can be computed by using the equation given earlier and are as given in Table III-26.

Although the "toxic" effect of CO is entirely due to its action in reducing the amount of oxyhemoglobin available to transport oxygen to the tissues, conversion of 40 percent or more of hemoglobin to HbCO has much more serious effects than loss of the same amount of hemoglobin by, for instance, anemia. In normal man at sea level, and at rest or light activity, only the upper half of the steep portion of the oxyhemoglobin dissociation

TABLE III-26

CONCENTRATION OF CO IN LUNG GASES REQUIRED TO PRODUCE VARIOUS LEVELS OF HbCO (NORMAL ATMOSPHERE AT SEA LEVEL)

%HbCO	pCO(mm Hg)*	CO(%)	%CO in shelter air equivalent to %CO in lungs**
10	0.0453	0.00596	0.00671
20	0.102	0.0134	0.0151
30	0.175	0.0230	0.0259
40	0.272	0.0358	0.0403
50	0.408	0.0537	0.0604
60	0.612	0.0805	0.0907
70	0.952	0.125	0.141
80	1.632	0.215	0.242

*Computed by using the equation

$$\%\text{HbCO} = \frac{\text{pCO} \times 250}{\text{pO}_2 + (\text{pCO} \times 250)} \times 100 \qquad \text{Eq. 10}$$

assuming pO_2 = 102 mm Hg and pCO is that which exists in the lungs.

**Computed by using the relationship

$$\%\text{CO (shelter air)} = \frac{\text{pCO}}{\text{P}_\text{B} - \text{pH}_2\text{O} - \text{pCO}_2} \qquad \text{Eq. 11}$$

where:

pCO = partial pressure of CO in the lungs, mm Hg

P_B = barometric pressure = 760 mm Hg

pH_2O = partial pressure of water vapor in the lungs = 47 mm Hg

pCO_2 = partial pressure of carbon dioxide in the lungs = 38 mm Hg curve is used in oxygen unloading, the lower part being kept as a reserve to be drawn on during exercise. The oxygen dissociation curves in the lower range of pO_2 are similar for percentages of HbCO within the range of zero to 40, and therefore oxygen unloading could be kept up to its usual value by using up more of the reserve available due to the shape of the dissociation curve. In normal human subjects at rest or light work, conversion of up to one-third of the circulating hemoglobin to HbCO does not depress the oxygen uptake of the body appreciably. Above 40 percent HbCO, however, the type of reserve given by the dissociation curve soon becomes exhausted and a dangerous situation rapidly develops (Roughton, 1954).

Most references to tolerance limits to carbon monoxide assume normal values for percentage of oxygen in the inspired air (about 21 percent). However, in cases of oxygen deficiency, two things happen to those tolerance values. First of all, if pCO_2 in inspired air has increased pulmonary ventilation,the rate of increase of HbCO to its equilibrium concentration is speeded up. In the second place, the decreased concentration of oxygen in inspired air increases the equilibrium concentration of HbCO. The result of decreased pO_2 and increased pCO_2, then, is to decrease tolerance times at a given percent HbCO and to increase the severity of response at a given percent CO in inspired air due to increased percent HbCO. Actually, since the actual stress is decreased availability of oxygen (which is proportional to %$HbCO_2$) rather than increased HbCO *per se*, tolerance levels should actually be based on %HbCO rather than %CO in inspired air.

Muraoka (1961) states that carbon monoxide concentrations should be limited to 100 ppm or less in shelter air. Apparently, this is meant to represent the level of effect of 100 ppm CO in an otherwise normal atmosphere. Therefore, it is interesting to determine the effects of oxygen depleted atmospheres on this value or, rather, to determine how the value of 100 ppm for CO would affect tolerance to lower oxygen concentrations.

First of all, it is necessary to determine the pO_2 in the lungs (alveoli) resulting from a reduced shelter air oxygen concentration. This can be done (assuming

pCO_2 of shelter air to be negligible) by using Equation 7

Assuming $Q = 0.9$, $pC = 38$ mm Hg and $P_B = 760$ mm Hg, the following table of equivalents was constructed:

TABLE III-27

ALVEOLAR pO_2 FOR VARIOUS SHELTER AIR OXYGEN CONCENTRATIONS

$\%O_2$ in Shelter Air	Alveolar (Lung) pO_2, mm Hg
20	101
19	94
18	87
17	80
16	73
15	65
14	58
13	51
12	44
11	37
10	30

Similarly, the pCO in the lungs (alveoli) at concentrations of CO in the inspired (shelter) air can be computed through use of the following approximate equation:

$$pCO = fCO(P_B - pH_2O - pC) \qquad \text{Eq. 12}$$

where:

pCO = partial pressure of carbon monoxide in the lungs (alveoli), mm Hg

fCO = fraction of CO in inspired (shelter) air

pH_2O = partial pressure of water vapor in the lungs (alveoli), 47 mm Hg at normal body temperature

pC = partial pressure of carbon dioxide in lungs (alveoli), usually about 38 mm Hg

Values computed for lung pCO equivalent to shelter air concentrations of CO are given in Table III-28.

TABLE III-28

ALVEOLAR pCO AT VARIOUS CONCENTRATIONS OF CO IN SHELTER AIR

% CO Shelter Air	pCO, mm Hg Alveoli
0.005 (50 ppm)	0.0337
0.010 (100 ppm)	0.0673
0.020 (200 ppm)	0.135
0.030 (300 ppm)	0.202
0.050 (500 ppm)	0.337
0.100 (1000 ppm)	0.673
0.125 (1250 ppm)	0.841
0.150 (1500 ppm)	1.010
0.175 (1750 ppm)	1.178
0.200 (2000 ppm)	1.346
0.225 (2250 ppm)	1.514
0.250 (2500 ppm)	1.683

Assuming that the partial pressures of oxygen and carbon monoxide in arterial blood are equal to their pressures in the lungs (the assumption is quite close for normal subjects at rest), it is possible to utilize alveolar or lung values equivalent to shelter air values to carry out the computation of percent HbCO and percent HbO_2 at various shelter air O_2 and CO concentrations. The method used here was adapted from that used by Roughton (1954; pg. 62).

If it is assumed that the amount of reduced hemoglobin present in a mixture of oxygen at partial pressure pO_2 and of carbon monoxide at partial pressure pCO is the same as it would be if no carbon monoxide were present and the partial pressure of oxygen was set equal to $pO_2 + 250pCO$, the amount of reduced hemoglobin (Hb) could then be read off the normal oxyhemoglobin dissociation curve for blood in absence of carbon monoxide (pCO_2 must also be known). If it is also assumed that the combined hemoglobin is still partitioned between oxygen and carbon monoxide according to Equation 10, then the following equations hold:

$$\%HbO_2 = \frac{100 - \%Hb}{1 + 250 \frac{pCO}{pO_2}} \qquad \text{Eq. 13}$$

$$\%HbCO = \frac{250 \frac{pCO}{pO_2} (100 - \%Hb)}{1 + 250 \frac{pCO}{pO_2}} \qquad \text{Eq. 14}$$

where pCO and pO_2 are known, and %Hb can be determined by the procedure described above through use of the oxyhemoglobin dissociation curve (Figure III-37 or 38).

The values of $\%HbO_2$ and %HbCO for a shelter air CO of 100 ppm and for various percentages of oxygen in shelter air were computed by using the foregoing equations and data, and are given in Table III-29.

TABLE III-29

EFFECT OF LOWERING OXYGEN IN SHELTER AIR ON HbCO AND HbO_2 IN ARTERIAL BLOOD (SHELTER AIR CO = 100 ppm)

$\%O_2$ Shelter Air	pO_2, mm Hg Alveoli (Blood)	%HbCO Arterial Blood	$\%HbO_2$ Arterial Blood	$\%HbO_2$ Arterial Blood w/o CO
20	101	14.3	85.7	97
18	87	16.7	81.3	96
16	65	19.5	75.5	91
14	58	21.1	72.9	87
12	44	24.9	65.1	78
10	30	29.1	51.9	58

From Table III-29 it can be seen very clearly that a constant level of CO in shelter air becomes increasingly important as oxygen concentration decreases, even for such a small "subthreshold" concentration as 100 ppm. Although the blood pO_2 is not altered significantly (from that which would be predicted in the absence of CO), the presence of CO means that reserve is significantly decreased such that collapse comes much earlier than for the case of oxygen deficiency alone. For instance, while "useful consciousness" can be maintained by healthy young men at 11 to 12 percent oxygen for a relatively long period of time, those same persons could do so at oxygen concentrations only as low as 16 to 17 percent in the presence of 100 ppm (0.01 percent) carbon monoxide, a concentration which has no noticeable effects at normal concentrations of oxygen. This factor is particularly significant in the "buttoned-up" shelter, or in the overloaded shelter with ventilation inadequate to maintain normal levels of oxygen.

(g) Total concentrations of trace contaminants in shelter air

The total concentration as a function of time of trace contaminants in shelter air will depend on the volume of the shelter, the rate of ventilation by outside air and the rate of production of each of the contaminants. Given that information, the concentration of contaminants can be calculated by using the equations derived in Appendix D.

Reliable estimates of rates of production of contaminants are difficult to obtain. However, a preliminary assessment for at least some of the contaminants can be arrived at by summing up the data presented in the foregoing sections. A consolidated list of contaminants, their sources and rates of production is given in Table III-30.

Unfortunately, many gaps exist in the data. But even if the gaps apparent in Table III-30 did not exist, the actual amounts of such substances as feces, urine and vomitus that would be exposed to the air could only be guessed. Furthermore, the rate at which odoriferous solids and liquids would diffuse into the gaseous phase could only be estimated at best due to the variable form factors and consistencies of the masses containing the substances.

Notwithstanding those difficulties, however, it is desirable to make an estimate, albeit speculative, of the rates of production of air contaminants to formulate at least some notion of the extent of the problem of air contamination in overloaded fallout shelters. To do this, Table III-30 was used as a basis for constructing a hypothetical (but in our view, quite possible) shelter situation. However, the reader should be cautioned against using the hypothetical situation for anything other than an illustration of the

TABLE III-30

SELECTED SHELTER AIR CONTAMINANTS, THEIR SOURCES AND RATES OF PRODUCTION

Contaminant	Sources	Rate of Production per Person (but not necessarily released to shelter air)
Methane	Flatus	4.3 ml/hr
	Feces	?
Hydrogen sulfide	Flatus	1.76×10^{-4} ml/hr
	Feces	?
Indole	Feces	2.5 mg/hr*
Skatole	Feces	?
Methylmercaptan	Feces	?
Ammonia	Feces	?
	Urine	20.8 ml/hr
	Sweat	11.6 ml/hr**
Volatile fatty acids	Feces	?
Ethereal sulfates	Urine	2.06 mg/hr
Lactic acid	Urine	6.5 mg/hr
	Sweat	465 mg/hr**
	Vomitus	?
Phenols	Feces	?
	Urine	0.87 mg/hr
	Sweat	7.5 mg/hr**
Carbon monoxide	Expired air	
	non-smokers	0.265 ml/hr
	smokers	0.875 ml/hr
	Smoking	13 ml/cigarette 70 ml/pipe 240 ml/cigar
	External sources	Perhaps 0.01% in outside air for 1st day in fire areas
Carbon dioxide	Flatus	8.27 ml/hr
	Feces	?
	Urine	2.2 ml/hr

TABLE III-30
(continued)

Contaminant	Sources	Rate of Production per Person
Hydrogen	Flatus	14.1 ml/hr
Hydrochloric acid	Vomitus	?

*Assuming 100 gm feces per person per day

**Assuming 150 ml sweat per person per hour (85°E. T., 10 ft/min air velocity, 75 kcal per sq. m. per hour metabolic rate)

principles involved and a first approach to defining the orders of magnitude.

In the hypothetical illustration, it is assumed that ten percent of feces and urine become exposed to shelter air; and that all of the gaseous constituents, all of the liquid constituents and a tenth of the volatile solid constituents enter the gaseous phase. Skatole is estimated at 25 percent of indole and methylmercaptan at 10 percent of indole. On a per person basis, fecal ammonia is estimated at 15 ml/hr, fecal methane at 8 ml/hr, fecal phenols at 5 mg/hr and fecal hydrogen sulfide at 2×10^{-4} ml/hr. Values for vomitus are not included. Using these assumptions and estimates, Table III-31 was constructed to serve as a basis for estimating the concentration of contaminants in shelter air for a hypothetical but possible situation.

Utilizing the values for rates of production of shelter air contaminants (except for CO) given in Table III-31, the value for steady-state concentration of each constituent was calculated and given in Table III-34. It can be seen that none of the constituents exceed limit values, nor do they appear to do so in combination. However, the concentrations shown do present a serious odor problem and are of the order of magnitude which would lead us to expect a contribution to the overall combined stressfulness of the shelter environment.

TABLE III-31

ESTIMATED RATES OF DIFFUSION INTO THE GASEOUS PHASE OF SELECTED ATMOSPHERIC CONTAMINANTS IN A HYPOTHETICAL SHELTER SITUATION

Contaminants	Rate of Diffusion per Person	
	ml/hr*	cu. ft/hr*
Methane (CH_4)	9.2	3.25×10^{-4}
Hydrogen sulfide (H_2S)	4.2×10^{-4}	1.48×10^{-8}
Indole (C_8H_7N)	4.2×10^{-6}	1.48×10^{-10}
Skatole (C_9H_9N)	1.2×10^{-6}	0.424×10^{-10}
Methylmercaptan (CH_3HS)	1.3×10^{-6}	0.459×10^{-10}
Ammonia (NH_3)**	16.9	5.97×10^{-4}
Lactic acid ($CH_3CHOHCOOH$)	0.13	4.59×10^{-6}
Phenols (C_6H_5OH, etc.)	0.002	7.06×10^{-8}
Hydrogen (H_2)	15.7	5.54×10^{-4}
Carbon monoxide (CO)		
No smoking (55% former smokers)	0.666	0.235×10^{-4}
Smoking (50% smoke 3 cig/day, 5% smoke 2 pipes/day	30.6	10.8×10^{-4}

*Adjusted to 30°C

**Includes ammonia converted to $(NH_4)_2\,CO_3$

The hypothetical illustration examined above assumes a limited, constant rate of exposure of waste products to shelter air on a per person basis. However, it is more likely that the rate of exposure of waste products per person would actually increase as overloading increased. In fact, at some point, not likely to be reached in reality since shelterees could leave the shelter, chaos would ensue. Only in such an event does it appear very probable that shelter air contaminants (except CO) would rapidly reach dangerous levels in a ventilated shelter.

In the case of methane and hydrogen, while no toxic effects would be expected per se, the danger of explosion is omnipresent. As shown in Table III-34, their combined concentration in shelter air for the maximum likely overloading (2.0) is almost 0.001 percent. According to Haldane (1935, pg. 430), "when about 5.4 percent of methane is present in air, the mixture becomes inflammable with an ordinary light, and explodes violently with a somewhat higher percentage." However, "with more than about 12 percent of methane the mixture ceases to be inflammable." Considering the presence of other combustible gases such as carbon monoxide and hydrogen sulfide, plus the probable presence of dust particles of organic origin, the hazard of explosion may be a very real one. Further research needs to be done to determine the conditions under which the hazard of explosion may become significant.

The problem of carbon monoxide in the shelter is more significant than for the other trace contaminants. Six cases were examined to determine the variation in shelter air CO concentrations as a function of amount of smoking and presence of CO in the ventilation air due to fire or smoldering material outside the shelter. The rates of CO production given in Table III-31 were used except for the case of smoking ad lib, for which a conservative value of 106×10^{-4} cu ft per person per hour was used. The results are given in Table III-33.

Neither the no smoking cases nor the limited smoking cases appear to present a serious problem, assuming ventilation air contamination never exceeds 100 ppm and that shelter air oxygen does not fall below 18 to 19 percent. However, in the case of smoking ad lib, even without ventilation air contamination, limit values for long-duration exposure are exceeded in the shelter overloaded by a factor of two or more.

TABLE III-33

CONCENTRATION OF CO IN SHELTER AIR, PPM

Overloading Factor	0 hrs.	1-24 hrs.	25+ hrs.
No smoking No external CO			
1.0	0 ppm	.13 ppm	.13 ppm
2.0	0	.26	.26
3.0	0	.39	.39
5.0	0	.65	.65
No smoking Ext. CO = .01% first day			
1.0	100	100.1	.13
2.0	100	100.3	.26
3.0	100	100.4	.39
5.0	100	100.7	.65
Limited smoking No external CO			
1.0	0	6	6
2.0	0	12	12
3.0	0	18	18
5.0	0	30	30
Limited smoking Ext. CO = .01% first day			
1.0	100	106	6
2.0	100	112	12
3.0	100	118	18
5.0	100	130	30
No smoking first day Limited smoking thereafter Ext. CO = .01% first day			
1.0	100	100.1	6
2.0	100	100.3	12
3.0	100	100.4	18
5.0	100	100.7	30
Smoking *ad lib* No external CO			
1.0	0	59	59
2.0	0	118	118
3.0	0	177	177
5.0	0	295	295

Ventilation rate = 3 cfm/person for the design loading (1.0) - proportionally less for overloading (e.g., 1.5 cfm/person at 2.0).

CO production rates as given in Table III-32.

TABLE III-34

ESTIMATED STEADY STATE CONCENTRATIONS OF TRACE CONTAMINANTS IN SHELTER AIR FOR VARIOUS DEGREES OF OVERLOADING (HYPOTHETICAL)

	Steady State Concentration, %			
Overloading =	1.0	2.0	3.0	5.0
1. Methane	1.80×10^{-4}	3.60×10^{-4}	5.40×10^{-4}	9.00×10^{-4}
2. Hydrogen sulfide	8.22×10^{-9}	16.4×10^{-9}	24.7×10^{-9}	41.1×10^{-9}
3. Indole	0.0822×10^{-9}	0.164×10^{-9}	0.247×10^{-9}	0.411×10^{-9}
4. Skatole	0.0235×10^{-9}	0.0470×10^{-9}	0.0705×10^{-9}	0.118×10^{-9}
5. Methyl mercaptan	0.0255×10^{-9}	0.0510×10^{-9}	0.0765×10^{-9}	0.128×10^{-9}
6. Ammonia	3.33×10^{-4}	6.66×10^{-4}	9.99×10^{-4}	16.65×10^{-4}
7. Phenols	39.2×10^{-9}	78.4×10^{-9}	$118. \times 10^{-9}$	196×10^{-9}
8. Hydrogen	3.08×10^{-4}	6.16×10^{-4}	9.24×10^{-4}	15.4×10^{-4}
9. Total of 3, 4, and 5	0.131×10^{-9}	0.262×10^{-9}	0.393×10^{-9}	0.655×10^{-9}
10. Total of 2, 3, 4, 5 and 7	47.6×10^{-9}	95.2×10^{-9}	143×10^{-9}	238×10^{-9}

Computed using equations derived in Appendix D, assuming ventilation rate = 3 cfm/person, shelter air volume = 65 cu ft/person, rates of production of contaminant gases as given in Table III-32. In all the above cases, time to reach 50 percent of steady-state value is 0.25 hours, and 90 percent of steady-state value is 0.83 hours.

If contamination of ventilation air also existed, limit values for CO might be exceeded by a factor of two or three, leading to headache, irritability, fatigue and impairment of judgment for normally, healthy persons, and possibly collapse for persons with certain kinds of impairments (cardiovascular disorders, etc.).

c. Nutritional Variables

Although not as critical as the thermal problem, undernutrition becomes increasingly important as the degree of overloading and the duration of enshelterment increase. The Office of Civil Defense has established a provisioning policy which provides each shelteree with 10,000 kilocalories of a "survival" ration which is primarily carbohydrate. Thus, in provisioning a 100 man shelter, rations containing 1,000,000 kilocalories would be stored in readiness for an emergency. If 100 people entered the shelter for a planned stay of 14 days, about 714 kilocalories per person per day could be distributed under a policy of constant level of rationing. If initial radiation levels permitted a stay as short as seven days, 1428 kilocalories per person per day would be available. However, if our 100 man shelter were overloaded by a factor of two, the number of available kilocalories per person per day would be reduced to half. In the most severe case, the rations might have been spoiled so that no food was available for the duration of enshelterment. Although it is probable that in severe cases foraging from the shelter or outside assistance might alleviate part of the problem, for purposes of analysis we assume that initial provisioning represents the only available food.

In overloading, two possibilities exist: 1) acute starvation for the duration of stay (no caloric intake); and 2) semi-starvation (a less than maintenance caloric intake). According to Keys et al. (1950), there are several very important differences between those two possibilities: "1) in total fasting the hunger sensation almost disappears after a few days, but it is progressively accentuated in prolonged undernutrition; 2) ketosis is a typical result of fasting but it does not develop in semi-starvation; 3) famine edema has never been reported in total starvation. There are important similarities - bradycardia and lowered metabolism are two of these —but it is obvious that the two situations are neither quantitatively nor qualitatively identical."

Undernutrition produces many important physiological and psychological effects which will influence the well-being and behavior of shelter occupants; they may be accentuated in the overloaded shelter and will almost certainly add significantly to the overall stressfulness of the experience. In a few instances, however, semi-starvation might produce desirable effects. For instance, basal metabolic rate tends to become depressed and sensitivity to heat is decreased (Keys et al. 1950), thus both lowering heat production in the shelter and reducing subjective reaction to heat. On the other hand, physical fitness is adversely affected by semi-starvation thus reducing physiological tolerance to heat. However, whether these results would be obtained during a relatively short period of ensheltermen t is problematical.

(1) Psychological effects

The important psychological effects of undernutrition in the early stages include nervousness and overactivity, greater irritability and emotional instability. With large calorie deficits and protein losses exceeding one kilogram (for adults), behavior changes in the direction of total immobility, apathy and depression. An increasingly self-centered sensitivity underlies the apparent apathy, superseding social and moral consciousness. However, it is not likely that the latter effects will be obtained in normal shelter inhabitants in a period not exceeding 14 days.

Semi-starvation has remarkably slight effect on test scores measuring such factors as spatial relations, verbal fluency, memory and reasoning. However, observed intellectual activity is reduced and narrowed. The apparent contradiction can be resolved by distinguishing between intellectual capacity and volition. The latter suffers greatly under the stress of starvation. (Keys *et al*. 1950).

In terms of group behavior, as semi-starvation increases there is a progressive deterioration in socialization, humor, conversation and sense of responsibility (perhaps shelter managers should receive an adequate diet even in the face of severe shortage). The observed effect is to place each man on guard against all others and to make group cooperation extremely difficult. Apathy and suspicion predominate. (Keys, 1959.)

(2) Physiological effects

The physiological effects of semi-starvation include disturbed function of the digestive system; hypotension; bradycardia with tachycardia upon minimal exertion; liver injury in the form of reduced protein and increased fat content, fibrosis and increased susceptibility to toxic agents; reduced enzyme activity; anemia; edema; disturbed nitrogen balance and, of course, reduction in body weight. However, for the levels and duration of undernutrition expected in the shelter situation, it is doubtful if the more severe of these effects will occur.

(3) Weight loss

Although weight loss is a useful measure of the effects of starvation, it has certain limitations which should be understood. First of all, the body is not a homogeneous structure but is made up of various "compartments"- muscle mass (active tissue), fat, bone and connective tissue, and water is one useful classification. In the conversion of body mass to energy during starvation, body fat is consumed more rapidly than muscle mass, thus making it possible for obese persons to survive a starvation regime better than thin persons. The relatively greater loss of body fat is apparent in Figure III-41, which shows the percentage decrements in body weight, muscle mass, and body fat for 32 men in the Keys et al. Minnesota Experiment involving 24 weeks of semi-starvation. The more significant index of starvation is not total body weight loss, but rather the percentage loss of lean body weight (muscle mass, active tissue, cellular mass, etc.). In shelter management, therefore, it is important to recognize the need of lean persons for more food during semi-starvation regimes than other, more generously endowed occupants. The significance of body weight loss is also different for growing children than for adults; a far smaller total and percentage weight loss can be tolerated by children.

According to Krieger (1921), the lethal level for loss of the original body weight is about 20 percent for the young, 40 percent for adults exposed to acute starvation, and up to 50 percent in cases of semi-starvation. Morgulis (1923) summarized the data on weight losses during experimental fasting, the record being held by Succi who lost 25.3 percent of his initial weight in a 40-day fast; Levanzin lost 21.9 percent of his original body weight in 31 days. According to Kerpel-Fronius (1947), with the help of adequate diet and blood and plasma transfusions, continued daily for 10 to 20 days, infants reduced to 50 percent and in some cases even to 40 percent of the standard weight would recover. It would appear that, except for general trends, the concept of a definite lethal body weight loss is subject to so many qualifications that it cannot be applied in any general sense. This is in agreement with the view of Keys et al. (1950) and of Zimmer et al. (1944) who state: "In contrast to the general belief, there is no state, except the final coma, when the disease (starvation) is irreversible." However, it does not seem unreasonable to accept the values given by Krieger as a general rule of thumb for normal, healthy people whose initial body weights are near the average for their age, sex

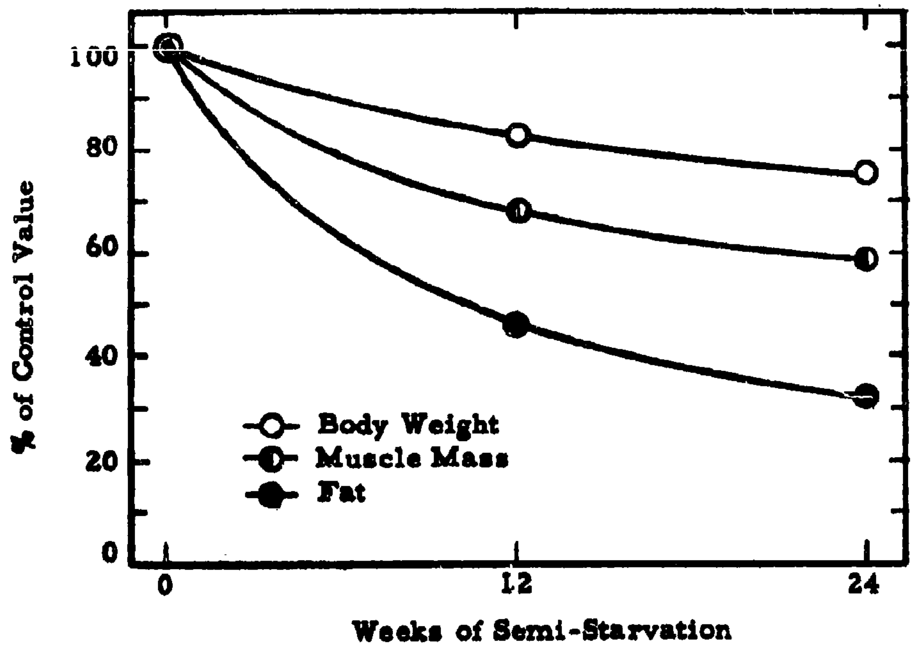


Figure III-41 Percentage decrements of body weight, muscle mass, and body fat in the Minnesota Experiment for 32 young men on a diet of approximately 1500 calories per day (Keys, et al., 1950) and body type. For shelter occupants, we would be more inclined to set the allowable limits for body weight loss at 5 to 10 percent for the young and 10 to 20 percent for adults with the full realization that many of them could sustain an even greater weight loss - but that a very few would find even that much weight loss intolerable.

(4) Weight loss of shelter occupants

Weight loss as an index of adequacy of shelter diet is useful providing reasonable precautions are taken in its interpretation. Therefore a weight loss prediction chart was developed as an aid to provisioning planning and analysis of effects of overloading (Figure III-42).

Basic to the chart is the assumption that the energy expended by the body in the form of heat or as measured by oxygen consumption is derived from the utilizable calories consumed, or from body tissue, and that a fixed, average factor can be applied to define the conversion of body mass to energy. The basic equation of balance, then, is:

$$M_t = M_i + M_a - M_l \qquad \text{Eq. 15}$$

where

M_t = body mass at a given time

M_i = initial body mass

M_a = body mass added due to "conversion" of food to tissue

M_l = body mass converted to energy

The equation could also be stated in terms of energy.

Reasoning from the above relationship, the following equation for percent weight loss can be defined:

$$\% \, WL = \frac{WL}{BW} \times 100 = \frac{K_1 (C_1 - K_2 C_2) t}{BW} \times 100 \qquad \text{Eq. 16}$$

where

WL = weight loss

BW = body weight

K_1 = a conversion factor, metabolized body tissue mass per Kcal energy

C_1 = heat output for the shelter population
= basal heat production x factor for activity level

K_2 = efficiency of utilization of food calories (i.e., ratio of calories actually utilized to calories ingested)

C_2 = assumed caloric intake, before adjustment for efficiency of utilization

t = time

In using the above equation for percent weight loss to construct a set of "iso-weight loss" curves, the following assumptions were made:

1. Initial shelter food provisioning is 10,000 Kcals per person for normal loading, proportionally less for overloading, in the form of a wheat survival biscuit (OCD Guide, 1962).

2. The efficiency of utilization (K_2) of the wheat survival biscuit is 81 percent of theoretical caloric intake (Wells, 1962, pg. 31). Therefore, provisioning at 10,000 Kcals represents 8100 Kcals actually utilized.

3. The conversion of body tissue to usable energy (K_1) is in the ratio of 0.120 gm of metabolized (energy producing) tissue per Kcal heat energy liberated. The reasoning is as follows: A person with normal weight will lose body tissue mass composed largely of fat with small quantities of protein. We assume that out of a gram of energetic body tissue consumed, about 89 percent will be fat and only 11 percent will be protein. The mass equivalents of a Kcal of fat and protein are 0.106 and 0.232 grams respectively (Webb Associates, 1962). Therefore, the body mass utilized in producing a Kcal of energy is:

$$G_{ms} \text{ per Kcal} = 0.89 \, \frac{(0.106 \text{ gm})}{\text{Kcal}} + 0.11 \, \frac{(0.232 \text{ gm})}{\text{Kcal}}$$

$$= \frac{0.120 \text{ gm metabolized tissue}}{\text{Kcal heat energy liberated}}$$

The body composition and mechanisms are such that body weight loss is a highly complex process. With daily deficits of 1500 to 2000 Kcal, the first days of severe undernutrition may yield higher than predicted weight losses composed mainly of water. As time passes, the percent of tissue water lost decreases. Although this does not invalidate the foregoing weight loss equation it does necessitate a careful interpretation of the equation's meaning - percent weight loss simply represents the energetic mass loss and would require adjustment for water content to make it equivalent to observed weight loss. Such complications merely confirm what has been known for years about the "masking" effect of water consumption and utilization with reference to body condition in undernutrition. In general, it appears that variations in energetic body weight can be a reliable index of nutritional state and may approach the observed weight loss reasonably closely under normal conditions of water consumption and utilization, and metabolism.

4. The weighted mean body weight (BW) and basal heat production (BHP) for the general population of U.S. males and females were used (52.0 kg and 56.5 Kcal/hr respectively; see Table III-3 in the section on population variables). For populations which do not resemble the general population with respect to distribution of sex and age, the conversion factors given in Figure III-43 must be used. Further adjustment is required for body composition varying widely from normal and for activity levels which deviate from that which was assumed. Although this was not provided for in the conversion charts, such adjustments can readily be made by using the basic weight loss equation.

5. An activity level of 1.72 times the weighted basal heat production of the general population has been assumed. Keys suggests that muscular activity can best be stated as a multiple of BMR (equivalent to basal heat production, BHP) and indicates values for various activities. To estimate the energy used by the shelter population it is necessary to determine the total time spent at various activity levels. The basis for our assumed activity level is as follows:

Activity	Duration (Hrs)	Multiple of BHP	Product
Sleep	8	0.9	7.2
Light activity	14	2.0	28.0
Moderately vigorous activity (exercising adults, playing children)	2	3.0	6.0
			42.2

The average hourly energy expenditure is therefore:

$$C_1 = \frac{1}{24}(41.2) = 1.72 \text{ x BHP}$$

The weight loss chart assumes $C_1 = 1.72 \text{ x } 56.5 = 97.2$ Kcal/hr.

A BMR multiple of 1.70 is cited by Keys as being equivalent to office-type activity, where no sports or hobbies are a part of the individual's activity pattern. While there is evidence that activities can become depressed in shelter confinement and some may respond by sleep patterns (Saunders, 1962), it seems desirable to superimpose survival-oriented group activity upon the range of spontaneous confinement responses found in the general population. A survey of recent shelter studies involving both family occupancy and military groups shows shelter activity levels ranging from sleep to active (Strope, 1960, 1961, 1962; Altman, et al, 1960; Saunders, 1962). Family groups, or groups with mixed ages seem prone to wider activity level ranges than more homogeneous groups. The problem needs further study.

6. The basis for the conversion chart is the following equation:

$$\%WL' = \%WL \left[\frac{(C'_1 - K_2C_2)BW}{(C_1 - K_2C_2)BW'}\right] \qquad \text{Eq. 17}$$

where the bracketed ratio is the conversion factor, the primed symbols refer to the new population in question and the unprimed symbols refer to the general U.S. population as represented by Figure III-42.

Two sets of curves have been included in Figure III-42. The first set allows the available Kcal intake per person per day (assuming constant rationing) to be determined as a function of degree of overloading and the planned duration of occupancy. The second set enables the average percent loss of initial body weight to be determined as a function of daily caloric intake and planned duration of shelter occupancy. Following are examples of the use of Figure III-42:

1. Assuming normal loading, $L = 1.0$, a planned duration of shelter occupancy of 11 days will allow a daily intake of about 910 Kcals per shelteree, resulting in an average body weight loss of 4 percent.
2. Assuming normal loading, if only 1000 Kcals are consumed per day for 10 days, the general population can be expected to lose an average of about 3.5 percent of its body weight.

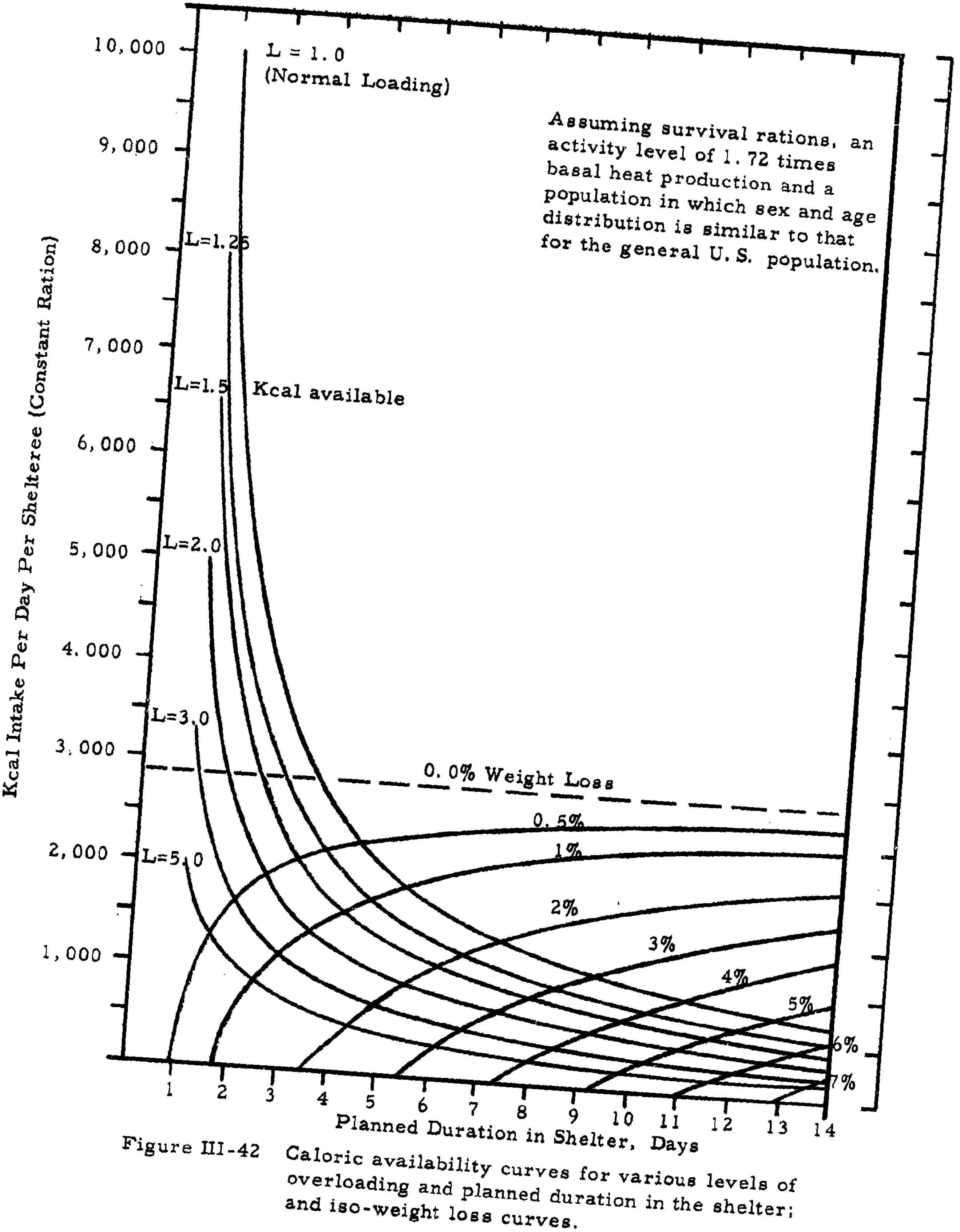
In the second example, we predicted a 3.5 percent body weight loss for the general population. Suppose we wished to determine weight loss at the same level of caloric intake for 1 - 4 year males. Figure III-43 indicates a conversion factor, CF, of about 1.73 for males 1 - 4 years old at an intake of 1000 Kcals. Using the relation

$$\%WL' = (\% WL)(CF) \qquad \text{Eq. 18}$$

where: $\% WL'$ is the percent weight loss for males 1 - 4 years old,
$\% WL$ is the percent weight loss for the general population, and
CF is the conversion factor, we have:

$\%WL' = (3.5)(1.73) = 6.05$ percent for males in the 1 - 4 year age group.

Note that a maximum average daily intake of about 2875 Kcals per shelteree per day should result in no average weight loss for the general population under the conditions and assumptions stated, but that weight may be either gained or lost by occupants within the various sex and age groups unless their caloric intake is adjusted in accordance with their respective conversion factors. A maximum average of slightly more than 7.5 percent weight loss is possible for the general population if no food is consumed for 14 days. It is also noteworthy that the current



Assuming survival rations, an activity level of 1.72 times basal heat production and a population in which sex and age distribution is similar to that for the general U.S. population.

Figure III-42 Caloric availability curves for various levels of overloading and planned duration in the shelter; and iso-weight loss curves.

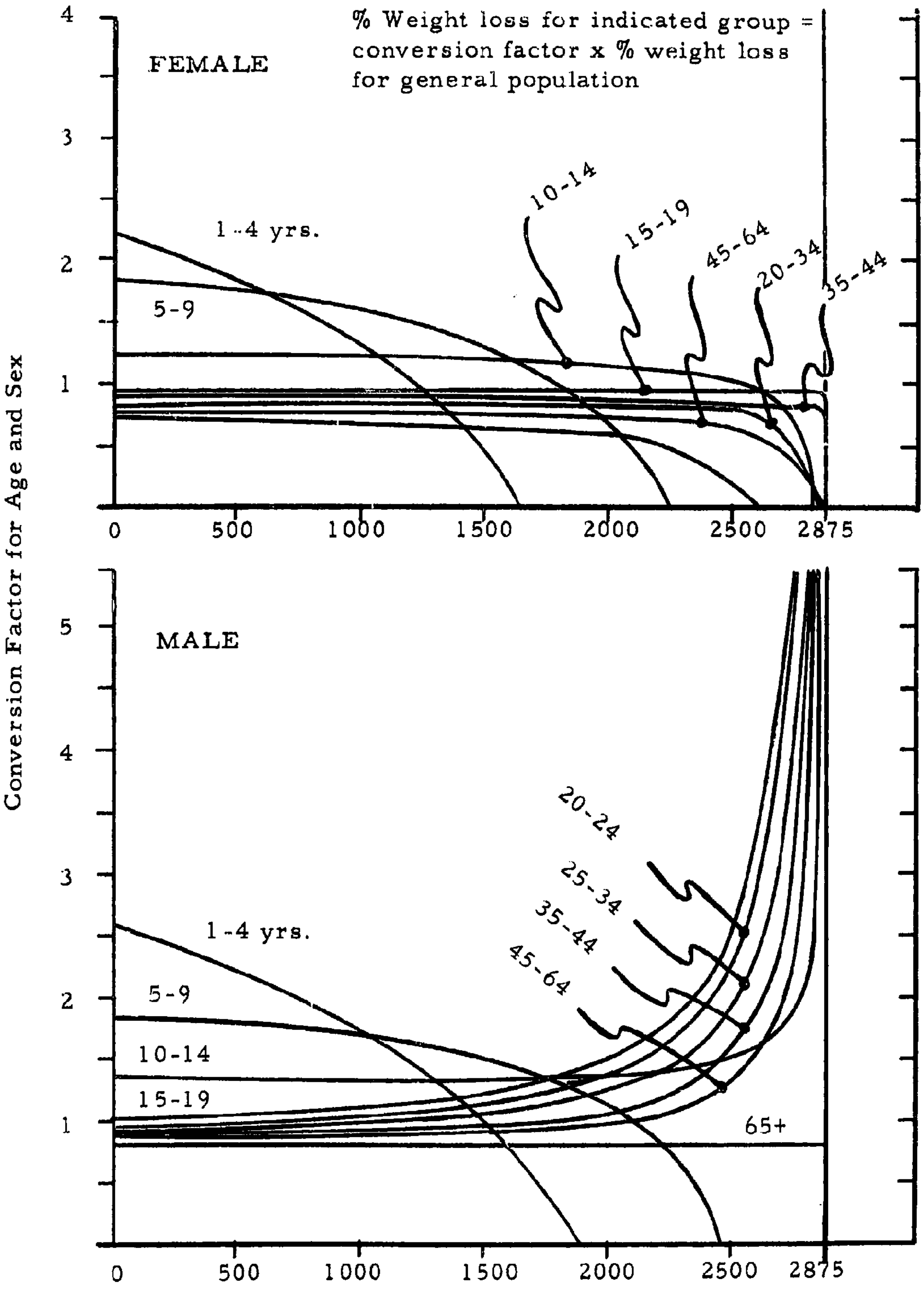


Figure III-43 Sex and age group conversion factors for body weight loss. Used to convert weight loss values of general population in Figure III-42 to values for sex and age groups.

OCD provisioning policy, even under normal loading, would result in an average weight loss of about 5.7 percent for a shelter occupancy period of 14 days.

What are the implications of the predicted 5.7 percent weight loss in 14 days in the absence of overloading? Altman (1960) fed family groups at the rate of 2000 Kcals/day for two weeks; the study revealed no significant physical performance decrements, nor psychological responses that could be linked to undernutrition.

Food was fourth of twenty-one items on a Discomfort Index filled in by 99 young sailors after spending two weeks in a shelter eating 1850 Kcal (Saunders, 1962). Despite elevated temperatures, upper respiratory infections, and low activity levels, no critical physical or mental responses were observed.

Moderately active individuals fed 500 Kcal/day suffered slight change in physical work capacity after 7 days. Dizziness was observed (cited in Wells 1962, p. 4).

In the Minnesota Experiment (Keys et al, 1950), it was found that 32 young men, fed at 45 percent of their normal diets and kept on an active schedule had lost an average of 24 percent of their body weight after six months. The adaptation of these men to prolonged undernutrition was complex. Psychomotor changes within the first two weeks were negligible. There was a slight increase in gross body reaction time with a decrease in manual speed (p. 705). These findings suggest motivation loss. The tendency was to reduce the magnitude and number of gross body movements in an effort to conserve energy. About 5 percent of the normal body strength was lost in 14 days. Deviations of the food drive (self rating) rose sharply from the first (p. 823). There were smaller depressions of the sex and activity drives. Despite extreme deteriorations in their capacity to perform severe physical work (52 percent of normal by the twelfth week), and an increasing tendency toward irritability and emotional instability as semi-starvation progressed into months, no significant deterioration in either physiological or psychological response was apparent at the end of 14 days.

The implications are that despite the immediate onset of total caloric deprivation in a shelter, such a regime can be borne by most normal adults without irreparable harm. The natural tendency is to decrease the physical tasks undertaken. There is also a reduction in the cost of physical activity due to weight loss itself.

Both theoretical and empirical investigations support the view that, for the general population, a provisioning of 714 Kcals per day for 14 days will be consistent with the capacity of most to survive the shelter and function adequately in the post-shelter environment. Even total deprivation will not be critical for adults. However, total deprivation would result in critical body weight losses for children.

Shelter management should be sensitive to the special population groupings in their shelter as well as to individual differences. Wells presents a concise analysis of the requirements of various nutritional groups (pg. 11). Obviously those with greatly decreased supplies of body fat, diseased individuals, or pregnant or lactating women will have unique dietary requirements. Care must be taken to adjust for these. In this respect, a "rule of thumb" tool would be useful to a harried shelter manager, permitting ready adjustment of provisions. Such a tool could eliminate any serious inequalities in rationing. It would extend the effect of the conversion factors available in the present tool, and thus further optimize each individual's survival potential under given loading conditions.

(5) Comparison of observed and predicted weight loss

An examination of the dietary levels of a number of studies appears to confirm the validity of the caloric intake-weight loss prediction tool presented above. Under the assumptions stated, a daily intake of 714 Kcal is about 20 percent of the 2875 Kcals intake calculated to result in 0. 0 percent average weight loss for the general population. Figure III-42 shows a 14 day weight loss of about 5. 7 percent. Using data from many sources, and assuming an average daily caloric requirement of 2860 Kcal to maintain body weight, Keys et al. suggest a body weight loss of 30 percent in three months (or 5. 8 percent in 14 days at constant rate of loss) on a diet containing 20 percent of the calories required for maintenance. Care must be taken in generalizing from the populations referred to in Keys to that used in this study, however, since his figures represent average values for normal adults.

Further confirmation of the prediction tool is indicated by Strope's studies in which weight losses in the range of 1. 6 to 1. 9 percent were observed at the end of 14 days at about 2000 Kcals/day (1960, 1961, 1962) as compared to a prediction of slightly over two percent using Figure III-42 .

However, other studies appear to indicate weight losses greater than would be predicted. Saunders (1962) recorded 4.8 percent average weight loss among 100 young sailors after 14 days of shelter confinement, whereas the adjusted prediction would be about 3.4 percent. Feeding at a rate of 2000 Kcal/day (or less) for 14 days, Altman et al. (1960) observed an average weight loss of 5.4 percent.

In the light of the earlier discussion of water losses concommitant with loss of energetic tissue, it is quite possible that the discrepancy between predicted and observed weight loss in the latter two studies may be accounted for on that basis. In addition, calories provided and calories consumed were discrepant. In Altman's studies, it was noted that not all the food was eaten. If the actual intake in Altman's studies was closer to 1500 Kcal per day and if a fourth of the weight loss was water, his figures would be consistent with predicted values. Furthermore, it is difficult to make valid comparisons without definite knowledge of activity levels and adjusting for population composition. For instance, Saunders' young sailors may well have been leaner than the average for that age group, a factor which could very well make several percent difference in percentage weight loss.

In general, it appears that the weight loss chart predictions are within the observed range of values for weight loss of groups confined in shelters. However, further work is needed to fully confirm the validity of the chart and the assumption of an activity level of 1.72 times basal heat production needs to be evaluated further.

d. Other Physiological Variables

A number of factors will influence the response of shelter occupants to thermal, atmospheric and nutritional stresses. Among them are such factors as noise, sleeplessness, morbidity and physical condition of the occupants at the time they enter the shelter.

(1) Noise

Noise level in a shelter will very likely increase markedly as loading is increased. Anyone familiar with cocktail parties has observed the spiraling phenomenon of increasing noise level resulting from ever-increasing loudness of speech. The "steady-state" noise level attained is a function of the number and density of people present. Noise levels of 70 to 80 decibels or even more are not uncommon in such situations, particularly in densely crowded rooms.

The presence of high noise levels makes communication (and therefore management) difficult, increases psychological tension and irritability, and tends to increase muscular tension, thus increasing metabolic rate. Sleeplessness may be produced, particularly in susceptible persons. It has been observed that high intensity "white" noise may have an anesthetic effect, masking pain, making coherent thought and speech difficult, and the like. However, it does not seem likely that shelter noise will grow to such intensities.

The character as well as the intensity of the noise is important. For instance, conversation, clanging of utensils, etc., is usually more distracting and detrimental to sleep when superimposed on an otherwise low noise level background than when a relatively high but meaningless noise level is present. However, in either case additional stress is superimposed on what may be an already barely tolerable level of stress from other causes.

Figure III-44 presents a generally accepted set of criteria for evaluating tolerance limits for continuous exposure to wideband noise in terms of sleep, speech interference level (S.I. L), hearing conservation and risk of deafness, and immediate physiological stress reactions and mechanical damage to the ear. Judging from the curves given in Figure III-44, it seems unlikely that actual damage will result from shelter noise, but sleep and speech communication might be

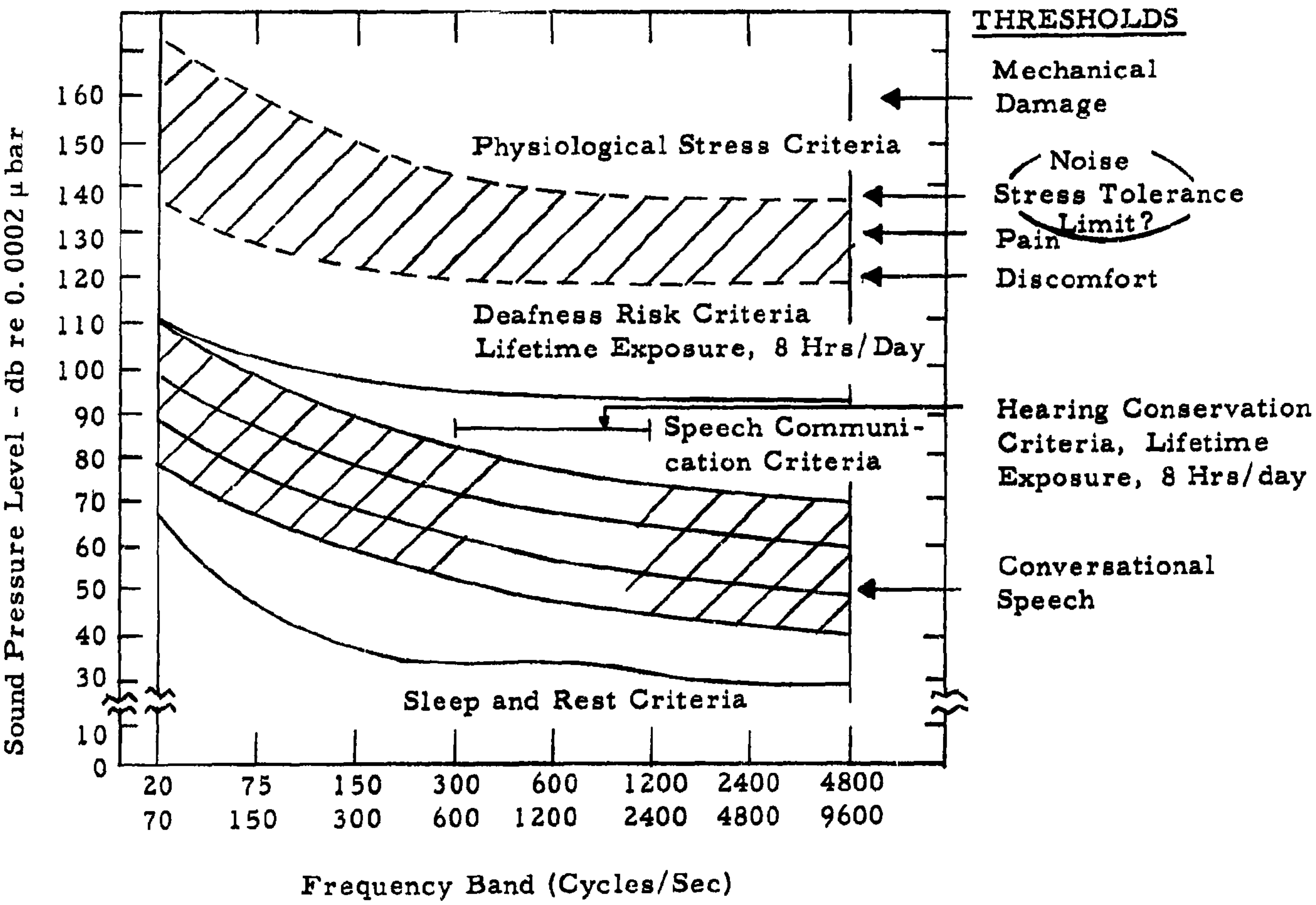


Figure III-44 Tolerance criteria for noise.

Criteria for evaluating tolerance limits for continuous exposure to wideband noise in terms of sleep, speech interference level (S. I. L.), hearing conservation, and risk of deafness; and for immediate physiological stress reactions and mechanical damage to the ear. (Adapted from WADC TR 58-622, 1958, after Parrack and Glorig, 1952, see Webb Associates, 1962).

interfered with, particularly in an overloaded shelter - unless strict "noise control management" is carried out. Experimental study of the effects of shelter noise levels as a function of loading should be carried out in future simulated shelter habitability tests.

(2) Sleeplessness

The significance of adequate sleep can hardly be overemphasized. Susceptibility to and recovery from disease are strongly influenced by the amount and quality of sleep and rest. In the absence of adequate sleep, physical fitness declines and tolerance to almost all stresses is decreased. For instance, some if not most of the increase in fatalities during heat waves is attributed to the fact that uncomfortably high temperature and humidity at night prevent adequate sleep, thus critically depleting energy reserves among people who are already marginally physically fit.

Sleeplessness is expected to increase as a function of degree of overloading due to increasing, unrelieved thermal stress; hard, cramped sleeping surfaces; increased noise level; jostling by neighbors; increased incidence of disease; psychological disturbances; and many other factors. Considering the great importance of adequate rest - which is even more important (and more difficult to obtain) in overloading than in normal loading - the inclusion of adequate supplies of sedatives in the shelter medical kit might very well mean the difference between survival and death or premature escape for occupants of a severely overloaded shelter.

(3) Morbidity

Disease incidence in the shelter will depend on the kinds of disease brought into the shelter by occupants, ventilation air, insects, rodents, etc.; the adequacy of isolation facilities, medical supplies and medical attention; the lag between onset and recognition with ensuing steps to prevent spread; the physical condition of occupants; the adequacy of sanitary facilities; and numerous other factors. Considering the factors which increase the probability of occurrence, severity of reaction, and spread of disease, it must be concluded that the probable occurrence of disease will increase significantly as the degree of overloading increases. The presence of disease decreases tolerance to heat, excessive carbon dioxide and carbon monoxide, toxic trace gases, dehydration, undernutrition, etc. Furthermore, if the disease is accompanied by diarrhea or vomiting, dehydration will result - and in the face of limited water supplies the situation may become critical within a very short time.

According to Table III-4, the probable number of persons entering a shelter with measles, German measles, whooping cough, mumps, chicken pox, scarlet fever, dyptheria, or smallpox is about .24 out of 100. For influenza and grippe, bronchitis, coryza and cold, sore throat, or laryngitis, the probable number is about .37 out of 100. These are significant probabilities, considering the limited facilities for dealing with them and considering the greater probability of contagion in the overloaded condition. Among the other ailments - totaling .77 per 100 - which would undoubtedly lower resistance to stress are pneumonia, pleurisy, asthma, tuberculosis, thyroid disease, diabetes mellitus, anemia, debility and malnutrition, cerebral hemorrhage, rheumatic fever, hypertension and arteriosclerosis, various heart ailments, functional digestive disorders, diarrhea and enteritis, ulcer of stomach and duodenum, appendicitis, and nephritis.

In all, out of 100 entrants, about 1.4 may be suffering from some form of acute disease and about the same number may be suffering from a chronic ailment.

It seems quite possible that disease may become the most important limiting factor in some shelters - particularly in overloaded shelters. Superimposed on other stresses, even what would normally be the least severe of diseases can become critical. If overloading is to be accounted for in shelter planning, serious attention must be given to means for preventing, limiting the spread of, and/or decreasing the severity of disease.

5. Psychological Variables

The purposes of this section are (1) to summarize the available data concerning psychological factors relevant to fallout shelter occupancy, (2) to illustrate how those factors can be expected to interact and evoke additional behavioral reactions, (3) to indicate the significance of those reactions in the overloaded shelter, and (4) to consider the results of some previous studies in the light of existing theoretical frameworks.

a. Summary Charts

(1) Chart 1 - Environmental Stresses (Figure III-45)

To accomplish the first goal, Chart 1 was constructed, compactly bringing together available information concerning psychological reactions to stressful environmental stimuli. Since more than one reaction generally is reported to result from a single stimulus, and since several stimuli may elicit the same response, the diagram seems best suited to illustrate the interrelations of the stimuli and reactions at a glance. All noun categories used in Chart 1 were taken directly from reports by the investigators whose works are presented in the accompanying bibliography. The only liberty taken with the data was to group seemingly similar categories of reactions; e. g., nausea and vomiting; exhilaration and euphoria; and lethargy, lassitude, and listlessness.

The charts are constructed similar to a schematic wiring diagram. Except where otherwise indicated by arrowheads, each reaction to stimuli can be found by following a line from left to right and either up or down. For example, the "Primary Reactions" to food deprivation are irritability (et. al.), depression, apathy, and lethargy (et. al.). Other reactions to food deprivation as indicated in columns headed "A" and "B" are "weakness," "muscle soreness," "general fatigue," and "dizziness" as well as defective "coordination" and "manual performance" and reduced "endurance," "concentration" capacity, "interest," "ambition" and "self discipline." Notice that only marked (i. e., dotted) intersections have meaning once a route has been selected. Intersections not marked can be treated as if they do not exist; these crossing lines are completely independent, for purposes of reading the charts.

The stressful stimuli listed in Chart 1 are limited to environmental (and provisional) stresses relevant to shelter existence. Since the stimuli are to a greater or lesser extent measurable, experimental findings and observations are able to relate definable resulting responses to initiating conditions. It is assumed that in every study each primary variable was controlled so that valid, generalizable stimulus-response relationships can be demonstrated.

Unfortunately, psychological and psychophysiological reactions frequently do not lend themselves to clear cut conclusions regarding their origins. For example, Dr. Eliot Rodnik* related some interesting complex relations he and his coworkers found in a study performed several years ago. When subjects were fed heated, humid oxygen through a mask their heart rates increased; when the rising temperature of the oxygen reached a critical level, they responded as if fear- or panic-stricken and attempted to tear off the mask. Interrogation and further investigation led Dr. Rodnik to realize that not only did the heat stress cause the heart to beat more rapidly, but the strong fear reaction which developed also produced a faster heart rate. Thus, he and his associates were unable to conclude with certainty the extent to which the increased heart rate resulted from the heat stress and the amount contributed by the fear reaction.

For the practical purpose of examining the psychological factors pertinent to the shelter situation, it may often be sufficient simply to know what observable behavior to expect under various general categories of stimuli, e.g., that most people will frantically tear off a mask which feeds them heated O_2. Why the behavior occurs, or whether it results directly or indirectly from the hot, humid oxygen <u>need</u> not enter into a description of reactions to various stimuli. Knowledge of the intervening responses and theories governing them will make it possible to establish a mode of operation when it becomes necessary to <u>do</u> something to alter or control behavior. Even then, one must first define the level at which a behavioral change is to be attempted.

Chart 1 simply indicates that a previously observed reaction may result from one or more stimuli. If the reaction is

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*Professor of Psychology, UCLA; from a verbal discussion held with the author on March 19, 1963.

detrimental to individual or group survival, corrective action might become necessary, and alleviating the environmental stresses (if possible) could be one such procedure.

(2) Chart 2 (Figure III-46) and Chart 3 (Figure III-47)

Charts two and three provide additional information regarding possible interactions of reactions and some interesting implications for control of behavior. For example, the line connecting "panic" to "depression, apathy" etc., would imply that to calm a very anxious individual one might rapidly establish a strong fear reaction by surreptitiously cutting off power to the ventilation system and announcing that lack of oxygen will cause general suffocation in a short time. Panic may reign, but once the ventilation system were again operating the relief would be likely to take the form of an over-compensatory reaction resulting in a reduction of activity of those whose anxiety level increased during the crisis. Similarly a very depressed person can often be reactivated by having his worst fears repeatedly exaggerated by someone else who can present the fear-bases with a subtle touch of satire. Unless an individual is mentally ill, he will probably respond with, "Well, things aren't that bad!"

(3) Psychological stresses

As stated earlier, Chart 1 begins with stressful environmental stimuli because they are measurable and, therefore, have lent themselves to investigation. There are, however, other stimuli which may be equally stressful but which are not readily measurable and which do not appear to have been independently controlled in a simulated shelter experiment. Those stresses include:

1. Separation from family members
2. Having observed (or been involved in) a catastrophe prior to entering the shelter
3. Widely mixed socioeconomic, religious or ethnic groups in the shelter
4. Poor, weak, or otherwise inadequate leadership
5. Breakdown of communication, ventilation, or other shelter equipment

6. Spread of disease

7. Communication that conditions outside or in other shelters are worse than expected

Of those, the most often discussed problem is that of inadequate leadership. According to one study (Altman, et. al., 1960), poor management will result in inferior adjustment and attitude on the part of shelter occupants (p. 98). Grinker and Spiegel (1945) list as outcomes, loss of confidence, insecure feelings and reduction of morale (pp. 46 and 47). Tannenbaum, et. al., (1961) comment on the reduced effectiveness of the group and the resulting management difficulties which a poor leader will have (p. 30). Cartwright and Zander (1953) indicate throughout their book that an inadequate leader will be unable to gain full cooperation largely because he cannot clearly define the goal of the group. Strope, et. al., (1961)* stress loss of interest and reduced standards of shelter living and conduct in a group poorly led.

The extensive interest in the value of good leadership warrants attention. People under severe stress are usually unable to manage their lives efficiently or effectively and require guidance. As shelter loading increases, the stresses will mount, and the capability of the leaders to manage special problems as well as planned activities may well establish the survival value of the shelter. Later in this report, methods will be suggested by which leaders can handle some special behavioral problems.

Inadequate communication can be expected to reduce morale also, according to Gautney and Jones (1962). Other results of poor communication are reduced group solidarity and confusion among shelter occupants regarding direction of purpose (p. 151).

Those reports indicate the general importance of adequate leadership and communication. It seems likely that the generalizations apply as well to the problem under consideration here. To investigate the effects of faulty leadership and communication specifically in an overloaded fallout shelter would require rigid controls of those variables in

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*See reference No. 15 in the chart bibliography.

a formal study, a study which might yield some questionable results anyway without the stresses associated with an actual holocaust.

The charts are sufficiently comprehensive that they probably include all the reactions which may be expected from the seven uninvestigated stresses in the list as well as those appearing on the charts themselves. For example, a man separated from his wife whom he is not certain to be safe in another shelter may enter his shelter anxious or worried, so that if communication with the other shelters is not achieved rapidly enough for him, he may become angry, complaining, or aggressive; such reactions do appear on the charts. A woman, having seen her child trampled to death by a panic-stricken crowd would probably enter the shelter crying and remain depressed and lethargic throughout most of her stay; expected results from such reactions can be derived from the charts. However, breakdown of equipment might stimulate hopeless depression in some people and interest in others who accept the challenge to be useful.

(4) Interpretation of the charts

Since the latter reaction is one which would be desired because it can lead to an effective solution, it is not included in the charts; the primary function of the diagrams is to illustrate negative factors - those which are detrimental to shelter survival and which are expected to be exaggerated in the overloaded situation. Chart 2, therefore, starts with the Primary Reactions from Chart 1 and expands on some of their effects. Chart 3 starts with the physiological, psychological and psychophysiological reactions and indicates both the interactions which may be expected and some added effects as well.

Charts 2 and 3 were derived primarily from broad clinical and experimental psychological knowledge. A few specific references are indicated; however, in general, Outcomes, Energy Disposition, Secondary Results, and other effects list information gained through familiarity with the psychological and shelter study literature.

The physiological effects of psychological reactions are subsumed under "Energy Disposition." In Charts 2 and 3 it is interesting to note that more lines are directed toward "Increased" than toward "Reduced Energy Expenditure." That fact cannot necessarily be construed to indicate that there will be an overall increased energy expenditure under adverse conditions. It is equally important to consider the number of people which the lines represent, a quantity which cannot at present be estimated. If most of the occupants revert to an apathetic withdrawal or passive depression (see Cohen, 1953), overall shelter energy expenditure will be reduced so that less food, water, and oxygen will be required and the heat, CO_2, noise and odor production will be kept at a lowered level.

The extent to which each of the factors included in the charts will occur within a shelter - overloaded or not - under the actual stress of a thermonuclear attack unfortunately could only be conjectured at this time. Rationale will be presented later for the belief that any or all of the reactions may be expected to appear concurrently within any given shelter. The degree to which leaders will be able to control excessive responses will be a function not only of the severity and history of the stimuli but also of (1) the extent and quality of people's previous training as to what to expect and what to do in the shelter environment, (2) the thoroughness with which organization and management within the shelter is pre-planned, (3) the effectiveness of selection and training of leaders, and (4) the characteristics (including behavioral predispositions) of the shelter population.

REFERENCED REACTIONS TO STRESSFUL E

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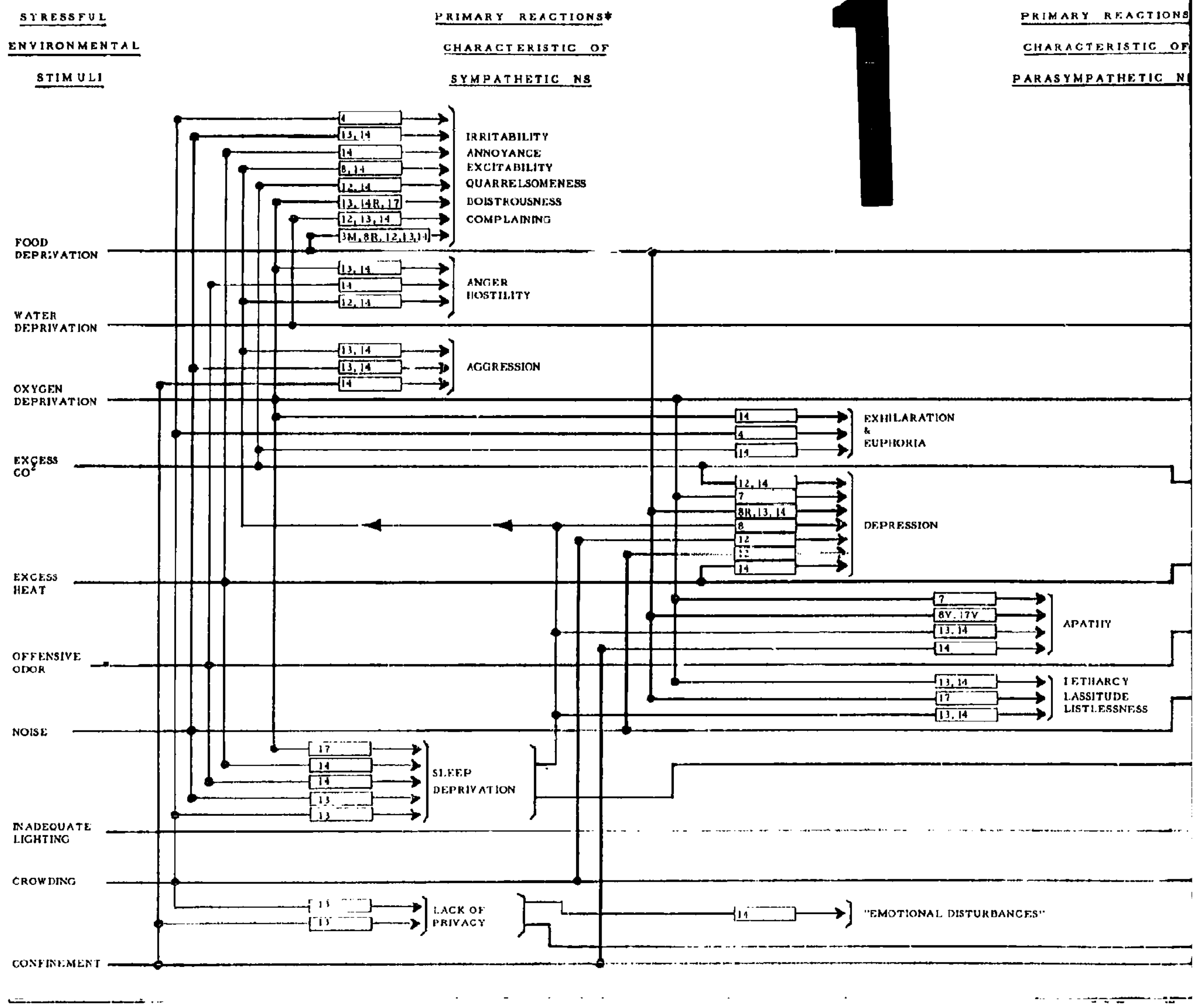

Numbers represent bibliographical references.

Numbers without letters indicate that the author merely reported the relationship without specifying how the relationship was obtained.

V following a number indicates that the relationship was simpl

R following a number indicates that the relationship was repor

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2

REACTIONS TO STRESSFUL ENVIRONMENTAL STIMULI

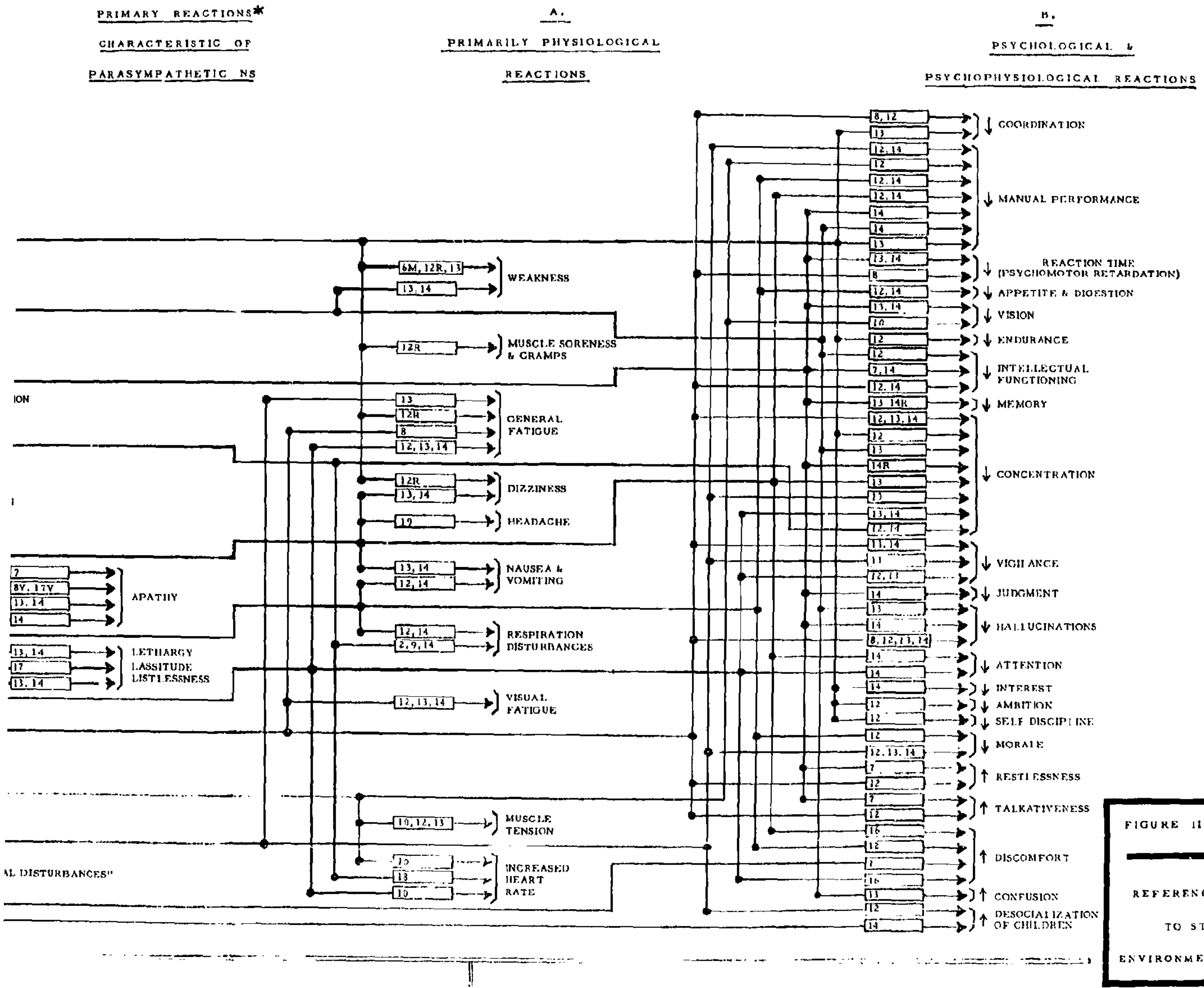


FIGURE III - 45. CHART 1

REFERENCED REACTIONS TO STRESSFUL ENVIRONMENTAL STIMULI

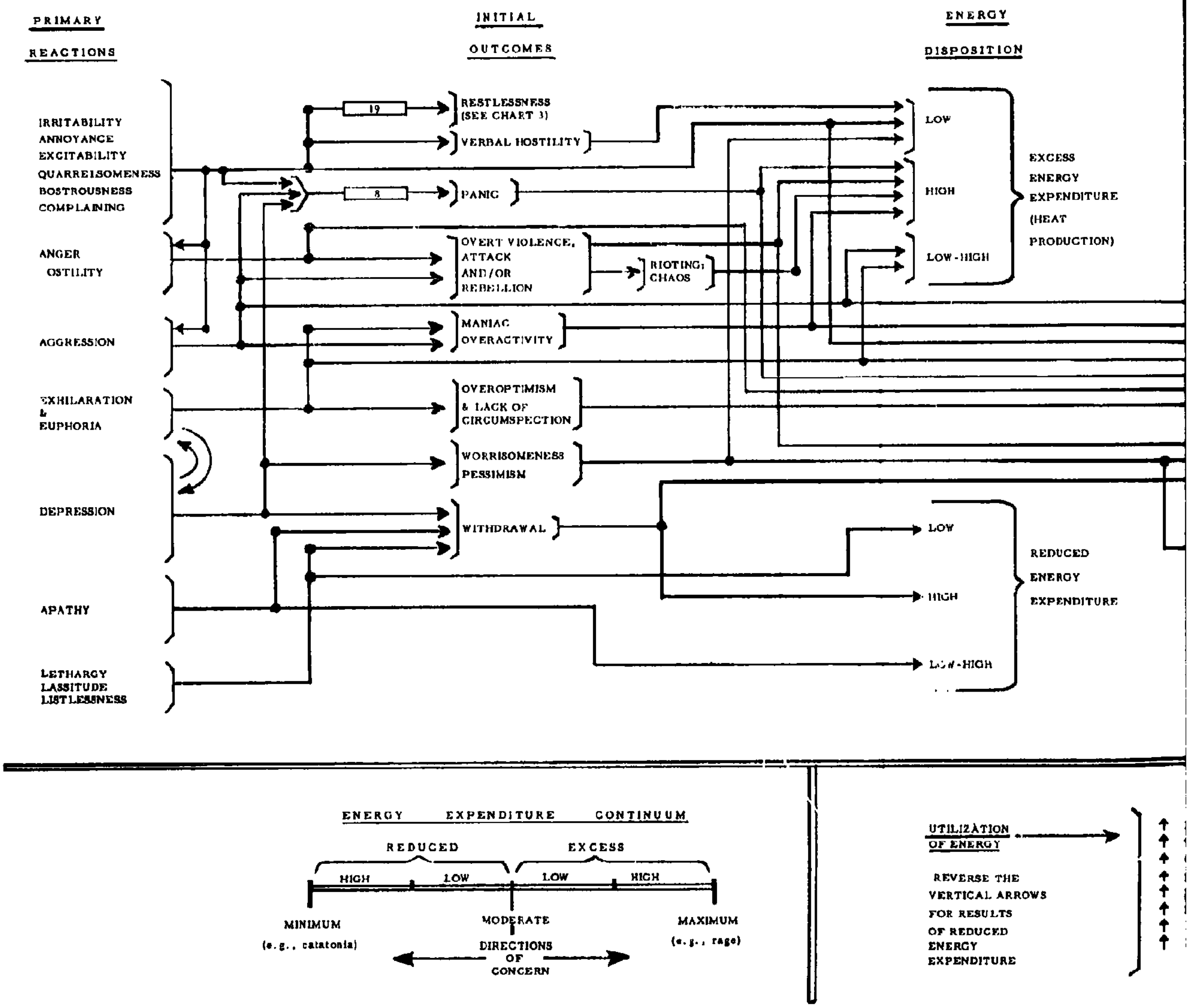
umber indicates that the relationship was simply observed

umber indicates that the relationship was reported by experimental subjects

umber indicates that the relationship was actually measured.

* These are general, some people will be more prone toward one pattern of reaction than another

EFFECTS OF


PRIMARY REACTIONS
INITIAL OUTCOMES
ENERGY DISPOSITION
IRRITABILITY
ANNOYANCE
EXCITABILITY
QUARRELSOMENESS
BOSTROUSNESS
COMPLAINING
ANGER
OSTILITY
AGGRESSION
EXHILARATION & EUPHORIA
DEPRESSION
APATHY
LETHARGY
LASSITUDE
LISTLESSNESS
19
RESTLESSNESS (SEE CHART 3)
VERBAL HOSTILITY
8
PANIC
OVERT VIOLENCE, ATTACK AND/OR REBELLION
RIOTING; CHAOS
MANIAC OVERACTIVITY
OVEROPTIMISM & LACK OF CIRCUMSPECTION
WORRISOMENESS PESSIMISM
WITHDRAWAL
LOW
HIGH
LOW-HIGH
EXCESS ENERGY EXPENDITURE (HEAT PRODUCTION)
LOW
HIGH
LOW-HIGH
REDUCED ENERGY EXPENDITURE
ENERGY EXPENDITURE CONTINUUM
REDUCED
EXCESS
HIGH
LOW
LOW
HIGH
MINIMUM (e.g., catatonia)
MODERATE
MAXIMUM (e.g., rage)
DIRECTIONS OF CONCERN
UTILIZATION OF ENERGY
REVERSE THE VERTICAL ARROWS FOR RESULTS OF REDUCED ENERGY EXPENDITURE

1

EFFECTS OF "PRIMARY REACTIONS"

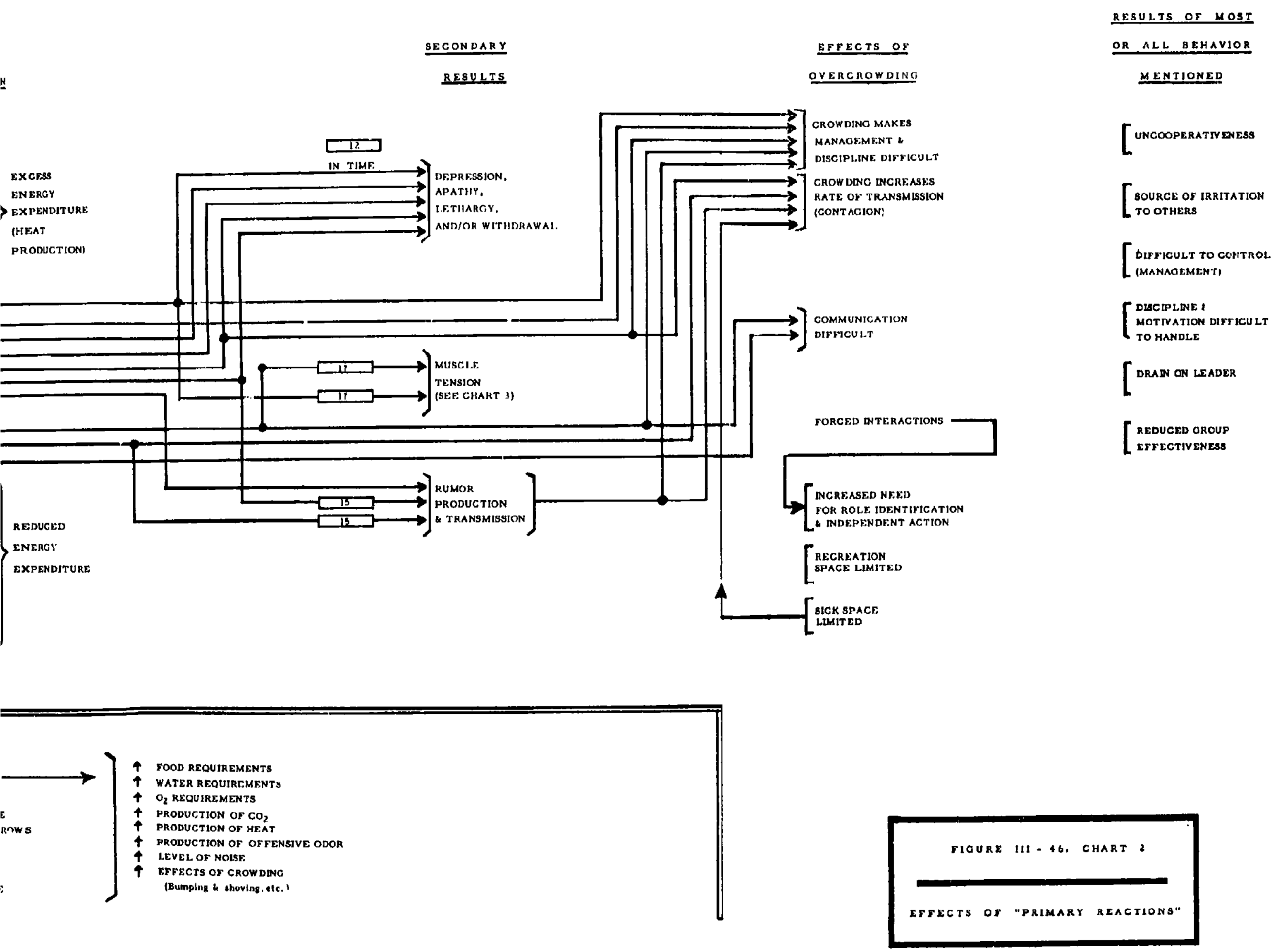


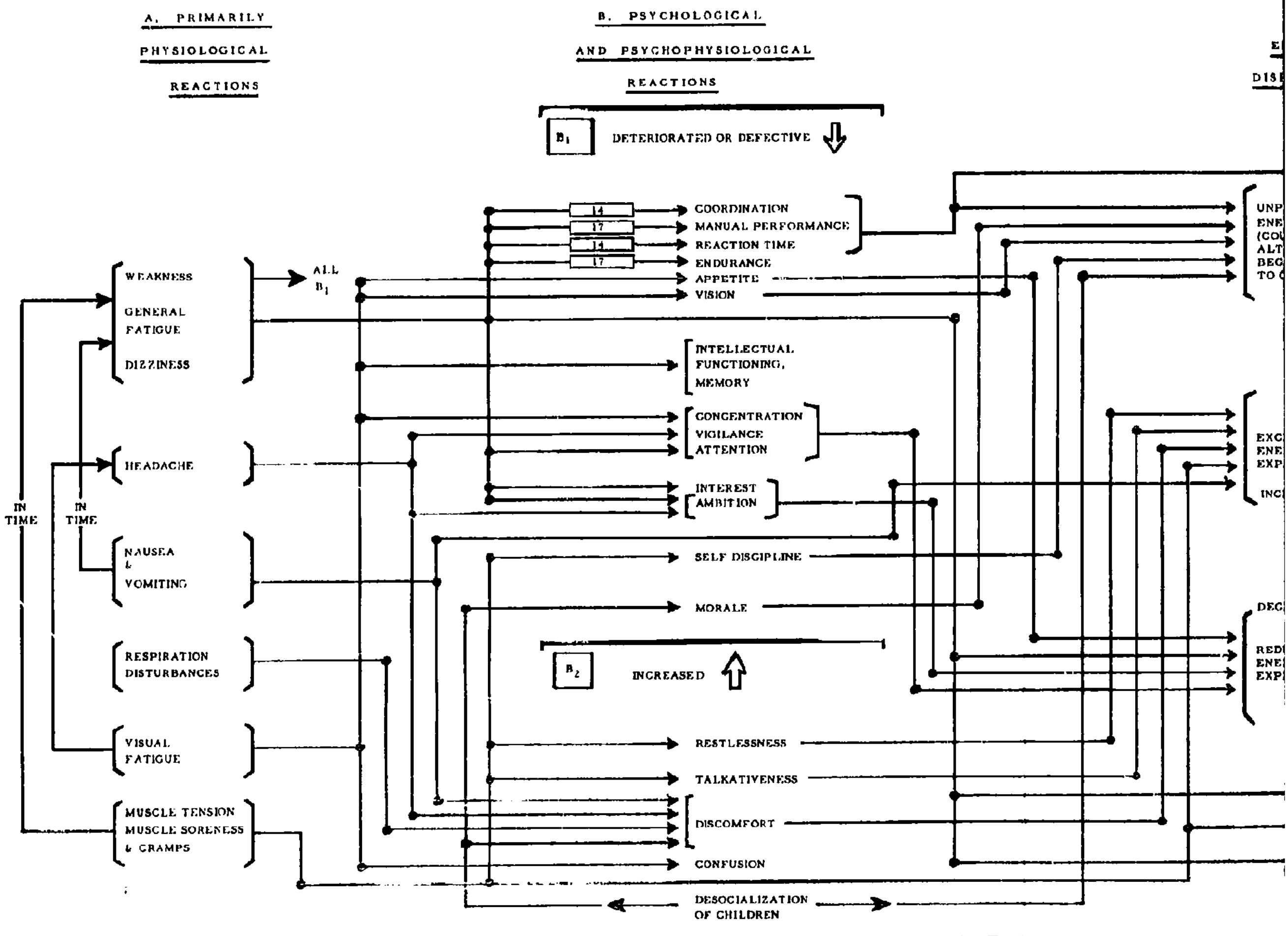
FIGURE III - 46. CHART 2

EFFECTS OF "PRIMARY REACTIONS"

2

INTERACTIONS AND E

PSYCHOLOGICAL AND PS



Some primary routes are shown. However, there is expected a high degree of interaction of effects between and within both columns A & B.

1

INTERACTIONS AND EFFECTS OF PHYSIOLOGICAL,

PSYCHOLOGICAL AND PSYCHOPHYSIOLOGICAL REACTIONS

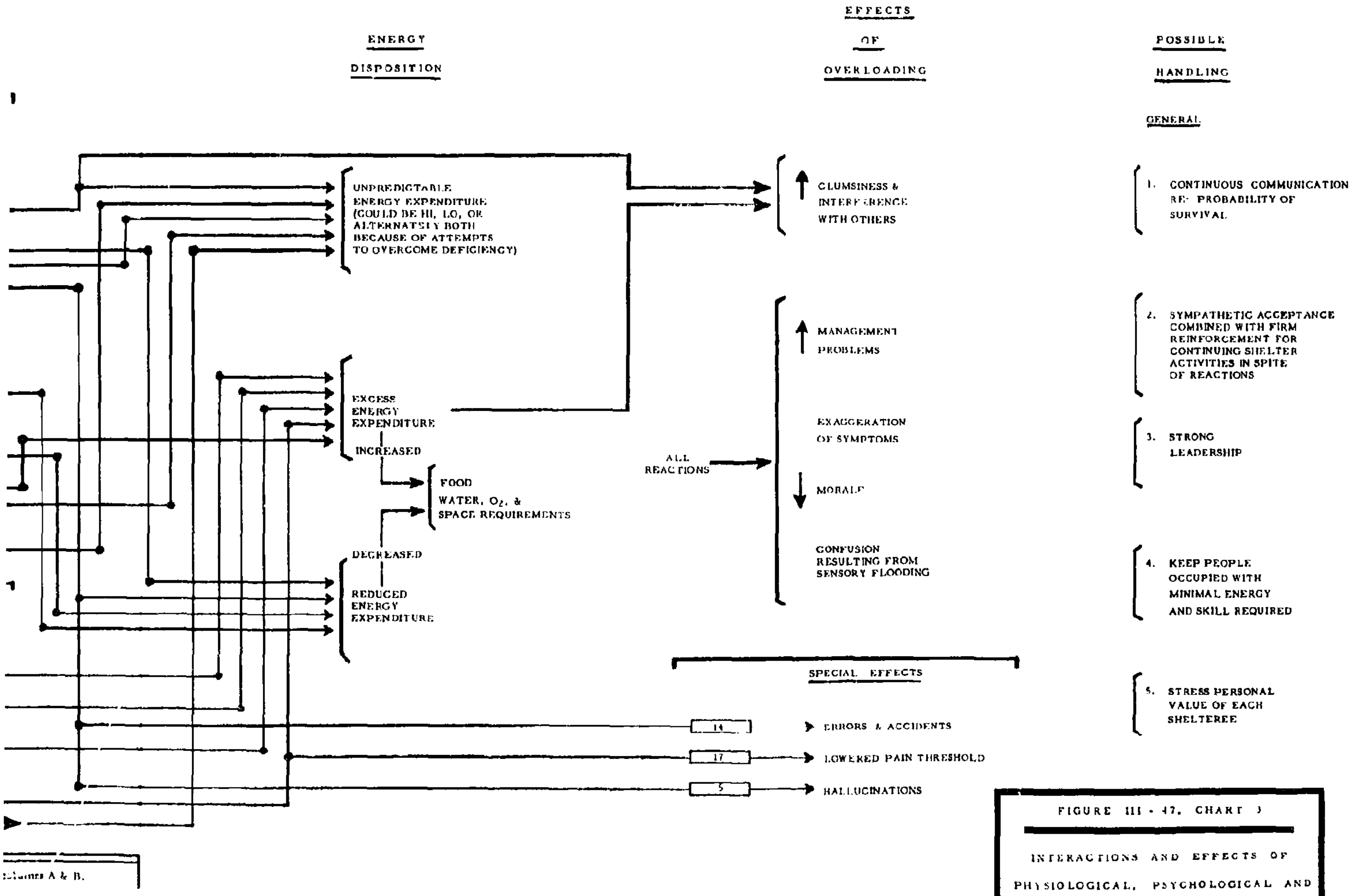


FIGURE III - 47, CHART 3

INTERACTIONS AND EFFECTS OF PHYSIOLOGICAL, PSYCHOLOGICAL AND PSYCHOPHYSIOLOGICAL REACTIONS

2

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b. Stress and the Temporal Course of the Behavior of Shelter Occupants

As the charts indicate, many studies have been reported concerning human reactions to stressful stimuli, such as noise, food deprivation, excess carbon dioxide, and the like. Generally, the findings have been consistent for any one of them. However, the evidence is conflicting regarding the temporal course of human reactions to the composite of constant and varying stresses expected to exist in the shelter situation. Probably the main reason findings differ is that each investigator formed his own concept of shelter living so that different kinds of experimental conditions were used to derive the bases for predicting reactions under different, individually conceived complexes of stresses.

In the shelter, the occupants may not only experience food and water deprivation, noise, crowding, and other stresses, but they will also be faced with the necessity to cope with an actual thermonuclear attack, possible destruction of their homes and possessions, and very likely separation from family members and friends. So far, no formal study has even approximately simulated those profound conditions. The manner in which people will respond to each of the stresses over a period of two weeks has been estimated by several investigators; however, the evidence is still too questionable to make confident forecasts of the overall behavior of a shelter population in time of real danger (Meerloo, 1957, p. 361).

(1) Support of Selye's concept of stress

To understand the basis of some of the predictions to be presented later, it is necessary first to define stress. According to Selye (1956), stress is an internal adaptive response to excessive or noxious stimulation (stressor), e. g., where cold is the stressor, the internal response (stress) is vasoconstriction of blood vessels near the skin surface, shivering, and other reactions. The response appears to be an attempt to maintain a stable body temperature, a process of adaptation.

The findings from his many studies of stress reactions led Selye to postulate a general "non-specific" response to all stressors which he designated the General-Adaptation-Syndrome (GAS). The GAS consists of three overlapping phases, the Alarm reaction, the Resistance reaction, and the Exhaustion stage.

On the basis of those three stages of stress reactions, Murray predicts people's reactions to becoming a shelter resident:

"The temporal course of adjustment may be anticipated to some extent on the basis of the work done on the general adaptation syndrome (Selye). The initial response to stress is a highly active one dependent on the sympathetic nervous system. This is called the stage of alarm and may involve fearful and aggressive responses. It is during this stage that the person will be most likely to enter the shelter. He will be keyed up, tense, and excited. Upon reaching the safety of the shelter, he may be elated and relieved. A spirit of good will may prevail in the shelter - even superficial euphoria, if the area has not been bombed. This will probably turn to inactivity, depression, and apathy as the stage of resistence occurs. This stage is based on the parasympathetic nervous system, and is conservative in nature. It may be thought of as analogous to hibernation. This is the sit and wait period. It is almost impossible to say just when the stage of resistance replaces the stage of alarm, since this depends on the nature of the stress and the individual patterns of reaction. A guess is that in a fallout shelter this would begin to occur within a day or two. However, as the frustration mounted and the conflict grew in intensity, it would be more and more difficult to maintain the passive wait and see attitude. Outbursts of irritability would occur, and tendencies to leave the shelter would mount. Finally, in what is known as the stage of collapse, sympathetically activated responses recur. The person may become more anxious, panic-stricken, and irrational. So, it would be anticipated that the initial period would be one of tension mixed with relief at being in the shelter, good will would prevail. This would be followed by a more passive, depressed, apathetic reaction. Finally, as conflict mounted, aggressive, regressive, and escape tendencies would become more manifest. Here, too, it is impossible to predict, without more research, just when and in which order these reactions will appear. In at least some cases, they would appear within two weeks" (Murray, 1960, pp. 74 and 75).

At least one study of behavior in simulated shelters reports findings resembling Murray's predictions. Within the experimental shelter, five phases of adjustment were differentiated by the investigators: (1) "Initial confusion and organization,"

(2) "Initial adjustment," (3) "Individual withdrawal," (4) "Readjustment," and (5) "Anticipation of release" (Altman, *et al.*, 1960, p. 62). The first and last phases were indeed, as Murray suggests, characterized by anxiety. In the Altman study,

"The initial stage of habitability was noticeably characterized by much confusion and noise. Feelings of anxiety generated by a fear of entering the unknown permeated the groups. This fear and/or anxious feeling was evidenced in the fact that (most of) the subjects arrived at the American Institute of Research as much as one hour early"(p. 62). "The last 24-36 hours of shelter habitability were marked by tension and some temper outbursts" (p. 65).

The primary limitations of that simulated shelter study are that the occupants were *volunteers under no real stress* from fear for their current or ultimate survival; they knew *they could safely extract themselves* from the experiment at any time; and food, ventilation and bedding were *not as severely different from normal* as those in actual shelters are expected to be. One single illustration from the study implies that all three of those factors were indeed operative: "One evening during the second, one week study a seventeen year old boy prepared a spaghetti supper. He was very proud of himself. Upon leaving the shelter he said to one of the observers, 'I hope you got a picture of me cooking supper because my mother will never believe I did it!' " (p. 64).

In a polar isolation study, stages of reaction similar to those in the simulated shelter study were observed. Rohrer (1960, pp. 21 and 22) distinguishes "four distinct phases of adjustment" that precisely correspond to stages (1), (3), (4) and (5) listed above for the simulated shelter study. The first phase is characterized by "heightened anxiety," the second by depression, the third by a reduction in depression and sleeplessness with a corresponding increase in work activity, and the fourth by "anticipatory behavior" accompanied by a "decrease in the effectiveness of the performance of work." Again, however, the subjects were volunteers with no need to be apprehensive about ultimate survival or the society into which they were finally to emerge.

(2) Evidence supporting Kollar's concept of stress

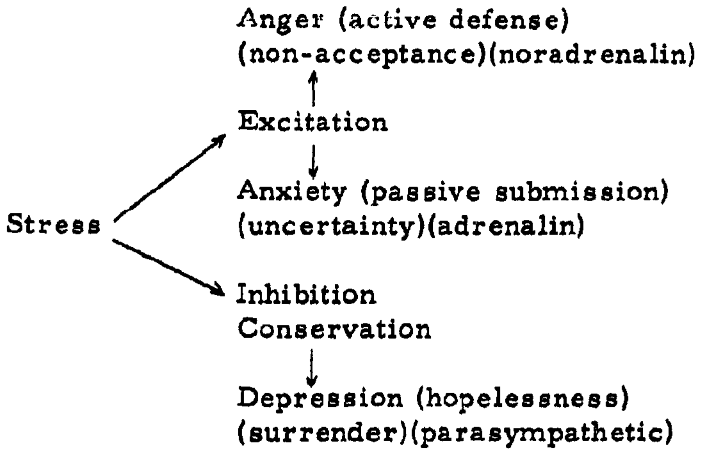
In the development of his theory of stress, Kollar (1961) demonstrates the way Selye''s theory of the GAS evolved from Cannon's theory that stress excites fear (p. 384). Yet, Kollar also states that most other theorists have postulated that stress leads initially to anxiety. Korchin (1962), for example, defines stress as "that stimulus condition likely to arouse anxiety" (p. 4). What then, is the relation between fear and anxiety?

According to Grinker and Spiegel, "the feeling tone and physiological concommitants in anxiety and fear are identical" (p. 120). Fear, they claim, is a consciously expressed emotion arising from the possibility that "something that is loved, highly prized and held very dear" will be lost (p. 120). Similarly, "apprehension or anxiety" arises from a threat "to the loss of what is loved most" (p. 121). Grinker and Spiegel describe the progression of reactions from fear and anger through anxiety as follows:

"The emotional reaction aroused by a threat of such a loss is at first an undifferentiated combination of fear and anger, subjectively felt as increased tension, alertness or awareness of danger. The whole organism is keyed up for trouble, a process whose physiological components have been well studied. Fear and anger are still undifferentiated, or at least mixed, as long as it is not known what action can be taken in the face of the threatened loss. If the loss can be averted, or the threat dealt with in active ways by being driven off or destroyed, aggressive activity accompanied by anger is called forth. Appraisal of the situation requires mental activity involving judgment, discrimination and choice of activity, based largely on past experience. If on the basis of such mental activity it is seen that the loss cannot be averted, the situation is hopeless and nothing can be done, then anxiety develops" (p. 122).

Thus, Grinker and Spiegel appear to take the stand that stress produces fear and anger which result either in aggressive behavior or anxiety. If depression occurs, it arises "after a long period of struggle with anxiety when it is clear that the fight to control the anxiety has failed" (p. 112). This concept does not seem adequate to explain some findings which will be presented later, although it is consistent with earlier theories.

Kollar (1961), in his theory of stress, completely disregards the intervening fear variable and places depression on an equal footing with the excitative reactions. He proposes that "anger, anxiety and depression represent basic psychobiological states" (p. 391) resulting directly from stressful stimuli. He represents them schematically as follows:



Note the similarity to Grinker and Spiegel in his description of the conditions under which each will be aroused:

"Thus psychological stimuli which evoke a state of stress arise from situations which the individual interprets to mean that a source of gratification either is threatened or has been lost. If the individual feels his source of gratification is threatened the response is excitatory (fight or flight). If the individual passively experiences this state of excitation it is called anxiety. Should the excitatory state be actively directed against the source of danger it is called aggression (rage or anger). If the individual feels he is deprived of gratification the response is depression (grief)" (p. 390).

Which will be experienced by people entering the shelter under threat of an attack is a matter of speculation. But it would be reasonable to expect that any or all three of those general types of reactions might occur!

Wallace (1956) lists the following adjectives to describe the initial reactions of the "disaster syndrome: " dazed, stunned, apathetic, passive and immobile. These reactions may last from a "few minutes to hours" (p. 109). After this period, there is a second stage characterized by extreme suggestibility which "may last for days" and which is accompanied by a recognition of the need for help (p. 117).

Similarly, Cohen (1953) remarks that the initial reaction of most people entering a concentration camp is one of apathy and depression (p. 170). That finding is in direct contrast to reports of initial anxiety in other studies, and tends to substantiate Kollar's theory of the primacy of depression as well as anxiety. Those prisoners who lived long enough ultimately achieved a state of "adaptation in a narrower sense," (p. 173) in which they became regressively dependent upon their guards. Thus, as time passed those people moved out of depression rather than into it.

Cohen further relates that during the adaptive phase people became increasingly sensitive to their lack of privacy; "Many prisoners became very irritable as a result of.... forced daily community with people who were widely divergent in character" (p. 131). Irritability appears to be a general and widely recognized reaction to stress (see Chart 1).

c. Specific Psychological Reactions

(1) Irritability

Bartemeir, et al., (1946) state, in reference to combat exhaustion, "There is almost unanimous agreement that the first symptoms of the failure to maintain psychological equilibrium are increasing irritability and disturbances of sleep.... It may exist without change for days, weeks or even months" (p. 374-376). Also in the survey by Murray (1960) reactions to food deprivation, vitamin deficiency, heat and humidity, cold and wind, oxygen deprivation, foul odors, fatigue, sleep deprivation, noise, glaring or poor lighting, sensory deprivation and confinement, all generally included irritability. In the Minnesota starvation study, behavior was described as apathetic with occasional outbursts of irritability (Keys, 1950).

Interestingly, in none of the studies does a definition of irritability appear, so that it is not obvious that all investigators actually infer the same reactions when they use the term. For purposes of this report, the physiological definition seems to be a most generally applicable one: "A condition of morbid excitability of an organ or part, when it reacts excessively to a slight stimulation." (Blakiston) On the gross psychological level, human behavior resulting from a reduced threshold to stimulation, i. e., irritability, may range from withdrawal to expressions of annoyance to overt hostile aggression.

All of those reactions can be expected to occur within the shelter. And it is likely that each individual will react differently depending upon his particular predisposition, how effectively he perceives the shelter as a means of survival, and his experiences immediately prior to entering the shelter. However, probably the most detrimental reaction to the crowded shelter situation would be overt aggression. Control would be difficult - so that the leader's prestige and management capabilities may deteriorate - the number of people affected is unpredictable, morale would be affected seriously, and the energy expended would be greater than probably could be afforded in the crowded confines where supplies are limited.

(2) Hostility and aggression

Saul (1947) has stated that, "... there is probably no impairment, frustration, conflict, or friction of any kind which does not result in hostility as a reaction" (p. 109). The work of Rosenbaum and DeCharms (1960) on vicarious hostility reduction suggests that the ability of the shelterees to express their hostility via communication to external authority will aid in the reduction of hostility. This suggestion is the basis for some recommendations to be made later.

Janis' (1958) studies indicate a possible way of anticipating which of the shelterees might be prone to react with overt hostility. For that reason, his findings are especially valuable as a basis for establishing a means of psychological control for preventing outbreaks of aggression.

In the overloaded shelter the problems arising from overt expressions of hostility, aggressiveness and dissatisfactions with the leader and others become acute. There will be very little space in which such feelings can be vented and the probability of uncontrolled rioting and/or rebellious activities will be increased. The effect on persons whose irritability will have been covert and under control may be to antagonize them into performing hostile acts themselves. Needless to say, such behavior would at the very least be detrimental to morale of the group, to subsequent effectiveness of the leader(s) and to carrying out of management policies. In addition, the resulting excessive energy expenditure would increase food, water and oxygen requirements and raise the shelter temperature. Not unrealistically, overt hostility could conceivably result in individual and possibly group fatalities.

(3) Reactions related to anticipatory attitudes

Because the universe of origins of behavior is so large, it may not be possible entirely to prevent such outbreaks by directing corrective efforts directly at the causes. However, the literature provides clues to some means of reducing the probability and potential number of outbreaks. Janis' research indicates that the more realistically adult humans perceive an expected painful situation before having to face it the more readily they can accept its difficulties and resulting adverse effects upon them. His study, therefore, demonstrates the need for extensive pre-attack education and training.

Even with prior training, however, some people will still inwardly refuse to acknowledge the pain and discomfort which are anticipated for shelter existence, either because the training will not have been sufficiently graphic for them or because they are unable to accept the imminence of an actual attack. It is anticipated that in response to an alert, such persons will enter the shelter without an adequate feeling or appreciation for the circumstances they will have to endure. They are the very types of individuals who, once reality imposes itself upon them, may be expected to respond in an overtly hostile aggressive manner.

On the other hand, there are some individuals who will have exaggerated the problems of ensheltering, and will enter the shelter with excessive or unmanageable anxiety. Thorough and realistically-oriented pre-shelter training may reduce the expected anxiety somewhat by preventing the formation of additional anxieties related to anticipations of the unknown. But it appears that those who are predisposed to that type of reaction will not readily relinquish their anxious feelings of apprehension. Once their fears have been realized even if only partially, it is expected that those individuals will act as if to say, "See there, I knew it! And the worse is yet to come!" That is to say, they will quite likely develop greater anxieties and neurotic reactions such as psychosomatic pains, headaches, excessive sleepiness, anger, and depression. The resulting detrimental effects on group morale would tend to reduce the group's effectiveness which in turn would lower morale further, producing a snowballing type of group reaction.

A third category of people are those who moderately fear or worry about what will happen. With adequate preparation prior to enshelterment it is expected that this group will predominate over the other two. Those individuals who will enter the shelter anticipating the crowded, hot, and generally uncomfortable conditions will be likely to handle the problems which arise in the most efficient manner possible. Their judgments will be unimpaired either by anxiousness or by the forceful unexpected imposition of the reality of shelter life.

The three groups correspond, respectively, to Janis' "low," "high" and "moderate" anticipatory fear groups; Janis used measures of pre-operative fear to separate several populations of pre-surgical patients into the three categories. Taking all his findings together, Janis indicates that the population is divided approximately equally between the three groups. The "low" and "high" pre-stress reactors obviously require special handling if the shelterees are to be given the best chance of survival. The statement is particularly true under overloaded conditions where discomfort and the many impositions and restrictions of shelter existence approach intolerability. Loss of control of the shelterees could lead to complete chaos.

In Section IV B. (Psychological Control) some methods are presented for making practical use of Janis' findings. In general, it appears feasible and necessary to attempt initially to manipulate the "low" and "high" reactors so that their demoralizing and destructive threat is minimal.

(4) The problem of premature exodus

Another threatening overt reaction, which could result from overloading and its complex of stresses, may be that some people attempt to leave the shelter before it is safe to do so. It is of little practical value to speculate whether such behavior will arise from temporary formation of ochlophobic and claustrophobic reactions or simply from the perception that conditions within the shelter are less tolerable than conditions outside the shelter. There appear to be no data supporting either of those - or any other - causative hypotheses for leaving the shelter situation. Specifically, pertinent data are needed to establish the types and extents of stresses which will drive a person to choose almost certain death in freedom over life (perhaps) in wretched confinement. Since concrete findings are not available, the problem must be analyzed essentially philosophically in the light of some current psychological theories.

(a) The "avoidance-avoidance" conflict

Within a shelter, after an attack, life may become so distressing to some individuals that a true conflict arises: should he remain under such piognantly experienced miserable conditions or should he take his chances outside? The rational tone of this question indicates, among other things, that (1) the outside is not truly perceived as disastrous (serious, non-hysterical suicide will not be considered here, since it is expected to be a relatively rare occurrence* and could probably not be prevented anyway) and (2) a so-called "avoidance-avoidance" conflict exists.

Both Lewin and Miller describe the avoidance-avoidance conflict as a basic one characterized by the "presence of two repulsive goals, excape from each of which is incompatible with escape from the other" (Helson, 1951, p. 243). If a third more positive alternative is not possible, "the individual will remain vacillating in conflict, trapped between the two sources of avoidance" (Hunt, 1944, p. 442). A shelteree in equivocal conflict will remain inside simply because he is already there.

A person who decides to leave the shelter will have resolved the conflict, and with or without an "avoidance-avoidance" theory, the shelter will have neglected to perform its intended function. However, the theory can be valuable if its implications are implemented effectively. Ideally, the conflict should not be allowed to gain strength in the first place, either by making the shelter tolerable, or by convincingly and repeatedly informing shelterees of the fatal conditions outside, or both. In the overloaded shelter, the first alternative may be exceedingly difficult, so that the incidence of people who consider leaving can be expected to be greater than under less stressful confinement. It will probably be necessary, therefore, to paint more strongly and

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*Cohen, 1953, p. 124 and Biderman, 1959, p. 23.

more frequently the figure of death waiting outside so that, at the very most, the valences of the two choices in the "avoidance-avoidance" conflict remain equal.

This solution appears simple, at first thought, and it would be if all people were exposed to the same life experiences, set of values, types of authority figures, physiological stresses, and so on. Of course, they are not. Therefore, how can shelterees be convincingly informed of the fatal conditions outside so that they truly perceive certain death for themselves out there? To answer this question could involve extensive discussion of numerous psychological theories. The approach here will be to take as practical a point of view as appears possible.

(b) A rational approach

The problem is complex, not only because the motivations directing human behavior are highly diverse and largely obscure but also because of the highly stressful nature of ensheltermen. It would be valuable, therefore, to attempt to strike at some basic human characteristics which are relatively independent - if possible.

According to Freud, the reality principle of a person's ego functions to preserve the self often in opposition to the pleasure principle of the id (Buhler, 1954, p. 628; Fenichel, 1945, p. 582; Freud, 1943, p. 312). The more effective the ego, the more likely will be the person's capability for performing effectively to save himself (Stein, 1960, p. 75). Fortunately relatively few shelterees will be devoid of an operable ego (i. e. , psychotic) (Biderman, 1959, p. 26) thus, most people will be amenable, to some degree, to evidence that personal destruction lurks outside. It is the nature of such evidence, then, that is of concern here.

Since Freud, the pleasure principle has been attacked, revised and completely overhauled, but it persists, at least in part, in the generally accepted concept of need satisfaction (Buhler, 1954, p. 639; Buhler, 1962, p. 445; Murphy, 1947, p. 397). There are various kinds of needs, some learned and some biological; for each individual they seem to be arranged in a kind of dynamic heirarchy which may change in time and space, but at any moment, one need or set of needs will generally take precedence over others. For example, in one person satisfaction of severe hunger may dominate the need to be accepted by a group; at another time or for another person the reverse might be true. In the shelter, each person will be the victim of severe stresses to his need system so that a new, overall need may emerge - to get out, away from the multiple stresses. This need then becomes as unique as the need for a particular group's acceptance, for a Cadillac, for smoking, or for any other learned value.

(c) Some findings relevant to control

To prevent the immediate satisfaction of the need would be to withhold pleasure; therefore, once a person decided to leave the shelter it would be difficult to restrain him. Yet, there are indications of tools which could be used for restraint as well as for preventive measures. Before mentioning them, several bits of information will be laid as groundwork.

1. Most people in a shelter will yield to the authority of an established leader; the desire to be guided during stress seems to be a general characteristic of our society (Goldstein, 1962, p. 15; Vernon, 1960, p. 72; NAS-NRC*). This finding is consistent with Erikson's concept of the need to "trust" someone.

2. People in a shelter generally arrive there on their own initiative; therefore, need for safety, self-preservation and/or avoidance as well as hope that their lives would be saved must have been operating to motivate them. According to T. M. French, the needful, hopeful act "stimulates the integrative mechanism" inherent in each person (Buhler, 1959, p. 571). That is, integrative capacity varies "as a positive function of one's confidence of attaining the goal" (French, 1952, p. 57). The integrative mechanism, responsible for reducing psychophysiological tension, includes the "integrative task" which is roughly proportional to the combined pressures of needs which are in conflict (French, 1952, p. 56). Below, it will be shown how the integrative task can be directed.

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*"Behavior in an Emergency Shelter. . . ," 1958, p. 25.

3. Hope is brought about by the fact that,

   > "the living being's existence through the order-upholding (integrative) mechanism extends into the future. Holding out for the future encompasses more than withstanding motivating pressures through means of hope. It entails 'information'. Information, the essential attribute of the feedback mechanism's functioning is essential for all integrative efforts" (Buhler, 1959, p. 572).

4. Finally, according to French and Buhler, (Buhler, 1959, p. 572 and French, 1952, p. 62) hope and confidence are the "dynamic factors that permit the deferment of pleasure," while belief that the purpose is worthwhile is the sustaining mechanism during unpleasant, difficult times. However, hope and confidence are not quite enough.

   > "The motivating pressure of a need seeks discharge in motor activity; but a well-directed effort to achieve a goal is something more than mere motor discharge of pressure. To achieve a goal it is not just enough to do something. One must also know what to do. To be of any use at all, efforts to achieve a goal must be guided by practical understanding of the problem to be solved, by some kind of plan for achieving one's purpose. Efforts to achieve goals result only when motor discharge of the pressure of a need is integrated with the guiding influence of a plan" (French, 1952, p. 53).

(d) Suggestions for applying findings

From such data some practical recommendations emerge. A person's leaving the shelter will be averted if: a respected leader will convince him that his original motive in seeking the safety of the shelter was a rational move, based on sound judgment; in that way his original hope can be restimulated. And then, all information regarding the qualifications of the leader, the data he has, and his mode of arriving at the conclusion that external conditions are fatal should be provided. In addition, whatever information is available regarding plans for post-shelter life should be described to encourage the desire to postpone the pleasure of leaving. Finally, the leader should stress in operational terms, if possible, the personal and social value of each individual so that everyone can best sustain his integrity during ensheltermert.

Those points are valuable for influencing people not to leave the shelter too soon, but they are also valuable to boost the general morale. Shelterees will require continued reassurances that the outside <u>will</u> soon be safe and that they <u>will</u> be able to live worthwhile lives there (Fritz, 1960, pp. 93 and 149; Goldstein, 1962, p. 12; Biderman, 1963, p. C-15). If those hopes are not sustained, and if the integrity of each individual cannot be maintained - due to shelter conditions - the shelter will have failed just the same as if ventilation or food or water had not been supplied!

In conclusion, then, people will leave the shelter when they perceive the shelter reality as being more dangerous than the reality of the outside. Reality, here, is used as defined by C. Buhler: "the generator and determinant of action not originating in the individual's own motivating system" (Buhler, 1954, p. 64). To avert those persons, not only must the outside danger be shown to be greater than inside, but every effort should be made by a resourceful leader and crew to discover and alleviate, if possible, the primary sources of perceived danger inside the shelter.

(5) <u>Depression and adaptation</u>

That which is dangerous to one individual may be perceived by another as gratification - depriving, or to a single individual one source can have both meanings at different times. When the individual experiences the latter - e. g., if conditions in the shelter preclude hope for survival or if he happened to observe a member of his family being killed before he entered the shelter - he can be expected to retreat into depression, according to Kollar's theory (p. 390). As indicated earlier, there is no consistent, clear-cut evidence to indicate whether depression will necessarily characterize all occupants or only a few or whether it will occur at the beginning, or later during shelter occupancy.

A type of depression likely to arise from the shelter situation is what Freyhan (1960) calls the exogenous type, in which somatic factors are the main predispositional causes. This type may be evoked by "any very unusual stress which makes a total demand on the personality - both emotionally and physically" (p. 11). He does point out, however, that the form of depression prevails in people over fifty, at least as observed in clinical practice. But again, depression is considered to be a serious possibility in the shelter (Murray, 1960).

Janis (1958) proposes that the probability of a depressive reaction is a function of the degree to which the stressful conditions are perceived as deserved. They are perceived as deserved as a function of the individual's past history in relation to abandonment, where abandonment feelings are said to increase with time. This chain of reasoning points to the importance of adequate external communication, for without it, abandonment feelings would certainly be aggravated.

(a) The positive value of depression

Murray (1960) suggests that depression may be adaptive in that body functions are slowed and Murphy (p. 582) proposes that depression can be an effective mode of handling a feeling of helplessness. While depression may have its advantages, two primary problems which seem likely to result from the depressive reaction are (1) its demoralizing effect on others and (2) its inhibiting effect on the development of survival capabilities.

Depressives will tend to avoid involvement in shelter activities and post-shelter survival training sessions, and their moping expressions of hopelessness may arouse in others both anger and empathetic despair. It would be pure conjecture to predict for the overloaded shelter either that there would be a more rapid contamination of depression or that counterbalancing forces would arise more readily than in the shelter with fewer occupants. However, Cohen's (1953) and Wallace's (1956) studies permit an optimistic viewpoint to be taken, for it appears that given sufficient time and hope people will tend to adapt to a stressful situation.

(b) Parallel reactions in cancer patients

Studies of cancer patients' reaction to knowledge of their illness generally support the findings noted. "The cancer patient when informed of his problem undergoes an understandable depression; and then, in order to face reality, he attempts to adjust by developing a new attitude toward life" (Miller, 1960, p. 242).

The precise relation between cancer patient reactions and those of shelter entrants has apparently not been pursued, however, there are unmistakable similarties: (1) Shelter-seeking results from radiation attack and is analogous to seeking a doctor's aid (possibly surgery) under the attack of malignancy; (2) The efficacy of neither the shelter nor the doctor's treatment can positively be predetermined; (3) Cancer surgery frequently alters a person's capabilities (e.g., laryngotomy removes speech capabilities) just as an attack may destroy family members, friends or possessions; (4) After surgery or other treatment or after having survived a shelter life, radical readjustments are necessary; (5) What the readjustments will be is not truly known during treatment or while in the shelter; (6) During treatment and when living in the shelter - particularly if it is overloaded - disturbing conditions reign (deprivations, uncertainties and pain) and confidence and hope for survival wane. The relation between cancer knowledge and awareness of a thermonuclear attack suggests that studies of the former can be helpful in understanding the latter. A big difference between them, however, is that cancer patients are alone in their illness while shelterees are members of a group; thus, although tendencies for individuals to react may be uncovered by studying people with cancer, people's behavior within a group will tend to be modified by the presence and activities of others. The fact remains that we may reasonably expect some people to respond with initial depression which evolves in time toward adjustment to the new situation. And if people are aware of others who are sharing similar reactions, this fact may tend to speed up the adjustive mechanism (Bovard, 1959, p. 274).

Neither this sequence nor adjustment can, of course, be assured. Despair may occasionally develop from severe depression with the result that very little if any help can be provided to alleviate the accompanying utter hopelessness and grief (LeShan, 1961). Such profound reactions, however, are rare, as evidenced by the paucity of suicides in isolation studies (see Cohen, 1953, p. 124) as well as among cancer patients (Miller, 1960, p. 242). If depression becomes chronic in the shelter and if it persists, it may become vital to shelter success that the leader use the techniques described earlier (for people trying to leave the shelter) to attempt to instill a feeling of hope and confidence in the value and likelihood of their personal survival.

(6) Withdrawal

Another type of expected reaction characterized by reduced activity is withdrawal. Altman, et al., (1960) found in their two-week study that the entire shelter population seemed to withdraw on about the eighth day. While Murray (1960) states that withdrawal is a form of reaction to frustration (p. 72), Rayner (1960) mentions only that "withdrawal as a result of starvation" has been documented.

Since deep emotional withdrawal is a severe psychological reaction generally associated with schizophrenia (Colemen, 1956) and since extreme reactions are expected only rarely,* it is doubtful that many people will withdraw to that profound an extent. This statement is not inconsistent with the comment by Biderman (1960) that "in the majority of cases, the onset of extreme apathy is reported as occurring after a longer period of incarceration than the expected maximum time persons will be required to remain in the shelters" (p. 33). If any shelter reactions are similar to those of prisoners in concentration camps, withdrawal reactions could conceivably characterize a few people during their entire shelter stay; there is more hope for the shelterees survival, however, than there was for the prisoners. No doubt, crowding may tend to pressure some people into a temporary introversive type of withdrawal where daydreaming and excessive sleep predominate, but external communication will still be possible so that hope and interest could, with aggressive effort on the part of the leaders, be aroused.

d. Some General Conclusions

The discussion thus far seems clearly to lead to the conclusion that evidence is inadequate to predict, among the entire shelter population, precisely what psychological factors will predominate at a given time or what course those factors will take, either in a normally loaded or overloaded shelter situation.

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*See section on Population Variables.

Experimental findings seem to be consistent within themselves, i. e., most observees in a study respond with similar reactions in a similar time dependent pattern. However, there appear to be two distinct categories of findings: (1) Those characterized by the three-stage sequence, anxiety-depression/apathy - anxiety and (2) those having the two phase pattern, depression-adaptation/adjustment. The primary factor differentiating the study conditions for these two categories is the reality of the overall stress. Generally, in studies whose results indicate the second category the people observed were actually under real threat to their lives while individuals in the first group of studies generally knew the duration of their confinement and that normal conditions awaited them when their confinement terminated.

From psychological theory, empirical findings, and reasoning it has been proposed here that within the unique shelter environment in times of true stress it appears likely that behavior will be highly diverse, particularly during the first few days. Individuals will have been exposed to different kinds and amounts of preparation for attack and shelter life; people will have had different experiences immediately prior to entering the shelter; some people will be completely cut off from other members of their families; and there will be varying types of predispositional responses to the emergency and catastrophic nature of the occurrence. In previous shelter studies, there was no stress from an actual attack, experimental subjects were about equally prepared, and separation from family members was not perceived as permanent. Therefore, the fact that relatively uniform behavior was observed in these studies is not surprising.

In spite of the conflicting evidence concerning the course which overall behavior will take, in the light of the discussion of shelter behavior and its diversification, it is predicted that, over the entire shelter duration, greater energy will be expended in the stressful, overloaded shelter than in the less stressful, normally loaded shelter. That is, the combined reactions of crowded shelterees during confinement can be expected to result in an overall "increased energy expenditure," very much as illustrated in Charts 2 and 3. For example, a study simulating the stresses of real attack might reveal a general reduction in activity due to a preponderance of depressive reactions; however, after a few days, adaptation and adjustment and its resulting activity would be expected to result in increased activity and an overcompensatory expenditure of energy - except in the presence of certain overriding physiological stresses such as excessive heat.

In the overloaded shelter, diversity of reactions may itself become highly stressful, particularly if there are hysterical women or children separated from their families while others enter in shocked depression unable to help during the initial organizational attempts. Whether or not the stresses of divergent behaviors are offset by the comforting feeling that "we are not alone in this" is uncertain; it would be a valuable socio-psychological study which could provide the answer to this problem!

But there is one characteristic which appears may be common to all shelter entrants. The people who will enter a shelter will do so because they have some degree of hope that it will protect them. If they truly believed that survival was impossible, they probably would not seek safety. It has already been pointed out that the more people's hope can be made conscious by persuasion and encouragement, the more they will be capable of coping effectively with the discomforts of shelter life. It will make shelter life and management simpler if the leaders could capitalize on this fact. Therefore, it appears that to a large extent, the degree to which a shelter will be able to tolerate overloading is an important function of the consensus, degree, and maintainability of the feelings of hope and confidence experienced by the shelter occupants.

e. Behavioral Characteristics of Population Subgroups

(1) Age groups

In general, the problems and recommendations presented so far apply to most of the adolescent and adult population of the U.S. Children probably will require special treatment because of their sensitivity and the immediacy of their needs. However, very little data are available relevant to the behavior of children in a shelter-type situation. Murray suggests that frustrated children may refuse to conform (1959, p. 69). Miller calls attention to the findings that children place heavy burdens on parents (1959, p. 53) and as a result "aggravate parent morale" (1960, p. 4).

Altman, et al., (1960) describe studies in which children down to the age of seven participated; no unusual problems were reported. In Vernon's study (1959) three children, ages 6, 3 1/2, and 2 years took part. The 3 1/2 year old boy "seemed to withdraw a bit, to become quiet, and uninterested in any activities" (p. 20) during confinement; a tranquilizer was employed to help restore his normal behavior. Except for this incidence, the children seemed to enjoy confinement, probably because the family was drawn into warm, intimate, prolonged, cooperative contact.

The study of Strope, et al., (1962) also revealed no special problems with children or infants whose ages ran as low as three months. "Children of all ages seemed to adapt remarkably well to the conditions of the shelter. There was no serious difficulty at any time related to either their health or their behavior" (weekend family occupancy study)

It is likely that even children accompanied by parents in the real shelter environment will sense the insecurity of the other shelter occupants. As a result, children may cry - raising the noise level considerably - but otherwise would be expected to remain close to their parents. In time, familiarity and restlessness would tend to stir small children to move about, thereby exaggerating the crowdedness and aggravating angry responses of irritable neighbors. Some hostility among other adults may be provoked because children will require and demand more water and food than might be provided; overt expressions of this hostility could set off stormy interactions between parents and complainers.

Children who are separated from their parents would be likely - if they were not too young - to be strongly influenced by the adults in the shelter. If, for example, children in an elementary school were confined with teachers who could make it appear as though shelter living were a game, the youths might be more easily manageable than an equal number of adults. Very young children deprived of their parents' love and attention would be likely to withdraw and cry; they would be expected to refuse to eat at first (cf. Murray, 1959, p. 73), and thus produce distressed feelings in some concerned adults. Because of the obvious difficulty in submitting small children to highly stressful conditions in an experiment, very little actual data may be able to be gathered concerning the course of children's behavior and their effects on adults in a shelter-simulated confinement.

Adolescents, according to Stein, et al., (1960) will probably follow a strong leader (p. 57). It has been generally observed that adolescents tend to seek to identify themselves with an ideal adult who contains "all the virtues that he himself wishes to have" (Farnham, 1952, p. 99). That the shelter leader might become the object of "hero worship" is not an unreasonable expectation. Need for social identification and acceptance may prove adolescents to be the most active - if not the most effective - members of the shelter population. Whether they react with eager cooperation or hostile rebellion will depend largely upon the adults' reactions to them and the favor they find in the eyes of their assumed leaders. "No group is more susceptable to the need for status and prestige than are the adolescents." And as a result, "they are always urgently seeking ways of finding... approval and acceptance of those around them" (Farnham, 1952, p. 93). If cooperation gains them the admiration they seek, then they will tend to contribute to group survival.

Adolescents may form cliques and establish peer leaders. To most effectively cope with these groups, the shelter managers should immediately establish a rapport with those leaders. If possible, this should be done even before the leaders have fully emerged; they can be spotted quite readily by briefly observing some interactions between members of growing cliques. The adolescent leaders can be very helpful to the managers by assuming some of the responsibility for managing work and training crews and by establishing their own recreation activities.

The flexibility, resourcefulness, and enthusiasm of teenagers was demonstrated in a study reported by Strope, et al., (1962). During a simulated power failure when children and parents started to react restlessly, some of the adolescent members began singing. "This calmed both mothers and children" (p. 39). A shelter manager who can quickly perceive and take advantage of adolescent characteristics will probably be relieved of many burdens.

Elderly people are expected to cause fewer problems than any other age group, except from the health standpoint. Miller (1959 and 1960) and Rohles indicate that older persons adjust better than young to isolated environments. Very likely fear of contracting an illness will be the most important psychological problem that may arise among the aged. Since older people *are* more susceptible to illness than others, the fear has a realistic basis. The leaders can best handle this problem by isolating sick people and restricting the elderly individuals to an area as far away as possible.

(2) *Sex*

Considering man's constant quest for an understanding of the differences between men and women, it is truly amazing how little information is available concerning their particular modes of behavior under stress. Is it possible that American men and women as general classes, do not respond differently to stressful conditions? It is doubtful that this question can be answered definitively to cover all situations. Some shelters may be composed predominantly or entirely of women, while others may contain mostly or all men. The ratio of children to men and women will probably also have some effect on the responsiveness of the two sexes to stress.

In the study reported by Altman, *et al.*, (1960), some women assumed as important a leadership role as men, although in all studies reviewed, including Altman's, the principal titular or nominative leader was always a man. But no studies have been reviewed where there was a preponderance of women over men, so it is not evident how women - in a group containing a majority of women - would compare with men as shelter leaders.

In the presence of children, it would be expected that women would assume a protective role. Yet, in the study reported by Strope, *et al.*, (1962), when volunteers were sought to care for the children, "not quite enough individuals volunteered and approximately six women were appointed to serve" in that capacity (p. 40); mothers were concerned for their own children, however (p. 41). Cohen (1953) quotes one female concentration camp prisoner, who, because of her extreme hunger, stated that she "could have stolen from husband, child, parent or friend," in order to live (p. 136). Such extreme hunger will not be likely to arise within the relatively short shelter stay, and confidence in survival will probably keep people sufficiently intact that they will not resort to such extreme reactions.

Jung's concept of the anima and animus characteristics of the unconscious in men and women, respectively, offers some interesting speculations. Under severe stresses, if the ego function weakens, other aspects of one's self must be called upon to direct behavior. A group of men, falling prey to subconsciously directed actions, conceivably could be less effective (or more irrational) than a similarly affected group of women. However, the apparent fact that most humans have developed effective integrative capacities, non-ego-directed behavior probably could not continue for very long. Whether the duration of shelter confinement would be too long for an all-woman group cannot be estimated without evidence. Nor would it be expected for an all-male group that anima-directed, instinctive or irrational behavior could continue for any length of time.

The theory poses some interesting questions for leadership in a mixed group: Under the severe stresses of thermonuclear attack, might not a shelter be managed most effectively by starting off with a female leader, or a man-woman team who, after a day or two, relinquishes leadership to a single, strong man who could assume a firm, benevolent father role? Might not hope for survival be most rapidly established in the initial phases of shelter life if shelterees first experience the comfort of maternal protection then develop courage as paternal direction gains ascendance? These questions offer interesting research possibilities.

Most shelter populations will probably comprise both sexes. As a result the problem of sexual interaction must be considered. In only one report has the problem of sexual expression been reported (Altman, et al., 1960); and it was not obvious what effect this had on the group; however, no significant demoralizing reactions were indicated. The group felt greater antagonism toward the already unaccepted leader than toward the petting teenagers. Strong leadership and the anxieties imposed in the shelter are both likely to deter sexual acts and feelings. Fear, anxiety, hunger and fatigue have been shown to inhibit sexual reactivity (Wenger, et al., 1956; p. 333), and at least one of these four stresses will be experienced by most, if not all, shelters.

This statement , however, is not consistent with some findings summarized by Biderman (1963); it is possible, he states, that "general stress of a short-term nature may increase sexuality" (p. 33). The question of the effect of shelter stresses on sexual responsiveness apparently remains open. But even if sexual needs do arise, it seems reasonable that firm leadership control plus overall feelings of confidence in survival and the likelihood of acceptable post shelter existence will make it possible for people to abstain until after their release.

(3) Race, religion, ethnic, and socio-economic groups

In the section on Population Variables, studies were cited to demonstrate that there is conflicting evidence regarding the existence of special psychological or sociological problems when members of different race, religious, ethnic and socio-economic groups suffer severe stresses together. That strained relationships might exist between discriminators and the discriminated seems reasonable; however, to what extent conflict might occur and how it would be manifested is unknown. Undirected anger in a bigoted caucasian might be directed toward a non-white; workers might express hostility toward arrogant foremen and businessmen; insecure and defensively aggressive men could conceivably attack an introverted person; etc.

On the other hand, it seems more likely that people may tend to relinquish their minority group habits as they identify themselves with a shelter group struggling for survival.

(4) Other subgroups

Very little data are available concerning general psychological characteristics of particular subclasses of people. . . Miller (1959) in his summary of some findings reports that "educated persons will experience less deprivation than will persons of poorer education" and that persons from a rural background are better able to adapt to an isolated shelter life than are those from an urban background (p. 4).

f. Psychological Factors and Overloading

Overloading, as defined earlier, is conceived in a dynamic sense, related to the total functioning of human beings; as a result, this concept becomes increasingly complex as more and more interacting variables are identified. And obviously many, many variables operate in man. If only strictly measurable physiological reactions resulted from one or more measurable stimuli, very good descriptions of overloaded conditions could be made. However, when psychological variables are included, such as individual and social motivations, past training, intelligence, frustration, tolerance, ego strength, defensive predispositions, and so on, the problem becomes more complex. Those variables function to alter not only reactions to physiological response but the very responses themselves. Withdrawal, for example, not only can remove from awareness the discomfort of hunger, but it also tends to reduce the requirements for food.

A crowded shelter is not necessarily an overloaded one, and, conversely, an overloaded shelter is not necessarily a crowded one. Crowding can be defined simply in terms of the space allotted to each individual, whereas loading must be defined with respect to people's reactions. It is conceivable that a shelter may draw only a small percentage of its planned allotment of occupants, yet in a very real sense the shelter would be severely overloaded if the water had leaked from its container (or if it were contaminated), if one of the shelterees were severely homicidal, or if one of the entrants were afflicted with a highly contagious fatal illness.

On the other hand, tolerance for extreme overcrowding has been noted among European Jews migrating to Israel on small ships (Biderman, 1963, p. 31). Because of psychological balancing factors, viz., "enthusiasm," "high morale" and "confidence," the degree of overloading could be said to have been low in spite of the severe crowding, heat, and very small allotments of food and water (Biderman, 1963, p. F-17). Of 4,554 passengers on the refugee ship, Exodus, 1947, only one death appears to have resulted indirectly from crowded confinement - a woman during parturition (Gruber, 1948, p. 48). (Three others were killed and many wounded during a British attack outside Israel but there were no other deaths or injuries resulting from the confinement per se (Gruber, 1948, pp. 48-51 and Robinson, 1947, p. 262).)

Biderman (1963) summarizes quite clearly the relationship between crowdedness and loading (although he does not refer specifically to loading) in his statement that "it is not the number of people that are together in a given space that is the usual source of distress, but rather the products of their joint activities in that space - the heat they generate, the quarrels they generate, the air they consume, the germs and rumors they spread, etc." (p. 13).

That constructive activity is necessary to favorable morale has been suggested by several authors. Hilmar (1960, p. 123) suggests that teaching children will provide some people with constructive responsibilities. Cartwright and Zander (1953, p. 316) note that in general a sense of responsibility derives from feelings that ones functional role is important. And Biderman (1963) also asserts that "to be affective, ... the environment must provide the essentials for sustaining a high level of physical and mental activity" (p. 31). In the highly crowded shelter, activity will very likely have to be restricted, but for carrying out the essential activities, the leaders will maintain the optimum level of morale if they carefully allocate responsibility so that every capable person takes a part and feels that he is contributing to his own and the group's survival.

The importance of a good leader cannot be too strongly stressed. Under inadequate management, even a small uncrowded group can become disorganized and ineffective; however, there is one possible exception: assuming a fairly healthy group, if the purpose and goal are meaningful and fervently desired by all members, morale and confidence may be maintained at a high level due to the perceived importance of the goal, and cooperation and cohesiveness may persist without a strong or permanent leader. Under these conditions, loading would essentially become a function of environmental and physiological variables.

A leader's basic and unique functions are to (1) analyze a situation in which an action must be taken and (2) initiate the required action (Cartwright and Zander, 1953; p. 559). In an overloaded shelter, by its very definition, the number of problems will be high - so high, perhaps, that leaders might be under constant pressures to determine what corrective actions are needed and to see to it that they are carried out.

Each manager will need the wisdom not only to solve the many problems as they arise, or prevent them before they arise, but also to perceive that his own fatigue could result in a reduction in the effectiveness of his judgment. In the overloaded shelter it will be particularly important for him to maintain an optimum level of psychological and physiological health. Therefore, he will need the insight necessary to perceive his need for rest and confidence in his temporary substitute or alternate.

To analyze a situation requires keen perception, a broad experiential background, and good judgment, i. e., the ability to relate observations with knowledge in order to arrive at a basis for action. If a man becomes suddenly and irrationally aggressive, the leader may quickly decide that unless the man is somehow stopped, general panic will develop; the man, then, must obviously be restrained.

Leaders will, however, be faced with more subtle types of analyses. For example, a leader of a shelter holding a large population of adolescents will recognize the potential danger of rebellion and realize the ultimate value of befriending emerging clique leaders. In a shelter holding a very pregnant woman, the perceptive leader will recognize the need to reduce worry and tensions by letting it be known immediately that he (or some other occupant) has both the know-how and materials for aiding childbirth, if necessary. The more analyses of preventive measures the leader is capable of making, the higher the loading threshold is likely to be. And as indicated repeatedly already, the most valuable preventive procedures will be those which succeed in providing each person with feelings of hope and desire for a meaningful post shelter life and confidence that each one of them can contribute toward achieving this goal.

Methods for encouraging these feelings will be presented later; however, the effectiveness of these techniques may depend upon providing individual attention. That will be increasingly difficult to do as the number of shelter occupants mount, yet precisely because the stresses of the crowded shelter will be exaggerated, it may become especially important to give each person some special attention. It will not always be adequate to explain or tell a person how valuable he is or will be; the leader's creativity and flexibility will be called upon to direct shelterees in activities in which they feel their particular skills and interest are needed. Thus, because some problems may be very subtle and because there are likely to be many different ways of handling an existing or potential conflict, a superior leader - in order most effectively to "analyze a situation" and "initiate the required action" - must be well trained and hopefully endowed with social insight and creative talents.

With exceptional leadership, it is conceivable that even an extremely crowded shelter might safeguard its occupants who - in spite of their thirst, hunger, sore muscles and aching bones - maintain a high morale, by being sustained on a vital diet of encouragement, sincere mutual interest, purpose, activity, hope, and confidence.

B. COMBINED VARIABLES

Although much of a *qualitative* nature can be inferred about the manner in which some of the stressors in the shelter will interact in terms of physiological and psychological response, the extent to which response to combined shelter stresses can be predicted *quantitatively* is greatly restricted both by scarcity of data and by lack of the required system model interrelating all the response mechanisms of the human body.

Progress in the ability to *predict* human response to changes in the environment depends on (1) the extent to which reliable relevant quantitative experimental and observational data on response become available, (2) the degree to which the underlying mechanisms become understood, and (3) the success with which the interaction of response mechanisms become describable in manipulatable, mathematical terms. Although great strides have been made in recent years in all those areas, it is not yet possible to make reliable predictions of human response to many, simultaneously imposed stresses.

Mathematical models are available for various portions or response aspects of the cardiovascular, respiratory, endocrine, nervous, musculoskeletal, auditory, visual and other systems. Prediction schemes partially interrelating various of those models for response to changes in the thermal and in the atmospheric environment have been created -- others could be mentioned as well. Unfortunately, none of them have evolved to the point where truly reliable predictions can be made even to single environmental stresses - except for very limited ranges - much less for combined stresses. However, with the techniques made feasible by both digital and analog computer technology, significant advances could be made by a *direct* attack on the combined stress problem using some of the more advanced computer techniques which are now available. It seems certain that rapid progress can be made in defining a quantitative model for the man-shelter-environment system with respect to physiological aspects; but constructing a total system model in which psychological aspects are included in terms of their affect on physiological response as well as overt behavior, requires a conceptual "breakthrough." Nevertheless, even a model which is deficient in that regard would constitute an extremely useful tool for evaluating specific shelter designs, comparing alternative policies and the like.

During the study reported here, some of the initial steps were taken toward the goal of creating such a useful prediction tool. A conceptual basis for defining the man-shelter-environment interaction has been laid, some of the more important variables and parameters have been listed (see the section on Parametric Considerations), and the probable ranges and effects of environmental stressors taken one-at-a-time have been estimated through the use of available data and theory. In addition, the K factor concept for relating thermal stress response to the widely variable degree of heat acclimatization in the general population provides a much needed missing link for quantifying the important parameters of heat response. Further progress can be made by defining the direction in which a second stressor would modify the physiological response to a first stressor. A "first cut" at this for some of the important stressors has been made and is summarized by Table III-35.

Six environmental parameters and eleven occupant "status" parameters are included in the table. For each stressor, six or seven physiological effects were selected on the basis of their importance to a mathematical prediction scheme. Many, many others exist and ultimately will have to be treated in a similar manner.

After each stressor an arrow indicates the most probable direction of change as a function of overloading and/or duration of stay in the shelter. Given the direction of change in the stressor, the accompanying change in each of the selected "effects" measures is also shown by an arrow. For instance, according to the table, as effective temperature increases, sweat rate increases - limited by some maximal rate - and body temperature remains constant until the limits of compensability are reached - at which time body temperature and metabolic rate increase. Here we are considering only the single stressor "rise in effective temperature;" therefore, it is assumed that water intake is sufficient to balance sweat losses so that total body water and blood volume do not change. Cardiac output, however, increases.

The stressors "pO_2," "pCO_2," "ingested H_2O," and "ingested calories" are all treated in a manner similar to the treatment for "effective temperature." For each of the stressors and their effects, however, it was necessary to make many simplifications in order to make the chart manageable for a "first cut." In most cases, the exact shape and occasionally even the direction of the arrows might be different depending on the rates of change, durations, and acuteness of the exposures. Therefore, the information given must be viewed as first approximations which provide a general notion as to the qualitative characteristics of response most frequently observed in medium duration exposures. Further extension of the chart should eventually provide for any differences between chronic and acute exposures, rate of increase or of onset, intensity or concentration for constant exposures, etc. For example, short term exposure to excessive CO_2 causes a decrease in blood pH, but in long term exposures to concentrations of only a few percent the acid base balance of the blood is adjusted through the mediation of the kidney, resulting in compensation and gradual return of the blood to a normal pH. In the table, blood pH is shown as decreasing with increasing pCO_2, which is true unless the exposure is for a duration sufficient for compensation to occur.

Another limitation of the chart derives from the nature of the available data. In most experiments, some contamination of response due to uncontrolled environmental and subject "status" influences is inevitable, making it necessary,for the present purposes, to estimate the extent of that influence and to adjust the observed response to account for it. Thus, some of the arrows do not correspond to certain bodies of classical data. For instance, observations on subjects working in the heat - miners, marching soldiers, etc. - frequently show that body water and blood volume decrease. Careful examination of the experimental conditions, however, indicates that this is due to inadequate ingestion of water - because it was not available or because the thirst stimulus is not sufficiently strong under such conditions to bring about complete, voluntary rehydration. On theoretical grounds, based on experiments in which sweat loss was completely replaced by periodic ingestion of measured quantities of water, it was determined that body water and blood volume should not change, although it might be redistributed among the various body compartments. Therefore, rather than contaminate the "pure" response to temperature, the empirical observations were adjusted to eliminate the accompanying effect of dehydration. In the table, the effect of dehydration is shown as a separate entry.

To show the effects of two stressors occurring simultaneously (such as dehydration simultaneous with heat), the stressors are entered again along the upper left hand side of the chart, thus forming a matrix with intersections representing every possible combination of stressors taken two at a time. In the space at each intersection, an arrow indicates whether the imposition of the second stressor increases, decreases, or has no effect on the effect of the first stressor. For instance, decreased ingestion of water superimposed on increased effective temperature causes a decrease in the amount of increase of the sweat rate produced by the increased temperature (but does not necessarily abolish sweat rate altogether). Similarly, the arrow pointing upward at the intersection of "decreased water ingestion" and "body temperature" response to effective temperature, indicates that the effect shown to the right of "body temperature" is augmented, namely, that the point at which body temperature may begin to rise will occur earlier, and that the rate of increase will be greater. The arrow pointing upward at the intersection of "alveolar-arterial pO_2" (to the right of single stressor "pO_2") and "effective temperature" (in the upper left hand row) indicates that the effect of pO_2 on alveolar-arterial pO_2 is augmented, namely, that it decreases by a greater increment for a given decrease in atmospheric pO_2 than would otherwise be the case. However, in the case of no change (a horizontal arrow) in a selected effect for a single stressor, the arrow at a matrix intersection indicates the actual direction of change of the selected effect given a second stressor - this is the only exception to the general meaning of the matrix intersection arrows. Thus, the arrows at matrix intersections (with the foregoing single exception) indicate operations which are performed on the response arrows in the center of the table so as to obtain a qualitative estimate of the combined effects of two environmental stressors. Absence of an arrow means that information was not available or that the complexity of the interaction required a more complex matrix for its display than was warranted here.

Most of the arrows for combined effects are based on theoretical considerations; consequently, they must be considered at least somewhat hypothetical. However, a few experimental studies were found which have a more or less direct bearing on the problem of response to combined environments. Some of them, such as the demonstration of synergism for mixtures of trace toxic gases (Sandage, 1961) have already been discussed. Others could be mentioned. For instance, Hale (1959) studied human cardioaccelerative responses to hypoxia in combination with heat by exposing subjects to each stress singly and then in combination. He found that the mean increase in heart rate of the group exposed to heat alone was equal to that for the group exposed to hypoxia alone (for his particular set of conditions); and that the increase in heart rate for the group exposed simultaneously to hypoxia and heat was equal to the sum of the two individual exposures. In other words, a clear case of additivity of the two stresses was demonstrated. However, the pattern of response did not fit into such a simple scheme: where the peak value during hypoxia occurred at the fifth minute, that for heat was at the fifteenth minute. The peak for hypoxia-heat agreed with that for heat alone. Furthermore, individual differences in response existed which were attributable to what we have termed "population variables" or status parameters: if instead of comparing means we group the subjects according to direction of response we find that only 12 out of 19 subjects showed an increase in heart rate, whereas the other seven did not. In fact, a few actually responded with bradycardia.

Hale's results are a clear-cut demonstration of the need to include terms representing population variability in a physiological response prediction model. A few such terms are included on the right side of the table, thus creating a second matrix to deal with the effect of shelter occupant status on "single stressor" responses. Since the arrows in the "selected effects" column are based on the response of healthy, young adult males, the directional arrows at intersections in the right hand matrix must be

TABLE III-15

COMBINED VARIABLES MATRIX FIRST CUT, TWO AT A TIME

INGESTED CAL. ↓	INGESTED H_2O ↓	pCO ↑	pCO_2 ↑	pO_2 ↓	EFFECTIVE TEMP. ↑	SINGLE STRESSORS	SELECTED EFFECTS ⟷		SEX ♀	PREG. OR LACT.	AGE ↑	INITIAL BODY WEIGHT ↑	INITIAL PHYSICAL FITNESS ↑	INITIAL HEAT ACCLIM ↑	ACTIVITY LEVEL ↑	FEVER ↑	DIARRHEA, VOMITING, ETC. ↑	WITHDRAWAL, ETC. ↑	ANXIETY, ANGER, ETC. ↑
↓?	↓		↑			EFFECTIVE TEMPERATURE ↑	SWEAT RATE	↗	↓				↑	↑	↑	↑?	↓	↓	↑
?	↑						BODY TEMP.	↗	↑?				↓	↓	↑	↑	↑	↓	↑
↓	↑						MET RATE	↗	↑?				↓	↓	↑	↑	↑	↓	↑
↘?	↘						BODY H_2O	→	→	→	→	→	→	→	→	→	↘	→	→
↘?	↘						BLOOD VOL.	→	→	→	→	→	→	→	→	→	↘		
↓		↑	↑	↑			CARDIAC OUTPUT	↗	↓?	↑?	↓↑	↑	↑?	↑?	↑	↑?	↓?	↓	↑
		→	↑↓		↑?	ATMOS. pO_2 ↓	ALV-ART pO_2	↘		↑				?	↑	↑?		↓?	↑
		↑	↑↓		↑?		ART %HbO_2	↘		↑				?	↑	↑		↓?	↑
↓?	↑	↑	↑↓		↑		TISS pO_2	↘		↑	↑↓	↑	↓	?	↑	↑	↑	↓	↑
			↓		↑?		ALV-ART pCO_2	↘											
			↓		↑?		BLOOD pH	↗											
		↑	↑		↑		ALV VENT	↗		↑					↑			↓	↑
↓?	↓?	↑			↑		CARDIAC OUTPUT	↗		↑		↑	↑↓		↑			↓	↑
		↓?		↓	↓	ATMOS. pCO_2 ↑	ALV-ART-TISS pCO_2	↗							↑				
		↓?		↓	↓		BLOOD pH	↘							↑				
		↑		↑			ALV-ART pO_2	↘							↑				
		↑		↑			ART %HbO_2	↘							↑				
↓?	↑	↑		↑	↑		TISS pO_2	↘		↑	↑↓	↑	↓		↑	↑	↑	↓	↑
		↑		↑	↑		ALV VENT	↗							↑			↓	↑
↓?	↓?	↑		↑	↑		CARDIAC OUTPUT	↗				↑			↑			↓	↑
			↘	↘		ATMOS. pCO ↑	ALV-ART pO_2	→											
			↓	↑	↑?		ART %HbO_2	↘								↑			
↓?	↑		↓	↑	↑		TISS pO_2	↘		↑	↑↓	↑	↓		↑	↑	↑	↓	↑
							ALV-ART-TISS pCO	↘											
							BLOOD pH	↗											
			↑	↑			ALV VENT	↗							↑				
↓?			↑	↑			CARDIAC OUTPUT	↗							↑				
↑						INGESTED WATER ↓	TOTAL BODY WT	↘						↑	↑	↑	↑		
↑							BODY H_2O	↘						↑	↑	↑	↑		
↑							BLOOD VOL.	↘						↑	↑	↑	↑		
↑							URINE RATE	↘							↑	↑	↑		
↑							SWEAT RATE	↘						↓	↓		↑		
↑		↓	↓	↓	↓		CARDIAC OUTPUT	↘?							↓		↑	↑	↓
	↑				↓	INGESTED CALORIES ↓	TOTAL BODY WT.	↘	↓	↑	↓				↑	↑	↑	↓	↑
					↓		BODY FAT	↘	↑	↑	↓	↑			↑	↑		↓	↑
					↓		ACTIVE TISS	↘	↓	↑	↓	↓			↑	↑		↓	↑
	↑↓				↑↓		BODY H_2O	↘↗?							↑↓	↑↓	↑↓		
	↑				↑		BLOOD VOL.	↘			↓	↓				↑	↑		
					↓		MET RATE	↘	↑	↓	↓	↓			↓	↓		↑	↓
	↑	↓	↓	↓	↓		CARDIAC OUTPUT	↘	↑	↓		↓			↓			↑	↓

interpreted in that light. Unless otherwise noted, it should be inferred that reversing the direction of an arrow for a status condition merely reverses the arrows at the corresponding intersections below it.

Clearly, Table III-35 represents a very preliminary estimate of combined effects and requires considerable refinement and extension before it can form the basis for the next step, which is to translate all directional arrows into quantitative statements. The chart is included here at such a preliminary stage in its development primarily to illustrate an approach to the combined variables problem which we feel holds considerable promise - namely, the treatment of all interrelated factors vectorially in terms of their partial effects.

In a very restricted sense, the approach we suggest has certain basic resemblances to that taken by Gray (1950) in developing his "Multiple Factor Theory" of the control of pulmonary ventilation. Although the number of factors he included in his model limited its predictive capability, his approach nevertheless pioneered a philosophy of approach to physiological "explanation" or "prediction" which has deserved more attention than it has received. Expanding the number of factors considered and "tooling up" with more sophisticated mathematical approaches might well result in a vindication of his approach. In his very small but admirable book "Pulmonary Ventilation and Its Physiological Regulation," dedicated to "those physiologists whose contributions of imperishable data provoke perishable interpretations," he had this to say about the applications of his theory to the problem of "explaining" or "predicting" pulmonary ventilation:

"A third solution to this problem... is based on the principle that each of the chemical as well as other agents, can be considered to act in its own right as a stimulus to respiration. These various stimuli vary according to many patterns, but each makes its own contribution to the actual ventilatory response. The simplest hypothesis is that the individual, or partial effects of the separate stimuli, are additive; so far, more complex assumptions, such as multiplicative properties, have not been required. According to this approach pulmonary ventilation should correlate with no single stimulus, but should show a multiple correlation with the several stimuli. It, so to speak, considers that the table top is supported by all its legs and not by one alone, nor by a single adjustable leg, nor an invisible leg."

Given more sophisticated tools, Gray would not necessarily have had to limit his approach to a consideration of additive effects. In fact, from basic chemical reaction rate theory, such an assumption seems unwarranted and unnecessary. Use of a computer should eliminate most of the practical obstacles to approaching the problem with less restricting assumptions. Introducing some of the analytical techniques developed by researchers in other fields - such as enzyme kinetics - might also prove quite fruitful for enriching the "bag of tricks" available to the researcher.

In conclusion, it is clear that the solution of almost any "real world" applied problem must take into account the combined influence of many factors. In the case of an overloaded shelter, the problem is merely more accentuated than is normally encountered. The confidence with which statements about one range of conditions can be applied to another range of conditions very frequently hinges on the degree to which the two conditions resemble each other with regard to "contamination" by "unaccounted for" variables. In the case of the overloaded shelter, examination of the potential effects of each of the multitude of stressors - and contemplation of the great amount of so-called synergism which is likely to be exhibited - lead us to conclude that the results of shelter habitability tests to date - if applied to thinking about overloading - would cause us to <u>greatly underestimate</u> the criticality to survival of what normally seem to be negligible influences. We also conclude that:

1. reliable estimates of shelteree reaction to overloading require a rigorous approach to the combined variables problem which was beyond the scope of the effort reported here;

2. such an approach, if taken, would undoubtedly be successful from the point of view of useful products, but would not, in the near future, result in a general solution to the formal problem of the man-shelter-environment interaction;

3. data, techniques, approaches and conceptual bases are provided here which may be considered to constitute the first phase of a more formally rigorous treatment of the shelter environment problem; and

4. the combined variables problem remains as an extremely significant aspect of the fallout (or any other kind of) shelter environment, and until that aspect is fully taken into account, predictions about human response in overloaded shelters must be utilized with reservation - even if they are based on shelter habitability simulations involving severe overcrowding, but in which the actual psychological stress provided by "the real thing" was missing.

IV. METHODS FOR INCREASING SURVIVABLE LIMITS

A. CONTROL THROUGH USE OF DRUGS

1. Introduction

Some types of shelter stresses can be controlled by strong and wise leadership, by attention-diverting techniques, or by some form of psychological or physical therapy. But frequently the simplest, quickest, and least time-consuming - and sometimes the only effective-technique is to administer appropriate drugs and/or medication. Of course, there are some distresses - such as those arising from infections - which may only be relieved by some form of medication, otherwise they normally grow worse.

Present plans for shelter provisioning already include a supply of several generally applicable types of drugs and medicines (5, p. 18).* Pencillin G and sulfadiazine are included to relieve infections. Aspirin is the planned analgesic which can be used for the treatment of headaches. And the chronically peevish neighbor might be calmed by giving him some phenobarbital, which is also included in the planned medication kit.

In addition to those drugs mentioned, the kit is also slated to include a laxative, Cascara Sagrada; a "toothache remedy," Eugenol; eye, ear and nose drops; isopropyl alcohol; diarrhea medication, kaolin and pectin mixture; petroleum jelly; sodium bicarbonate, and salt tablets. That each of these may serve to relieve some form of discomfort - and thus the total of shelter stresses - is evident. However, it is not immediately obvious whether (1) the drugs listed are the best ones available to serve their intended purposes or (2) the list is adequate to handle all the most important kinds of contingencies of confinement that might be treatable by drugs - particularly for the overloaded shelter.

To evaluate the effectiveness of the planned and additional drugs, several of the most recent and comprehensive sources of information concerning drugs were consulted. From the data gathered, a "Drug Table" (see Appendix E) was constructed to summarize the uses, modes of introduction, contraindications, and side effects of

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*In this Section, all parenthetical references will be made only to the Drug Bibliography appearing at the end of Appendix E. The first number in the parentheses represents the bibliographical reference number, the second locates the page on which the relevant information appears.

those drugs which appeared to have potential value for use in the shelter. Although many hundreds of drugs are described in the literature, only a relatively few (64 are included in the table) appeared potentially valuable for shelter stress control. The following are the basic criteria which were used for including a given drug in the Drug Tables:

1. The drug appears on the OCD list of Kit C contents (5, p. 18). (In the tables, an asterisk identifies these drugs.)

2. The drug is a possible substitute for one on the above OCD list.

3. The drug can be stored at room temperature.

4. Parenteral administration is avoided; whenever possible oral introduction or surface application are the preferred modes of use.

5. The drug does not need to be accompanied by excessive intake quantities of water, food, or any other restricted shelter provisions.

6. The drug is not a "diagnostic" or a unique remedy for a relatively obscure disease.

7. A minimum of medical attention is required.

8. The drug appears to be potentially valuable, even though some of the above criteria cannot apply, and no substitute was discovered.

2. Evaluation of Drugs in Kit C and Some Possible Substitutes

a. Acetylsalicilic Acid, "ASPIRIN" (Table Item No. 45)

Headaches are reported to be among the most common physiological complaints in studies of shelter habitability.* Sore throat and muscle soreness have also been observed. The need for analgesic in the shelter is strongly indicated not only by these findings, but by the very fact that in the normal American

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*In the General Bibliography, see Strope, et al., 1961, p. 35 and Altman, et al., 1960, p. 85.

population approximately eight percent suffer from chronic headaches.* That more than the normally expected number of headaches are likely to occur would be predicted from theory; Ostow (10, p. 56) remarks that under stress an individual's ego libido is depleted, and a "decrease in ego libido is generally accompanied by headache."

As indicated in the tables, aspirin has several possible undesirable side effects. In addition, because it is an acid, unless adequate water or an antacid is taken with aspirin, gastric hyperacidity may follow. Since water will be restricted in the shelter, it seems advisable that a substitute be available in the shelter for people who are especially susceptible to gastric hyperacidity and the other side effects of aspirin. Of course, aspirin's low cost is one of its most attractive characteristics and, therefore, should be recommended for use whenever possible.

By the same reasoning, Sodium Gensalate, (Item 44), is not highly recommendable as an analgesic because of its diaphoretic characteristic. The retention of body liquids will be important to minimize water intake.

Item number 42, Dextro-Propoxyphene (Darvon), seems to be the most generally useful of the four analgesics listed because it can be used to relieve pain apparently without side effects. While it is non-addictive, its action is said to be similar to that of codeine (5, p. 47).

Morphine Syrettes (Table Item No. 58) are suggested for conditions causing severe pain (i.e., compound fractures, crush injuries).

b. <u>Cascara Sagrada (Table Item No. 50)</u>

As a laxative Cascara Sagrada is considered as a preferable preparation (4, p. 234); there seems to be few contraindications to its use, since it is safe for almost everyone at any age. The tablet form is preferred to minimize the possibility of loss through dropping or spilling.

"COLACE" or "DOXINATE" (Item 51) or the methocellulose products (Item 52) are objectionable because of their dehydrating effect.

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*See Coleman, 1956, p. 238.

c. Eugenol (Table Item No. 41)

As a topical anesthetic, Eugenol or oil of cloves (included in Kit C), is a very safe medicant - however, more effective and generally useful preparations such as Xylocaine should be considered (Table Item No. 59).

d. Kaolin and Pectin Mixture, "KAOPECTATE" (Table Item No. 48)

This preparation is a liquid and is not specifically effective against the bacterial dysentaries - which seem to us a likely cause of diarrhea. A suggested substitute might be Intromycin Powder (Table Item No. 60) or Neomycin Tablets (Table Item No. 61).

e. Penicillin G (Table Item No. 31)

Since its discovery, the number of penicillin resistant strains of bacteria have increased continually; allergic reactions are not uncommon, and periodically anaphylactic shock has been reported. Within the past decade the market has seen the addition of some new antibiotics which apparently not only replace penicillin but have a broader spectrum of effectiveness, i. e., they are both gram negative and gram positive bacteriocides (or bacteriostatics) and affect many viruses as well. Two of these which are rarely toxic and purportedly produce no side effects are Erythromycin (Item No. 34) and Oleandomycin (Item No. 35) both of which can be administered orally. For infants, Colistin (Item No. 33) appears to be an advisable drug.

Since those antibiotics are relatively new, and since penicillin has had years of proven application, it is understandable that the latter should have been selected for the shelter kits. However, the addition of one or more of the new drugs - if not a total substitution by them - is considered essential to insure overall shelteree protection from the spread of contagious infections.

f. Phenobarbital (Table Item No. 5)

While phenobarbital has long been used successfully as a sedative, its side effects require careful consideration in evaluating its use in a shelter where medical aid may not be available. Among its virtues, it is quite suitable as a safe sedative for infants and children who detoxify it readily. An infant can easily take a one grain dose of sodium phenobarbital without ill effects. However, in adults it may rarely reduce respiration rate and increase heart rate (1, p. 391) and thereby produce restlessness and excitement, which could set off a fear reaction within the person to whom the drug is administered or in those around him. The possible "hangover" will probably call for additional medication. Phenobarbital is particularly to be avoided in the elderly among whom it frequently acts as an excitant drug. Several substitutable sedatives are available for adults, many of which appear to be devoid of side effects and are not habit forming barbiturates. Items 9, 10, and 11 seem particularly safe, and the Ectolurias (Cytran) might be especially valuable in the shelter where tensions due to anxiety may prevail.

Specifically for the shelter situation, Compazine Dimaleate (Item No. 12) seems exceptionally well suited. It purportedly can have a neutralizing effect on almost any extreme reaction to stress - from aggression to lethargy and apathy. In moderate doses, the side effects, even if they do occur, might be helpful rather than detrimental for tolerating expected shelter conditions, particularly overloaded conditions. In addition, Compazine delayed-action capsules, 15 mg, should be considered as a routine aid to be given every 12 hours to all shelter inhabitants during the first few hectic days of confinement.

Paraldehyde (Item No. 13) is objectionable because of the pungent odor of the drug per se and as it is expelled via the lungs.

g. Sodium Bicarbonate (Table Item No. 57)

The usefulness of sodium bicarbonate as a treatment for gastric hyperacidity is questionable. One reference source states that it is effective, but it causes "rebound" acidity of the stomach (7, p. 125), while elsewhere one finds the comment that it does not cause a significant "rebound" effect; rather "its neutralizing action is very short-lived" (3, p. 224).

It is generally agreed, however, that sodium bicarbonate can be used to alkalinize the urine, especially valuable in connection with sulfonamide therapy. If sulfadiazine were not included in Kit C (and that will be suggested later), sodium bicarbonate would be relatively ineffective as a medicant.

Since shelter stomachs will be empty much of the time, more than usual hyperacidity may be expected among the occupants. The discomfort from gastric acidity may be as widespread as headaches. Therefore, it would seem advisable to include an effective antacid in the Kit. For those reasons, two possible substitutes, CO-GEL and DIMACIDGEL, are listed in the Table (Items 55 and 56), neither of which have any side effects nor any contraindications to their application. Both are undoubtedly more expensive than sodium bicarbonate, but they are far more effective. Since both "CO-GEL" and "DIMACIDGEL" are stable and available in tablet form, they are readily stored and have long.shelf lives.

h. Sulfadiazine (Table Item No. 37)

Of all the early sulfonamides, sulfadiazine is reported as potentially least harmful to the kidneys; nevertheless, it is known that crystals of acetylated sulfadiazine can be deposited in the renal tabules and result in partial or total suppression of urine or in hematurea (15, pp. 125f). To reduce the probability of damage to the kidneys, sodium bicarbonate and large quantities of water must accompany sulfadiazine administration. The recommended fluid intake exceeds three quarts per day (4, p. 8). Since planning for a normally loaded shelter provides for only a quart of water or so per day per person for a full stay of 14 days, and since even less will be available in an overloaded shelter, it would be strongly suggested that a substitute replace the sulfonamide. The three antibiotics listed above in the discussion on Penicillin G would be effective replacements for the sulfadiazine and penicillin supplies now planned for Kit C. If one of the sulfonamides were to be included a better solution might be provided in Sulfisoxazole (Gantrisin) (Table Item No. 62) in tablet form. This preparation does not require an alkaline urine for proper excretion nor an excess of fluid intake.

3. Additional Medicants

As shelters become more and more crowded, the probability increases that (1) within the shelter someone is carrying a contagious disease, (2) due to weakness (reduced resistance) and close contact with others, contagious diseases will spread more rapidly and (3) people will respond with a greater variety of complaints than in the less crowded shelter.

a. Nausea and Dizziness

In Section III. A. 5, Chart 1 illustrates the findings that excessive heat, food deprivation and offensive odors may cause nausea, dizziness and vomiting. Children are sensitively prone to nausea with inadequate feeding. And, in addition, some necessary medicants - e. g., aspirin - may cause dizziness and/or nausea. Nausea may lead to vomiting which, in a crowded shelter, can cause a multitude of problems: (1) others may feel nauseated at the unpleasant sight and smell; (2) a more than normal quantity of water would be required due to dehydration resulting from vomiting, and water will be at a premium; and (3) the odor may be offensive to many others causing additional discomfort and a multitude of possible undesirable reactions.

To combat nausea, two apparently safe and effective antiemetics, Dimenhydrinate and Hydroxyzine HCl, are listed in the Drug Tables (Items 46 and 47). Both come in tablet form and neither seems to have any side or toxic effects. It might be noted that since nausea is a common reaction to radiation sickness, an antiemetic will be essential for relieving the victims, if severe dehydration is to be avoided. It is further suggested that the Dimenhydrinate (Dramamine) be provided in syrette form since orally administered medications are of little use after vomiting has once begun.

b. Colds

Biderman[*] reports a finding that among people confined under stress, there is a lower incidence of common colds than in the normal population. That observation was made in a concentration camp and no clear corroborative evidence has been found. However, Altman, et al.,[**] reports contradictory findings; in that study, about 30 percent of the experimental occupants reported "cough or common cold symptoms."

At some point in the future it may be possible to obtain a drug which will kill the multifarious viruses responsible for colds. At present, however, there are only a few drugs available which are proven virucidins, but only against a relatively few viruses. One such drug is the antibiotic, Erythromycin (Item No. 34); this drug will not kill all cold viruses, however.

The usual remedies for colds are rest and liquids. In the shelter, the former will practically be forced and the latter practically impossible. The greatest physiological danger

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[*] See General Bibliography, Biderman, 1960, p. 26.

[**] Altman, et al., 1960, p. 85.

from a cold is bacterial infection resulting from a drop in resistance; however, antibiotics can be used to treat such infections. The greatest shelter problems for which the common cold might be responsible will arise from the distress created by its symptoms.

To relieve this distress, many "cold remedies" are available. Analgesics may help relieve pain associated with a cold, but they do not affect nasal congestion, sore throat, running eyes, and so on. Table Items 24 through 28 list cold and hay fever remedies which tend to reduce those symptoms. And Items 29 and 30 list four safe medications effective against the discomfort of acute coughing. Treatment for all of these effects can be obtained in tablet form, a fact which helps to reduce storage and wastage problems.

c. Skin Rash

In the shelter simulation study reported by Strope, et al.,[*] the second most common complaint was skin rash. (The first was headache, as mentioned earlier.) Altman, et al.,[**] also report some cases of skin rash among their shelter populations.

In the crowded shelter, rashes will quite likely arise as a result of the excessive heat and humidity. Some skin disturbances (dermatitis, itching, and so on) can be expected among many mild pschoneurotics. In addition, insects which may have made homes in the dormant shelter may feel free to feed on shelterees and cause other forms of skin irritation.

Finally, it can be expected that fear of contagion may become an important social problem; an obvious but harmless skin rash could cause more immediate and widespread fear than a subtle virulent disease. Managers should be able to handle the social problem by adequately informing shelterees regarding the nature of the problem. Also, if treatment is available, fears will be allayed.

Three medicants are listed for relieving various forms of skin difficulties. These appear as Table Items 38, 39, and 40. The most versatile and easily stored of the three is "DRONACTIN: (Item 38) which may cause drowsiness. In the shelter,

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[*] See General Bibliography, Strope, et al., 1961, p. 34

[**] Altman, et al., 1960, p. 85.

this side effect may serve a useful function by reducing overall activity, so there are no apparent contraindications to its use.

d. Upset Stomach

Atlman, et al., * found that about 30 percent of the occupants of their simulated shelter complained of an upset stomach. For this reason, several apparently safe medicants listed as "Laxatives, Antiflatulants, and Antacids" are included in Table Items 49 through 56. Most of these were discussed earlier in the evaluation of Kit C under the headings "Cascara Sagrada" and "Sodium Bicarbonate." Those comments will not be repeated here since the need for them already appears to have been considered important by shelter planners. The need for an antiflatulent, especially for children, is suggested for consideration, since the abnormal shelter diet may cause unpredicted digestive problems.

e. Psychological Drugs

In Section III the point was stressed that there appears to be no clear-cut evidence of how people will react to the stresses of thermonuclear attack and shelter living. That various psychological and physiological responses will be manifested seems likely. And in the overcrowded shelter, not only will people be likely to experience greater environmental stresses and respond more severely than in a more comfortably loaded shelter, but the severity of reactions may snowball and spread because of the very nearness of people who have developed unpleasant modes of behavior.

Immediate control of severe overt displays of aggression can take the form of restraint; however, an aggressive individual may not calm down. If he remains overactive, he will not only utilize more energy than can be tolerated because of the restricted quantity of food, water, and oxygen, but others will have to expend more energy to hold him in check.

Psychological drugs are available for effectively controlling overactive behavior due to anxiety. The sedatives were mentioned earlier in the discussion of Phenobarbital. In addition,

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*Altman, et al., 1960, p. 85.

there are now available several new and apparently safe tranquilizers which can serve the purpose of calming overly nervous people. One drug expert has claimed that tranquilizers do not bring "peace of mind" to normal individuals (13, p. 86). It is probably safe to assume that the shelter entrants under their catastrophic stresses will not fall into this "normal" category.

Four types of apparently safe and potentially effective tranquilizers are listed as Items 1 through 4 in the Drug Table. To calm the active individuals, "Melleril" or one of the Mephenoxalones would appear to be advisable.

For general use, to check many forms of anxiety reactions, "Elavil," Amphenidone, or Emycamate may be valuable. As indicated in Section III, anxieties due to depression may well be expected among many of the shelter occupants. It is not possible to predict what percentage of people will be unable to manage their anxious feelings, but the resulting reduced morale of shelterees could conceivably be serious in a very crowded shelter where everyone's cooperation will be important to survival.

Consideration might be given to handing out "Elavil" or Compazine to all people as they enter a shelter as previously suggested. This procedure might serve to make new arrivals amenable to initiation and training and to reduce the initial tension connected with doubts concerning their survival. The leader's organizing problems might be minimized and the discomfort from overcrowding - if it exists - could be kept down. Once a routine has been established, once the leaders have demonstrated that the shelter can keep the occupants alive and well, and when the people have been supplied a basis for feeling confident that they will survive, the drug will have served its purpose. It is quite conceivable that subsequent management and operations would be simplified if cooperation were achieved at the beginning. The shelter might be considered safe simply because it offers relief from anxiety right from the start. Individuals might tend thereafter to associate protectiveness with the shelter, a fact which may help to promote feelings of well-being and hope for survival.

Stimulants may also be classified among the psychological drugs, although some stimulants have an almost purely physiological value. For example, ammonia (Item 18) has often been used to revive someone who has fainted. However, it is not recommended that ammonia be included among shelter medicants; it is mentioned in the Table because it has so frequently been used in the past to stimulate the heart rate or respiration for resuscitation purposes. According to Henderson and Haggard,* ammonia can cause "intense congestion and swelling of the upper respiratory passages and possibly rapid death from spasm or edema of the larynx... the influence of ammonia on respiration and the heart is due to reflexes from the upper respiratory tract. If the concentration is high, respiration may be stopped." In the enclosed shelter, where ventilation may already be poor, a spilled bottle of ammonia could be dangerous.

If passive depression or withdrawal becomes a serious problem Pipradol HCl or "Marsalid" (Items 22 and 23, respectively) could be very helpful to regain the affected person's cooperation, which at least will be needed for post shelter survival training. Inactivity may also be a demoralizing factor. But before an energizer is administered, the demoralizing factor will need to be weighed against the fact that a reduced expenditure of energy will tend to conserve food, water, oxygen, and space requirements. So as not to increase activity too much, the use of stimulants will have to be carefully controlled and restricted to severe cases.

Chart 1 in Section III.A5indicates that food deprivation, sleep deprivation, crowding and noise may be expected to produce fatigue. All of those stresses will be exaggerated in the highly crowded shelter, so that fatigue may become a serious problem. It is claimed that drugs 19, 20, and 21 produce relief from feelings of fatigue; they may be invaluable to survival if shelterees become incapacitated by fatigue and are unable to respond to post-shelter training. Also, in-shelter activities will be essential for maintaining an effective level of physical fitness. Again, however, caution would need to be taken not to overstimulate occupants of a shelter where excessive activity could not be tolerated.

Among the stimulants are the so-called anorexiants (Table Items Nos. 16 and 17). In the crowded shelter, they have the advantage of reducing fatigue and the desire for food, which will be very restricted, and at the same time of stimulating

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*See General Bibliography, Henderson and Haggard, 1943, pp. 112 and 126.

alertness and attention. In spite of frequent claims to the contrary, there are also some disadvantages: resulting over-activity may irritate others, increase the shelter temperature, and make greater demands upon space. Sleeplessness and irritability may appear in some who take the drug. And some individuals go into a depressive state after the drug wears off (1, p. 389).

There have been many studies of the effects of amphetamines (Table Item No. 17) on performance; the results indicate that these drugs may be useful to stimulate shelter occupants who have special abilities but lack energy or motivation to use them, e.g., the leaders and doctors. One study reports that under the effects of d-Amphetamine accuracy of performance is somewhat improved, but reaction time is very significantly less than without the drug (14, p. 465). Other investigators also found that motor performance is improved only slightly, but they added that accuracy is not impaired (11, pp. 183f). Still others, however, report that performance is improved, and so is motivation; also it is stated that judgment is at the same time not impaired, eventhough insomnia may be a side effect (12, p. IV-74).

Thus, in a crowded shelter at times of crises when the leader may have many responsibilities, he will need to sustain his ability to perform effectively if he is to handle the multitude of problems successfully. The amphetamines could be a significant and, perhaps, an almost essential contribution to his functioning in an appropriate manner. The drug would help him to perform effectively over a longer period of time and to act quickly without having his judgment impaired by fatigue.

4. Drug-Induced Hypometabolism ("Hibernation")

Since the physical limitations of a given shelter area place definite limits on the length of time a given number of inhabitants can survive it seems reasonable that methods of reducing individual metabolic requirements should be considered. The control of excessive motor activity and emotional turmoil can be fairly well accomplished by the use of sedatives, thus reducing the occupants to a "basal" state. The next logical step might be to consider drugs that can lower the metabolism below the basal level.

Reasonably safe thyroid repressing drugs (Table Item No. 63) are available and have had fairly extensive clinical trial in both hyperthyroid individuals and in persons having normal thyroid hormone output. The latter group include patients made hypothyroid in order to reduce the workload of diseased hearts (Ref. 16, 17, 18, 19).

The characteristics of hypothyroidism whether due to surgical removal of the thyroid or ingestion of antithyroid drugs include poor appetite, a gastric juice containing little acid, diminished sexual activity, absence of menses, drowsiness and increased sleep requirement, indifference to heat and a general decrease in motor activity - all of which may be distinctly advantageous in severe overloading. The basal metabolism can be lowered to 40 percent below normal with equivalent decreases in oxygen and nutritional requirements and in production of body heat. All three of those factors are critical in determining the length of time and/or degree of overloading for which a given shelter area could be tolerated. Conversely the hypometabolic state can be terminated in a matter of hours through the use of thyroid hormones; i. e., a basal metabolic rate of minus 40 percent can be raised to normal within 24 hours by administration of 1 mgm of L-triiodothyronine (Ref. 20) (Table Item No. 64).

Although the use of metabolic depressants is certainly not recommended here as a "cure-all" for the ills of shelter overloading, the technique does nevertheless offer certain attractive advantages. It seems quite likely that survivable overloading could at least be doubled by depressing the metabolic rate through administration of Tapazole to all but the shelter managers, pregnant or lactating women and the rare case of sensitivity to the drug - all of whom could be brought back to normal in a day's time through administration of L-triiodothyronine. Of course such a technique would not be advised except as a sheer lifesaving measure. However, for such a lifesaving feature to be available, a supply of Tapazole and L-triiodothyronine would have to be pre-stored in shelters located in areas where significant probabilities of overloading exist.

One possible scheme for "metabolic management" might be as follows:

Severity of Overloading	Control Technique
Underloading to normal (planned) loading	No special control. Allow any activity consistent with normal shelter functions.
Slight overloading (1.1 - 1.3)	Restrict activity levels to those necessary to critical shelter functioning and maintenance of physical fitness of occupants.

Severity of Overloading	Control Technique
Moderate overloading (1.4 - 2.0)	Use sedatives as necessary to maintain environment and/or occupant reactions below critical levels.
Severe overloading (2.1 - 4.0 or higher) (For even less severe loading in the event of unusually hot environment, greatly limited water supplies, durations much longer than two weeks with little or no food, ventilation inadequate to prevent critical rise in CO_2 concentrations, etc.)	Use Tapazole or equivalent metabolic depressants on all but pregnant or lactating women, infants (use phenobarbital), drug sensitives, and management personnel. Return to normal in shifts for training or other critical activities requiring mental alertness.

Whether "metabolic management" through use of sedatives and/or metabolic depressants should be used as opposed to the heat acclimatization exercise regimes and/or wetted fabric "replacement" of the sweating mechanism, depends on a number of factors, including the economics of shelter construction and provisioning, the relative effectiveness of the various potential procedures, the specifics of the exposure (duration, etc.), the probable incidence of severe cases, and a host of quasi-political and situational factors.

5. Implications for Overloading

Clearly, the number of people who can be crowded into a shelter before overloaded conditions exist is inversely related to the number and extent of stresses experienced by shelterees. The less the stress, the greater the number of occupants that can be tolerated.

In the preceding pages, an attempt has been made to identify the most pertinent physiological and psychological stresses which might become real problems in the shelter and which could be alleviated by the use of drugs and medicants. All the distresses mentioned have two implications relevant to the crowded shelter interaction: (1) an afflicted person's effectiveness is reduced and (2) other shelter residents are bound, in one way or another, to be disturbed by the problems of their neighbors. A very flatulent person might feel embarrassed, and provide a source of irritation to those around him. An individual with an "itchy" skin rash is both uncomfortable and a source of irritation to others - and may be a source of fear of contagion. In an extremely crowded situation, either of these problems could provoke undesirable movement and reactions which might critically add to the overall stress.

It is important that behavior be under control in any shelter situation to reduce the overall feelings of discomfort and insecurity. Particularly in the crowded shelter, where control will be even more difficult because of the numbers of people and the increased environmental stresses, physical and psychological distresses are likely to be exaggerated. If these problems can be solved or alleviated by the use of drugs, more people will be tolerated by a shelter before a critically overloaded condition will be reached than if the disturbing condition were permitted to go unchecked.

In a more speculative vein, the relatively more drastic control measures which not only return people to a "near basal" state but essentially put them in a "hibernation-like" state, offer possibilities which warrant further investigation - possibilities which should be evaluated within a "life-or-death" context rather than from the point of view of the clinician.

B. PSYCHOLOGICAL CONTROL WITHOUT DRUGS

Shelter managers will be responsible for handling whatever behavioral problems arise in the shelter. Therefore, they will need to be familiar with methods of controlling adverse psychological factors as well as methods for minimizing the likelihood that the reactions will arise in the first place. The most reasonable and probably the most effective time to start applying preventive measures is during the orientation period when people will probably be unorganized, uncertain, and as a result malleable. To pre-set the psychological stage could be highly critical because it will influence the likelihood and extent of later reactions which would require special corrective attention. The recommendations for early preparation derive primarily from the Janis' (1958) findings which were discussed earlier (Section III. A. 5).

Pre-shelter training will minimize misconceptions regarding shelter life. This point has been made so often by other reporters that it need not be expanded here.

However, even with prior knowledge, some people may still become difficult to manage. In order to minimize the likelihood of damage to themselves, others, and general group morale, those people must be identified, as effectively as possible, upon shelter entry and given special treatment. The following tentative recommendations are made to accomplish those goals at least in part:

1. Each shelteree should be introduced to everyone else. He would be asked to state his name, age, occupation and <u>how he feels about his present predicament and probability of survival.</u> Crew members taking notes should be alert to identify the people whose apprehensions are excessive and those who are hardly concerned.

2. The leader should graphically describe the reality of the shelter problems anticipated, including possible individual reactions to these problems and to other people. This presentation should include estimates of the likelihood of survival under various degrees of group and individual cooperation. (While the leader is talking, crew members are busy grouping people according to the degree of anxiety expressed in 1 above.)

3. The leader should then indicate and stress the importance of the role which each person will have to play in carrying out his or her responsibilities both during and after the shelter occupation period. He should provide all possible evidence for his confidence in the effectiveness of the shelter for survival.

4. With the help of the crew members two special groups for immediate independent orientation should be formed, one of apathetic individuals and one of highly anxious people, as determined by the groupings made by the crew members.

   Intensively describe to the first group the specific kinds of difficulties they will encounter until they seem to understand as well as possible. The second group would benefit most from a form of group therapy. One crew member (or a psychiatrist, psychologist, or social worker, if a capable one is available) should gather the anxiety-ridden people together at the peripheri of the main group and allow each person to express his feelings to the leader and to other members of the group. Anxieties probably will not be eliminated in this way, but a means will have been established for relieving some of the anxious feelings either in subsequent group meetings or between members of this group or both, thereby reducing internal pressures which could lead to destructive overt acts. Subsequent meetings should be held if it is observed that initially observed worrisome reactions grow worse.

After the shelter occupants are oriented, probably the most effective procedures to prevent undesirable acts from being committed will be to: (1) keep the shelter occupants well informed during frequent regularly-held meeting periods regarding all known conditions both inside and outside the shelter, (2) focus and maintain attention on, and secure participation in, a survival-oriented group program to keep people occupied, to train them for the new society, and to maintain their confidence in the survival value of the shelter, and (3) stress the value of each individual as an integrally functioning part of the group within the shelter and as a required member of the post-shelter society. The leader (or, if the shelter population is large, the crew members) will be most effective if he will rapidly become familiar with each person's conception of his capabilities. A housewife must feel that she will be needed to take care of the children, prepare food for the men who will be rebuilding places to live, etc. A carpenter or laborer will be needed for reconstruction. Each member of the shelter group must feel that he is invaluable to shelter survival and indispensable for post shelter reconstruction.

Within the overloaded shelter, the number of people will be so large that the task of sustaining each individual's integrity may be exceedingly difficult but even more necessary than in the normally loaded shelter because people will be likely to feel submerged by the crowd. And loss of privacy will tend to aggravate that feeling.

Irrational behavior can be expected to increase with overloading; withdrawal, aggressions, and attempts to leave the shelter too soon are a few of the difficult-to-manage reactions. Withdrawal may be demoralizing to others, but can be tolerated because energy is conserved. Since depressed and withdrawn people require care, a leader might well capitalize on them by emphasizing the value of persons whose responsibility it becomes to take care of them. Aggressive persons or those wanting to leave may need to be restrained until they can be calmed down. A patient, quasi-rational approach on the part of the leader or his crew members may be effective:

1. Explain the destructive nature of the acts with non-reprimanding comments regarding the understandable reason for the outbreak.

2. Indicate prior rational behavior, e.g., "You wisely came here expecting safety from radiation. You are safe now because of your good judgment; so use that good judgment to help us survive these miserable conditions." Note that the comments (a) are not reproving (b) give the listener credit for wisdom and judgment (c) prove the prior effectiveness of his judgment, (d) provide hope that everyone will survive, and (e) acknowledge his feelings and the fact that shelter life _is_ wretched.

3. Explain conditions outside and inside the shelter succinctly, accurately and in a step by step manner.

4. Make the person feel that he is needed in the shelter now and in the post-shelter society by explaining what his duties are and will be - based upon his unique capabilities - and precisely how his efforts will make it possible for everyone to survive. This procedure will require some knowledge of the individual and his pre-shelter activities.

As already indicated, even though individual attention will be difficult to provide when there are many people and management problems mount, some form of personal aid may be necessary if the shelter is to be effective and chaos is to be prevented. And if aggressive behavior is chronic, continuous attention may be needed. There are, however, procedures for handling more than one potentially or actively destructive person at a time, if they can be influenced to cooperate by using the techniques outlined above. If there is anyone in the shelter who has had training in social work or psychology, a form of group therapy can be instigated. It would be valuable to include essentials of group therapy in the leaders' training curriculum. The primary bases for the effectiveness of such a group is that (1) members express their emotions and feel accepted in spite of the fact that they tend toward or have displayed destructive behavior, (2) they recognize their own worthiness and (3) they are not alone.

In conclusion, it is suggested again (see Section III. A. 5) that management in the overloaded shelter will be simplified - though, very likely, not simple - if constant preventive measures are taken to (1) maintain a high level of hope for and confidence in survival, for under conditions of "high morale and anticipations," Biderman (1963, pp. 30 and 39) reports, overcrowding has been shown to be tolerable; (2) stress the importance and value of each individual as an integral part of the shelter society and as a functioning member in post-shelter reconstruction. People under severe stress need a "sense of belonging and being accepted." (Meerloo, 1957, p. 371); (3) maintain communication with outside and with other shelters and report all conditions frequently to shelterees (Rohrer, 1960, p. 24); (4) keep people busy at meaningful, organized activities (Rohrer, 1960, p. 23).

All of the recommendations imply activities on the part of shelter leaders. The responsibilities for management are so great that good leadership is imperative; therefore, the selection criteria must be carefully derived. It is not the purpose of this paper to describe the characteristics of the strong and effective group leader; numerous documents and books are available on the subject. One rather obscure study, however, is worthy of brief comment. Smith and Goodchilds (n. d.)* have reported some studies of the effects of wits within groups. They found that "groups with deliberate (effective) wits as members evaluate the group more favorably."** Furthermore, wits have a positive effect on "morale and problem solving efficiency of their groups."*** That a leader endowed with an effective sense of humor may receive greater cooperation and maintain a higher level of morale than a somberly serious person is indicated by such findings.

C. PHYSIOLOGICAL CONTROL WITHOUT DRUGS

A number of possibilities exist for increasing loading limits through procedures based on physiological considerations. Two basic approaches (or both) could be used, namely, to reduce the environmental stress through rigid control of the activities of the occupants, or to improve the

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*In two reports for the A. F. Office of Scientific Research of the Office of Aerospace Research, under Contract No. AF49(638)-1216.

**"The Wit and His Group"

***"The Wit in Large and Small Established Groups" stress tolerance of the occupants through special techniques. Although we have not attempted to make an exhaustive catalog of all possible approaches, a few which seemed particularly promising for further consideration are discussed below.

1. Rotation to the Ambient Environment

One possibility is suggested by the fact that after the first few days, radiation decay rates might be reasonably predictable. Given that fact, it should be possible to modify an "Entry Time - Stay Time Total Dose Nomogram" such as the one given in the OCD Handbook for Radiological Monitors, so that occupants could be allowed to leave the shelter each day for ever-increasing periods of time to decrease the total heat output in the shelter, to decrease their response to heat, and to perform other useful tasks such as foraging. It has been pointed out earlier that even short periods of relief from heat can go far toward increasing the level and duration of heat exposure which can be tolerated.

2. Alteration of Physiological Characteristics

A second, more elaborate approach, which might be considered if rotation to the outside environment turns out to be unfeasible on further study, is suggested by our study of the heat acclimatization process. It is clear that a serious problem in the overloaded shelter is the detection and subsequent treatment of the small fraction of the population which is highly susceptible to heat stress. We therefore suggest a first attack which is directed toward dealing with this problem. The attack is two-pronged; firstly, the identification of the more susceptible occupants and the prescribing of appropriate procedures to bring them up to the level of the population median with respect to heat stress resistance (or "acclimatization"), and secondly, the devising of a regular routine of behavior, training, and exercise for the total shelter complement, which will raise the level of the tolerable limit for all.

a. Categorization of Shelterees as to Heat Stress Resistance

Within hours of the loading of the shelter, a record sheet should be prepared on each individual which will contain the data upon which to base a rough computation of his K factor (i. e., sweat response characteristic). The initial data to be entered on this sheet will be the body weight and skin temperature while at rest, together with the time at which the determination was made; sometime later, the exact duration being dependent partly on the sensitivity or accuracy of the balance used, a second weight and temperature will be taken for the record. Subsequently, on the occasion of the first heat treatment given for the primary purpose of improving the sweat response, a second set of weight and skin temperature measurements should be taken. A simple difference calculation based on the sweat rate and skin temperature under the two conditions described will suffice to provide, to a first approximation, the K factor for that individual.

It is not clear at this time what the most economical number of categories would be, since we have little if any information about the lowest K factor that we must be prepared to expect. It is anticipated that the useful number will be of the order of 10 categories.

b. Techniques Expected to be Effective in Rapidly Increasing the K Factor

1. The first requirement, it is believed, is for the imposition of a regime of carefully designed and regulated exercise; there is every reason to suppose that the design can be such that useful external work can be obtained as a by-product, by means of extremely simple apparatus, and utilized to enable the remaining features of the prophylactic procedure to be recommended in what follows. The design of the exercise regime must have as its primary goal the maximizing of the degree to which the vasomotor control system is exercised.

2. Next in order of importance is the institution of a program of at least one, and probably several, exposures daily to a high heat stress relative to the particular individual's stress resistance or K factor. The first of these exposures will be under standard conditions, sufficient to permit the determination of the initial K factor as described above; subsequently, the severity of the heat treatment will be tailored to the individual, and modified day by day as his resistance improves, in the interest of achieving the most rapid rate of increase in his K factor possible.

3. As an essential antidote or safety feature, vis a vis the heat treatment procedure described above, it is necessary to have a means of rapidly cooling at least one person at a time.

The function of this provision is to produce sudden vasoconstriction in a person whose surface skin blood vessels are dilated. Thus, anyone who begins to feel slightly faint, nauseated, or unduly fatigued in the course of his heat treatment, will be removed immediately to the "refrigerated shower," where, in a few moments he will fully regain his sense of well being and can be transferred to the normal shelter environment with practically no diminution in the effectiveness of the heat treatment.

By far the more frequent, and probably more significant usage of this facility will be for the routine daily exposure of each shelteree, for as long a duration as is possible, taking into account the total number of occupants and the capacity of the "cool room," or "cool cabinet." The primary purpose of this daily exposure to a cooler environment is to permit the cessation of sweating and the drying of the skin for a finite length of time each day. At present, our knowledge of the minimum requirements for the prevention of prickly heat and the various heat rashes in general is insufficient for us to be able to relate quantitatively the duration of daily cool exposure and probability of experiencing heat rash. Intuitively, the evidence seems to indicate that any reasonable period will be better than none at all, and the effect of brief exposures of this kind may be of considerable significance in minimizing the tendency for sweating to be reduced after long periods where the skin is totally wet.

The means of achieving this limited area cooling facility can be selected only on the basis of an engineering trade-off study; the critical criterion is the rate and amount of reduction in skin temperature that can be achieved. Whether the cooling means is through refrigerated water sprays, increased air velocity by means of fans, or a reduced temperature of the radiant surround, cannot be decided at this stage. Presumably of central importance is the consideration of the relative ease with which the exercise regime recommended in Item 1 can be coupled to the machinery which produces the cooling effect.

4. The final item proposed for feasibility evaluation is one which could be adapted to meet several of the elements in the foregoing requirements; in the extreme, it is conceivable that mechanization of this capability might eliminate the need

for most of the other provisions recommended above. The facility referred to is a high velocity "needle-point" shower designed to permit the efficient flushing or cleansing of the total body surface area in a few moments.

Such a facility, in the ultimate, could be conceived of as replacing the human sweating mechanism altogether, thus eliminating the need for improving the sweat response of individuals; in this application, a light-weight, close-fitting, comfortable, and highly-absorbent garment would be worn which would cover most of the body surface. The shelteree would periodically pass through the shower, retaining sufficient water absorbed in the garment to provide for his evaporative needs for the next period of perhaps a half to two hours. Occasionally, the shower would be used for purely hygienic purposes to remove sloughed epithelium, sebum, etc., by mechanical means alone (i. e., without using soap, which would complicate the filtration and reclamation system).

Note that the specialized garment assembly described neatly eliminates the modesty problem which seriously complicates the thermal problem where the sexes are mixed and children and adolescents are included in the population.

The hygienic value of the high velocity shower cannot be over-emphasized in view of the well-established seriousness of the fungal infection and general irritation problem in a warm humid atmosphere.

5. Whether or not any or all of the foregoing special engineering provisions are introduced, some means of handling cases of incipient heat collapse is needed. The very simplest of such means is one which is expected to be extremely effective if a suitable technique for its utilization can be worked out, and at the same time it is quite undemanding as to modifications required in current shelter stocking and equipment policy. This is to store within the shelter a number of bottles of ethylene chloride with spray dispenser heads. The only difference from the standard medical use of this material in the relief of pain which the proposed technique calls for is that application should be made of the fine spray to as large an area of the body surface, simultaneously, as possible. It is thought likely that the design of an extended length applicator head would present no particular difficulty.

The effectiveness of the spray application of ethylene chloride to the skin in treatment of incipient or acute heat collapse lies in the extremely powerful vasoconstriction stimulus.

c. Ancillary Benefits of the Special Provisions Suggested for Thermal Control

1. Depending on the extensiveness of the exercise apparatus, as to the number of persons doing work at any one time, a source of emergency power is made available.

2. The organization of a serious routine of work and thermoregulation training will be, it is thought, far more effective in morale maintenance than will the imposition of any "busy work," and can further be justified as physical fitness training in preparation for the possibly strenuous requirements of the post-attack world.

3. The flushing off of the skin at least once a day by means of a high velocity shower will not only cleanse the skin from a bacterial standpoint, but will also prevent any accumulation of salt, which would reduce the evaporative potential. If the recirculated water system were to contain a mild bactericidal agent of the cumulative effect type, such as Zephiran, it should be possible to build up an immunity to infection of impressive magnitude.

4. Obviously, the engineering difficulties (for specially constructed, underground shelters) involved in the task of reclaiming water from that which condenses in the shelter air-conditioning system or on the walls of the enclosure (as a possible approach to the water limitation problem) are vastly simplified if that water is to be mixed with a bactericidal agent and merely sprayed upon the clothing or skin of people, rather than being intended for ingestion. Knowing that people can tolerate indefinitely conditions which cause them to sweat at the rate of six quarts per 24 hours, and that they may be capable of withstanding conditions associated with still higher rates for very considerable periods, it is obvious that we must either re-use the water that is stocked or eliminate the need for reliance on the physiological mechanism of sweating. In the latter case, it is probably still logical to recirculate water, even though the total quantities required per day are probably much less when the water for evaporation is applied externally instead

of passing through the complex absorption and excretion systems of the body.

5. To whatever extent water is provided externally to the skin surface, the hazards of electrolyte imbalance are reduced. With the total replacement of sweating suggested above, the problems of chloride imbalance and of dehydration should be totally eliminated.

d. Effect of Exercise Regimen on Shelter Heat Balance

In recommending that regular exercise be required of shelterees, and that useful work be extracted from such exercise with the maximum achievable efficiency, we have not overlooked the effect on the overall heat balance of the shelter.

While it is true that the increased heat production associated with exercise must tend to raise the shelter temperature, the practical significance of this effect will be minor if the proportion of the total number of occupants who are working at any one time is kept low.

It is believed that the advantages gained by the maintenance of vasomotor, venomotor and muscular tone, as well as the improvement in the general fitness factor, which pertains primarily to the cardiovascular system characteristics, will outweigh any simple effect on the thermal load imposed on the chamber air-conditioning system.

The question of the type, duration and severity of the exercise will require careful and thorough investigation, taking into account the probable entering state of fitness of shelterees, morale, and the engineering problems of coupling to work output devices.

V. CRITERIA FOR ESTABLISHING SHELTER LOADING LIMITS

It has been suggested earlier that the loading limit for a fallout shelter might be that loading which results in severe but reversible effects in a substantial proportion of the healthy population, where reversible refers to spontaneous recovery without expert medical assistance in a few hours to a day - given adequate food, water and rest in a comfortable environment. In the light of the subsequent analysis of shelteree response to overloading, we must now re-examine that criterion with regard to the possibility of predicting the loading at which such a condition would be obtained. A second aspect to be considered is what is implied by a substantial proportion of the healthy population? To answer those questions, it is necessary to consider the distribution of environmental stress response in a mixed population, and how that could be related to criteria which have operational meaning.

Let us assume that we are able to define response of various segments of the population to a given set of environmental stresses in terms of the distribution of specified levels of response and associated response times. By examining the distribution either of times to reach a specified response intensity or of response intensities at a given time, we might discover two modes, one which represents persons with organic deficiencies; and another, much larger, which represents a so-called normal or healthy population. By analyzing the constellation of "defects" found in persons falling within the more severe response mode, it might then be possible to separate the population into "normal" and "handicapped" responders, and to characterize each group with respect to a mean and variance for time to reach given response levels which have meaning in an operational sense.

Let us next define criteria which can be related to response levels on the one hand and to operational criteria on the other. At the outset, it is useful to define a series of criteria corresponding to a range of responses. One way such a series could be developed is presented in the second column of Table V-1, which lists nine levels of "Shelteree Status Criteria" ranging from "1. Preserve life; no decrement at any time; comfortable" to "9. Death." In the column to the left are "Activities or Conditions Consistent with Status Criteria" which are operational criteria that would be satisfied by each of the shelteree status criteria. The operational criteria thought to be especially relevant are: (1) the ability to perform duties required for smooth shelter functioning; (2) the ability to perform and/or receive in-shelter training which would increase shelteree usefulness and survival potential after leaving the shelter; and (3) the ability to rapidly assume a useful role in the community after leaving the shelter.

The corresponding status criteria, then, are the amount of decrement during ensheltermert; and the rate, conditions and extent of recovery subsequent to ensheltermert.

The next step would be to relate categories of response levels, in terms of some integrative index, to the levels of decrement and recoverability represented by the status criteria. The kind of information required is obtained by careful analysis of clinical data for the more severe decrements and of physiological experimental data for the less severe decrements. The importance of an integrative index becomes obvious when the enormous number of possible combinations of environmental exposures are considered. An index, which in turn is a function of many other factors related to environmental stresses, acts as a transducer or transfer function making it possible to translate response into statements about condition which correspond to status criteria.

Now, given (1) adequate experimental response data for various population segments; (2) an analytical technique (most likely a mathematical model) for applying the data within the context of a usually complex environment which may become more severe with time; and (3) an analytical technique for predicting the shelter environment as a function of the man-environment-shelter interaction; it should then be possible, for a given shelter configuration, population composition, and duration of ensheltermert, to determine the probable number or proportion of each population segment which would fall within each of the nine categories of status condition. Note that in the third column of Table V-1, population segments are separated into the major groupings "Normal" and "Disabled," with space in a column to the right to enter the probable per cent of each population segment for which the status criterion applies. The fifth column reflects the fact that procedures exist which, when administered to all or some segment of the population, would shift the more severely affected population segments from the lower to a higher region of the table.

Except under unusual circumstances, it appears that normal loading of shelters under current planning should probably result in the satisfaction of Shelteree Status Criterion Number 2, more rarely 1 or 3. For overloading, we have suggested a limiting criterion equivalent to Number 5, or at the most 6, for the normal, healthy population. At such a level, the "disabled" group (perhaps 10 per cent or more judging by the incidence of chronic ailments in the general U. S. population) would be in serious trouble (criteria levels 7 to 9) unless remedial or preventive procedures were applied. A number of possible procedures have been pointed out in Section IV.

Now, having defined a reasonably systematic way to relate statistical response data to operational consequences within a status criterion framework, the next step would be to arrive at some sensible way to decide on the worst allowable distribution for healthy occupants - e. g., what percentage of the healthy population can exceed level 5, level 6 and so on. Although we cannot hope to give final answers to what is essentially a problem of policy involving moral considerations, we can, nevertheless, offer the following comments:

1. It probably makes good, practical sense to establish a primary policy based on the unaided (undrugged) response of the "healthy" segment of the population.

2. The "handicapped" can probably be given much the same in-shelter survival chances as the "healthy" group through control procedures - such as Tapazole administration, special cooling, training the sweat response, etc. However, depending on the kind of procedure used, they might not be able to carry out shelter duties or to respond well to training.

3. A mathematical examination of shelter policies indicates the desirability of a strategy based on maximizing the number of survivors rather than minimizing the number of shelter deaths (see Appendix A). Furthermore, dynamic policies, although more difficult to administer, hold distinct advantages over static policies. Rotation of shelterees to the ambient for periods depending on radiation dose rate is an example.

4. Data suitable for estimating the response characteristics of a mixed population to a complex environment are not yet available to make it possible to fill out the last two columns of Table V-1. However, as provisional rules of thumb for the more important stresses, the limiting values or methods for determining them - discussed in Section III of this report - should be useful.

5. Until the nature of the combined stress response is more fully explored, it would be wise to apply a safety factor to tolerance limits established for single stresses.

Since much of the required information is missing, and since the need to establish limiting criteria for environmental exposure is immediate, it is suggested that somewhat modified limits, based on current data can be used as an interim measure if at the same time a few basic remedial techniques are made available to the shelter manager. In particular, some of the control techniques involving administration of sedatives and metabolic depressants should be considered as a safety measure to make up for current uncertainties about the extent of variation in the general population. Given such precautionary measures, and given strong and wise shelter leadership, the following levels of prolonged environmental stress appear to represent critical limits beyond which a widespread crisis would be likely to occur in a shelter containing a mixed population:

• Oxygen concentration	12-11%
• Carbon dioxide concentration	3-5%
• Effective temperature	90-94°F
• Dehydration (predicted from P4SR, urine output and water ingested)	5-10% of Body Wt
• Acute starvation weight loss	
children	10-15% of Body Wt
adults	30-35% of Body Wt

Note that these values are only for stresses one-at-a-time. For instance, dehydration would considerably lower the effective temperature which could be tolerated; and increased effective temperature, by increasing sweat rate, increases dehydration.

A multitude of other factors are also involved as we have attempted to demonstrate in the preceding sections of this report. If more than one stress is to be imposed, the safe procedure would be to reduce the stress levels to at least half the values shown.

In conclusion, while much can be said about response to single stresses for limited range of the population, it is not yet possible to establish limiting criteria in terms of the kinds of environments and occupants expected in the shelter. Therefore, a firm basis has not as yet been derived for limiting admittance to a shelter in the face of demands for entry. However, considerable alleviation of the adverse effects of overloading can be achieved through the use of dynamic policies and remedial measures which were discussed in Section IV, and extensive use of them as "stop gap" measures is recommended until the analysis has been carried far enough to enable reliable criteria to be established.

TABLE V-1

A PROPOSED SCHEME FOR RELATING POPULATION RESPONSE CHARACTERISTICS TO OPERATIONAL CRITERIA

			Environ. Cond.: (Onset, Level, Duration)	
Operational Activities or Conditions Consistent With Status Criterion	Shelteree Status Criterion	Population Segment	% of pop. segment for which status criterion applies	% of pop. seg. for which status crit. applies giver remed./prevent. proc.
• Unrestricted performance of normal shelter duties • In-shelter training • Immediate post-shelter usefulness	1. Preserve life; no decrement at any time; comfortable	"Normal" Group Infants (1st yr) Children (1-19) Adults, female Adults, male Aged "Disabled" Group		
• Performance of all normal shelter duties with strong leadership • In-shelter training • Immediate post-shelter usefulness	2. Preserve life; no decrement of normal function throughout stay; discomfort	"		
• Performance of most normal shelter duties given strong leadership • In-shelter training • Post-shelter usefulness in less than an hour	3. Preserve life; nearly normal function during most of stay with some decrement only toward the end; rapid, spontaneous recovery; no subsequent disability	"		
• Performance of light shelter duties with strong leadership • Some in-shelter training	4. Preserve life; some functional decrement during stay; spontaneous	"		

TABLE V-1 (continued)

Operational Activities for Conditions Consistent With Status Criterion	Shelteree Status Criterion	Population Segment	Environ. Cond.: (Onset, Level, Duration) % of pop. segment for which status criterion applies	% of pop. seg. for which status crit. applies give remed./prevent. proc.
• Post-shelter usefulness within an hour or two	recovery; no subsequent disability	"Normal" Group Infants (1st yr) Children (1-19) Adults, female Adults, male Aged		
		"Disabled" Group		
• Performance of very few shelter duties - may require periodic care • Very limited in-shelter training • Post-shelter usefulness after several hours	5. Preserve life; moderate to severe functional decrement during stay; moderately prolonged, spontaneous recovery; no subsequent, permanent disability	"		
• No performance of shelter duties - requires care • No in-shelter training • Limited post-shelter usefulness after several hours, normal usefulness after several days	6. Preserve life; severe functional decrement during stay; recovery requires non-specialized care and/or first-aid procedures; no subsequent, permanent disabilities	"		
• No performance of shelter duties - requires care • No in-shelter training • No post-shelter usefulness for long periods of time	7. Preserve life; severe functional decrement during stay; recovery requires specialized med/surg procedures; no subsequent, permanent, incapacitating disabilities	"		

TABLE V-1 (continued)

Operational Activities for Conditions Consistent With Status Criterion	Shelteree Status Criterion	Population Setment	Environ. Cond.: (Onset, Level, Duration)	
			% of pop. segment for which status criterion applies	% of pop. seg.for which status crit. applies given remed. /prevent. proc.
• No performance of in-shelter duties - requires extensive care • No in-shelter training • No post-shelter usefulness for very long periods of time - may be a continuing burden on the community	8. Preserve life; complete incapacitation during stay; recovery requires specialized med/surg procedures; subsequent permanent, incapacitating disability	"Normal"Group Infants (1st yr) Children (1-19) Adults, female Adults, male Aged "Disabled" Group		
• Creates a severe morale problem among survivors • Disposal problem	9. Death	"		

VI. SUGGESTIONS FOR FUTURE STUDY

Undoubtedly the most critical deficiencies in the data and techniques available for defining the effects of shelter overloading lie in the areas of response to combined stresses, population variability in stress response, and extended as opposed to short term exposures. Research approaches to those problems are discussed in several sections of this report. We give special emphasis to the requirement to make a direct attack on the combined variables problem (see Section III. B, pgs. 225-231).

Another area of investigation which we feel is vital to the shelter overloading problem is in the further definition of the acclimatization (K factor) phenomenon as it relates to the distribution and improvement of heat tolerance within a mixed population.

Many of the ideas on thermal tolerance which have been presented in this report are too recent in origin to have received the considered attention of the scientific community. Many of the key experimental results have not yet been published, or are found only in relatively obscure documents, and data to confirm empirically some of the hypotheses which were advanced are either yet to be generated or are buried in the files of research workers who have since gone on to other areas of investigation.

Obviously, then, considerable work remains to be done before the present synthesis of thermal tolerance data and development of a unifying theory of acclimatization and individual difference can be brought to full fruition in the form of positive and precise recommendations for practical application.

The most immediate and pressing task is to uncover as much basic raw data as possible relative to sweat production, skin temperature and metabolism for all kinds and ages of people, and particularly for organized regimes of environmental exposure involving some degree of acclimatization (see pg. 103). In view of the presumptive evidence presented in this report that ethnic and geographical differences are minor, if not insignificant, in comparison with factors of physical conditioning, training and activity history in hot climates, the search of contributing data should be world wide.

Second only in importance to the need for information on how people respond to heat as a function of age, sex, size, state of health, etc. is the requirement to establish as quickly as possible the upper limits of the human adaptive potential. As has been clearly indicated in this report, these limits have only been glimpsed very recently, and this more or less incidentally, in the course of an investigation oriented along academic lines and aimed at elucidating the physiological mechanisms underlying the acclimatization phenomenon. At the time of writing, only personal notes taken by one of us during the delivery of a revolutionary paper by Dr. Fox at the Physiological Congress in Leiden and in conversations with him in his laboratory in London were available. In view of the critical importance Fox's work has assumed in the argument developed in this report, a careful examination of all his raw data and detailed discussions of the relationship of his experimental observations to the practical questions of shelter occupancy raised by this report assume central importance.

Another area which is critical to defining loading limits is the interaction between psychological and physiological response which, in the case of an overloaded shelter, is expected to be significant indeed. To gain some concept of the degree of interaction, we studied numerous reports of shelter confinement studies. While much of value to this study was reported, certain critical elements were missing.

Probably the most severe objection ubiquitously applicable to all the studies we reviewed is that the actual threat of a thermonuclear attack is absent. Very few means appear to lie at the researchers' disposal for attempting to simulate the catastrophic condition. One possible approach would be to observe a group of people who are led to believe that a thermonuclear attack is actually imminent. The dangers of this approach, however, are obvious: people may be hurt or killed or irrevocable damage may be inflicted upon property. These acts would be difficult, if not impossible, to justify.

Another procedure could employ hypnosis. A group of trained, hypnotized subjects could be given the suggestion that a real attack is about to take place and they would act as if they believe the suggestion were a fact. Furthermore, precautions could be taken, by appropriate suggestions, to preclude anyone's expressing aggression or rage in a harmful or destructive way.

However, there are other moral problems which at this time seem insurmountable: (1) even though they may volunteer, subjects may afterwards resent their behavior and the extreme stresses under which they were placed, and (2) no one can predict what lasting effects the induced stresses would have in the future.

Furthermore, for purposes of controlled experimentation, it is unlikely that suggestions will remain equally effective for all subjects for a period as long as several days. Frequent mass-hypnotic sessions could be used to sustain the suggested attitude, but the effects of the interruptions might not be extractable from the totality of reactions to the perceived stresses. This factor plus the restriction from performing harmful acts are the main drawbacks, aside from the moral ones, in the use of hypnotic suggestion.

If hypnosis were feasible for use as a tool, a simulated shelter situation could be observed under varying conditions of crowding, leadership, and communication. In addition, the effects of many variables otherwise not able to be simulated could be studied. For example, a female subject could be told under hypnosis, "The alarm is sounding, and as you, your husband and son are rushing to the shelter, your husband and son are separated from you in the rushing crowd, and you arrive at the shelter alone." An additional stress could be imposed by suggesting that she sees her hopelessly inaccessible son trampled on by the panic-stricken crowd. The number of possibilities for varying stresses are too great to enumerate here. If hypnotic suggestion could be used, a wide range of highly informative experiments could readily be designed.

While hypnosis as a technique does not appear to be morally feasible at present, it is conceivable that if the threat of actual attack reaches an emotional level such that the general population experience true apprehension, moral objections will become secondary to the practical need for thorough and accurate knowledge. Hypnotic procedures may then become essential for gaining knowledge in spite of the present moral objections.

There are also some indirect approaches which were considered for investigating people's reactions to an actual attack and subsequent enshelterment. These procedures involved the use of projective tests, such as a modified TAT (Thematic Apperception Test) and Rorschach Test. TAT-type pictures of people entering and interacting in a shelter might be used to discover how people believe they would act under the pictorial conditions. Unfortunately, this technique is limited by the fact that a person may report how he thinks he would (or should) act, and there is no basis upon which to compare the reported anticipations with the expected, true behavior.

The Rorschach would provide some interesting information, such as people's propensities toward aggressiveness or withdrawal. Ego strength (tendency toward psychotic or neurotic behavior) and functional intelligence could be evaluated to predict how well individuals would tolerate stress. However, the Rorschach does not provide direct information regarding how people act under specific conditions, and therefore, its use in shelter studies would be limited. This test would be particularly valuable in an investigation designed to determine how shelter conditions affect personality; tests administered before and after enshelterment would be compared for any differences.

Earlier in this report some recommendations were made to the effect that the leader organize group discussions for particularly anxious people in order to relieve experienced tensions. Janis (1958) comments frequently on the effectiveness of personal communication to relieve patient's apprehensions. In Kramer's (1957) discussion of group psychotherapy, he remarks, "There seems to be a comforting feeling in suffering shared by others, probably based on the feeling of not being left alone." (p. 43)

Since Janis did not actually use a form of group therapy, it would be valuable to investigate whether surgical patients with high anticipatory anxiety benefit from a directed form of verbal interaction prior to surgery, after surgery, and both as compared to those who are left to suffer their anxieties. Also valuable would be an experiment in which group therapy is provided to cancer patients immediately after they are informed of their affliction; the course of reactions of these people could be compared with responses of individuals not provided the opportunity for verbal interchange.

In both groups - pre-operative and cancer patients - apprehension regarding safety or survival is real and, particularly in the latter, probably justified. The first study could supply information regarding the efficacy of group discussion to relieve anxiety while the second experiment would evaluate the use of verbal intercourse to speed up adaptation to a depressing situation.

In neither of the experiments should a trained psychotherapist be used. Rather, a potential shelter leader type is recommended. However, he should have been presented the essentials of group psychotherapy as part of his overall training. Ideally, he should be one of the patients himself, for the shelter leader will be under the same threat to his survival as the other occupants.

An added variable in the experiment with cancer patients could be included to investigate the value within a leader. It was mentioned in Section III. A. 5 that morale was improved when witty persons were members of the group (Smith and Goodchilds). The responses and progress of a group led by a person endowed with creative wit could be compared with those of a group led by a person having an otherwise comparable mode of operation, background, and education. To find two leaders with all characteristics similar except for wit would be the most difficult part of performing the proposed investigation.

One of the main points of emphasis in the discussion of psychological factors was the fact that hope and confidence increase a person's capacity to tolerate and endure severe stresses. Some techniques were recommended for providing the emotional support which will be likely to stimulate hope and confidence when such feelings become submerged under the strains imposed by the shelter. The suggested techniques derive from clinical psychological methods. But there have been no studies to show either (1) the extent to which the procedures will be effective in the shelter situation, or (2) whether other simpler, more reliable, and/or more effective procedures might be used.

To fill those knowledge gaps, a two-phase study would be necessary. The initial phase would involve an intensive survey of possible techniques which might be effective; the literature might be helpful, but the best information sources, for pragmatic purposes, would be practicing psychiatrists and clinical psychologists. After several applicable procedures are identified, they can then be evaluated in the second phase by applying them to groups under multifarious stresses and comparing their effects on behavior and measures of attitude between groups for which all other variables are held relatively constant. The first phase is intensive but patently practicable; however, the second phase may appear too vastly extensive and not very practicable because of the many, many groups seemingly required. Certainly, several groups would be needed, but a reasonable experimental design could appropriately be conceived to minimize (within practicality) the number of subjects necessary. For example, it may be possible - and desirable - to combine some techniques without excessively increasing the complexity of the procedures. In addition, the design might involve a method of serial application such that attitudes are tested after each technique is used, and increments of changes are compared. In any case, the design would depend upon the data collected in the first phase. Hypnosis could be valuable here; since amnesia could be induced by suggestion, the same people could serve as subjects in several groups without having their behavior mnemonically affected by their involvement in previous studies.

Many other areas of research would be valuable to the further definition of loading. Many of them we suggest are intended to fill missing gaps in existing data or techniques, and most of them have been discussed in preceding sections of this report. They are listed below in abbreviated form:

<u>Additional Study Tasks Needed to Further Define Loading Limits</u>:

1. Estimate the probable occurrence and degree of overloading in terms of cite, time of the year, degree of completion of the shelter identification and/or construction and provisioning program, and such natural factors as initial jamming near entrances with eventual redistribution throughout the shelter.

2. Construct a computer - programmed mathematical model to be used for specific shelter design evaluations, representing the

man-shelter-environment interactions which influence loading limits.

3. Consolidate into usable form the large and scattered body of data characterizing all segments of the U. S. population.
4. Evaluate the possibility of using the ratio: "skin blood flow/total cardiac output" as a measure of physiological strain due to thermal stress.
5. Evaluate methods for increasing heat acclimatization of shelter occupants (see pg. 106).
6. Experimentally determine the relationship between tolerance times for constant level exposure to CO_2 and tolerance times for various rates of build-up of CO_2 concentrations, and create an analytical technique for relating the two.
7. Determine human tolerance to combined toxic gases derived from human waste products. Although an experimental approach is preferred, an analytical approach based on their sites of action would be useful (see pg. 153-154).
8. Determine the conditions in the shelter under which the liklihood of explosion may become significant. Include conditions produced by overloading.
9. Experimentally validate the weight loss prediction charts given on page 178 and 180 of this report, and alter as necessary. Extend to include variations in activity level as well as other pertinent factors which may be discovered.
10. Determine the relationship between perceived external threat as balanced against stress level in the shelter to define the conditions under which occupants will prematurely leave the shelter and define techniques required to prevent premature exit.
11. Evaluate the use of sedatives, tranquilizers and metabolic depressants to reduce shelter stresses and minimize undesirable reactions (see pgs. 243-245).

VII. RECOMMENDATIONS

The analysis of factors limiting shelter occupancy and the establishment of shelter loading limits has by no means been completed by the study reported here. Indeed, as the study progressed it became more and more apparent that, in the relatively short period of time available, we would most likely come up with many questions; define a number of promising approaches; sift through an enormous amount of data, some of which would be utilizable; make progress in the direction of synthesis, more in some areas than others; discover many fascinating sidepaths which would have to be bypassed regretfully in getting on with the task at hand; and formulate a number of recommendations immediately useful to the shelter program, plus numerous tentative suggestions; - but it rapidly became apparent that the sum total of our efforts would constitute only the first portion of the work which needed to be done. And indeed, our anticipations were confirmed: although we were able to make good progress in directions which we think will prove to be quite significant to a more complete understanding of the stresses of shelter living - particularly for the sub-marginal or overloaded shelters - there is nevertheless a great amount of progress which can and should be made in the immediate future - both of a theoretical and experimental nature. Consequently, our first recommendation is that the study be continued.

Much remains to be done in the collection and analysis of data, but considering the amount which has already been accomplished, even greater emphasis can now be placed on synthesis and the creation of indices and other tools of interpretation and application. The rate of generation of results directly applicable to the Civil Defense program should increase rapidly as the foundations layed by past efforts come to fruition by incorporation into future efforts.

Although we have not as yet reached a point where it is possible to provide definite and reliable rules for establishing loading limits, in our analysis of factors influencing physiological and psychological reactions to both normally-loaded and overloaded shelters, we uncovered a number of ways in which either shelter environments or shelteree responses might be improved. The ones we considered most important are summarized below:

A. PRE-ATTACK PREPARATION

Greater emphasis should be placed on pre-attack indoctrination of the general population. In particular, the public should be made more aware of the shelter conditions which would most likely prevail and the expected duration of enshelterment. Considering the likelihood that sleeping facilities will be inadequate or missing altogether in many shelters and that special requirements for medication may be impossible to fulfill, individuals should be instructed to carry bedding and any special medication with them.

It is understood that these recommendations have been made before and that Civil Defense planning has incorporated them. However, an informal canvassing in the Los Angeles area by one of the investigators indicates that few people have thought about such factors, and that increased emphasis on pre-attack preparation is warranted.

The importance of bedding is particularly apparent in the overloaded shelter. It has been pointed out in a preceding section of this report (p. 185) that inadequate sleep results in decreased tolerance to almost all the stresses which would be present in an overloaded shelter. Consequently, the importance of any measure which improves the ability to achieve adequate, restful sleep cannot be overemphasized.

B. SHELTER DESIGN

1. Increase in the Minimum Rate of Ventilation by Outside Air

The degree of allowable loading will probably be more than doubled by an increase in ventilation rate from 3 cfm to 6 cfm per person (see Appendix C).

2. Increase in the Velocity of Air Movement Within the Shelter

Although significant reduction in sweat rate (and thus water requirements) does not occur in the region of 80-85° E. T. for air saturated with water vapor, significant reductions in sweat rate can be predicted for increased air velocity when shelter temperatures are elevated to around 88° E. T. or higher. The upper left hand figure in Figure III-32 (p. 99) is a dramatic illustration of the savings to be obtained. Comparison of the three figures in Figure III-32 reveals the fact that the percentage decrease in sweat rate for a given increase in air velocity becomes greater as metabolic rate (activity level) and air temperature increases. An effective air velocity of 50 to 75 ft/min impinging on the surface of the occupants is a desirable minimum. If this recommendation is followed, the minimum water allocation recommended below could be re-evaluated downward.

C. PROVISIONING

1. A Means for Rapid, Total-Body Cooling

Prolonged exposure to shelter temperatures of 85° E. T. or higher will result in at least a few cases of heat collapse which can be detected in the incipient phase. Therefore. a means for rapidly cooling at least one person at a time as a preventive and remedial measure is recommended for inclusion in the shelter, particularly for shelters in the warmer regions of the country or for shelters which, due to location, are likely to be overcrowded. As mentioned earlier, rapid, total-body cooling might be accomplished by using a cold-box, a highly ventilated area set aside for that purpose, reduction in temperature of the radiant surround, an ethylene chloride spray unit, etc. (see pgs. 252-255).

2. A Heat Acclimatization Kit - Tentative

Since further work needs to be done before the feasibility of controlled heat acclimatization in the shelter can be ascertained, we put forth a tentative recommendation only, that a kit for that purpose be developed and included in the shelter provisioning. The basic requirement for such a kit would include a means for measuring body weight and skin temperature, a means for controlled exercising (possibly coupled to another apparatus to produce useful work, such as re-charging storage batteries, running a fan, etc.), and a set of instructions and forms for keeping individual records on progress. A means of rapid, total-body cooling, definitely recommended above, would be an advisable adjunct. Such a kit might be particularly valuable in shelters located in hot climates or in shelters for which the probability of overloading is significant.

3. A Means for Measuring Wet Bulb and Dry Bulb Temperatures

In the "management" section below, it is recommended that the shelter manager monitor the thermal stress load in the shelter to establish a basis for water allocation and thermal management. For that purpose, a simple, inexpensive sling hygrometer or its equivalent would be indispensable.

4. Increase in Minimum Water Provisions

Any determination of water requirements should take into account the predicted sweat rate at various thermal loads (see Figures III-30, III-31 and III-32). In overloading with increased shelter temperatures, water supply becomes limiting before anything else. For instance, at a 90°F saturated air temperature and effective air velocity of 10 ft/min (about 90° E. T.), at even the minimal resting metabolic rate of 50 $Kcal/m^2$ hr, physically fit, acclimatized young men would lose about 6 quarts of water per 24 hours due to sweat alone. With relatively light exertion (say a metabolic rate of 75 $Kcal/m^2$ hr) that rate would double. While at 85° E. T., with a resting metabolism of 50 $Kcal/m^2$ hr, very little sweat is produced, just increasing metabolic rate to 75 $Kcal/m^2$ hr increases the P4SR (Predicted Four Hour Sweat Rate) to about half a quart, or approximately 3 quarts per 24 hours. It seems clear that the provision of one quart of water per day is inadequate for shelters in warm climates. If any significant degree of overloading is to be anticipated, a minimum temperature of 90° E. T. should probably form the basis for the water requirement. At 90° E. T., allowance should be made for 6 quarts per day for adults at rest and for 12 quarts per day for light activity. Dehydration at the rate which would occur at an intake of one quart per day would lead to a high probability of heat stroke within a day or so according to the evidence brought forth by the present study.

5. Food and Water Allocation Charts for Shelter Managers

This report presents evidence that minimum food requirements vary significantly with age, sex, state of health and particularly with the amount of body fat. In the overloaded shelter, or for extended durations, the satisfaction of minimum requirements must be taken into account in rationing food allowances. Particularly sensitive are children in rapid growth phase, pregnant women, very lean people, and sufferers from some diseases. A guide which would enable the shelter manager to determine minimum required food allowances for each inhabitant might be indispensable in the event of severe food shortage, and would have the further virtue of removing the burden of blame for apparent inequalities in food distribution from him to the "chart."

Likewise, daily water requirement, on an individual basis, is reasonably predictable, but would require taking into account a number of factors which could best be left to a "chart."

It is recommended that both water and food rationing charts, along with record forms, be included in the shelter manager's kit.

6. Recommended Additions, Deletions and Substitutions to the Shelter Medical Kit

Since each of the following medications have been evaluated in detail beginning on page 233, they will only be listed here:

Medication	Recommendation
Aspirin (see pgs. 233-234)	Substitute "Darvon"
Cascara Sagrada (see pg. 234)	Use tablet form
Eugenol (see pg. 235)	Substitute "Xylocaine"
Kaopectate (see pg. 235)	Substitute "Intromycin Powder" or "Neomycin Tablets"
Penicillin G (see pg. 235)	Substitute "Erythromycin" or "Oleandomycin," add "Colistin" for infants
Phenobarbital (see pgs. 235-236)	Avoid its use for the elderly. "Compazine Dimaleate" is preferred for adults
Sodium bicarbonate (pg. 236)	Delete if recommendation for "Sulfadiazine" is followed
Sulfadiazine (pg. 237)	Substitute "Gantrisin" or one of the recommended substitutes to Penicillin G
Morphine Syrettes (pg. 234)	Add to kit
Dramamine (pgs. 237-238)	Add to kit in both tablet and syrette form
Compazine Dimaleate (pgs. 240-242)	Add to kit to combat anxiety reactions, sleeplessness, etc. (15 mg, delayed action capsule every 12 hours)
d-Amphetamine (pgs. 242-243)	Add to kit, mostly for use by shelter leaders if needed to maintain alertness, but also acts as an appetite depressant.

D. TRAINING IN-SHELTER

As part of the in-shelter training exercises, a modified form of group therapy should be considered as a technique for releasing tension and ameliorating anxiety reactions (see Section IV. B).

E. MANAGEMENT

1. Rationing of Food and Water

It is highly recommended that the shelter manager institute a rationing system based on population characteristics, shelter environment and activity level to insure that occupants with lower tolerance or higher requirements are not allowed to be more severely penalized in terms of physiological decrement than the average for the shelter. As discussed in earlier sections of this report and under "provisioning" in this section, a dynamic rather than a fixed rationing policy should be used, based on age, sex, degree of obesity, etc. A control procedure for both dehydration and caloric weight loss is not difficult to carry out providing a scale is available for weighing and a relatively simple procedure is followed. Adequate information exists for developing such procedures.

F. LOADING LIMITS

No single answer can be given to the loading limit problem, since variation from shelter to shelter, from area to area and from one season to the next are significant to the extent to which a shelter can be overloaded before a generally critical situation develops. Furthermore, definition of the ultimate limits of overloading requires consideration of combined stresses and specific population characteristics which has not yet been accomplished. However, it should be possible to define a "maximum" condition which exceeds normal loading but which does not reach the limiting criterion set forth in earlier sections of this report. Although this has not as yet been done, it seems feasible that a nomographic shelter evaluation procedure could be devised which accounts for local conditions, and which would enable a provisional, but sub-limiting overload capacity to be computed for each shelter for various times of the year. Such a procedure would need to account for local climatic factors, specific shelter configuration and provisioning, any significant differences in the probable occupant population, and a number of other factors which are usually definable at least in a statistical sense. The creation of such a procedure is recommended for use in shelter evaluation surveys and should serve well as an interim measure. In the face of our current uncertainty about the way in which some factors interact, such a procedure should lean in the direction of conservatism.

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APPENDIX A

INFLUENCE OF LOADING POLICY:

A MATHEMATICAL EXAMINATION OF CONSEQUENCES OF LOADING POLICIES

APPENDIX A

INFLUENCE OF LOADING POLICY:

A Mathematical Examination of Consequences of Different Policies

Shelter Loading Policy

Shelter loading policy will, to a considerable extent, determine the actual loading limits. To provide a general context for considering loading policies, a number of policies have been explored mathematically with respect to characteristics which are not dependent on the exact shape of the "non-survival" or "irreversible damage" curve.

A number of criteria and attendant assumptions are described and examined below. The emphasis is upon an investigation of a range of policies and the implications for the meaningful determination of quantitative survival limit functions. The description below is supported by derivations at the end of this Appendix.

Policy Parameters

The population elements are identified as follows:

N_p = population serviced by a given shelter

N_i = shelter entrants in N_p

N_e = non-entrants in N_p

N_{is} = survivors among entrants

N_{id} = deaths among entrants (or irreversible damage)

N_{es} = survivors among non-entrants

N_{ed} = deaths among non-entrants (or irreversible damage)

The basic relations among the above population elements are:

$$N_p = N_i + N_e = N_{is} + N_{id} + N_{es} + N_{ed}$$

$$N_i = N_{is} + N_{id}$$

$$N_e = N_{ed} + N_{es}$$

Policies

The policies which could be established regarding entrance into the shelter are:

1. Maximize the total number of survivors

   $N_{is} + N_{es}$ = a maximum, or

   $N_{id} + N_{ed}$ = a minimum

2. Maximize the number of shelter survivors

   N_{is} = a maximum (as will be shown below, this is not equivalent to N_{id} = a minimum)

3. Maximize the shelter survival fraction

   N_{is}/N_i = a maximum

4. Admit shelter occupants until the predicted shelter survival fraction would equal the survival fraction for non-entrants

$$\frac{N_{is}}{N_i} = \frac{N_{es}}{N_e}$$

5. Minimize shelter deaths

   N_{id} = a minimum

6. Dynamic policies

Policies 1 through 5 can be considered as static or dynamic. A static policy would consider the preservation of the allocation between N_i and N_e throughout the occupancy period. An illustration of a dynamic policy would be one whereby shelter occupants are released when the non-entrant survival fraction decreases below its original value.

Survival Functions

The shelter survival function may be defined:

$$N_{is} = f(N_i, t, C)$$

where t is the time duration of shelter occupancy, and C is a complex factor representing shelter capacity, geometry, ventilation, water, food and medical provisions, etc.

The non-entrant survival function may be defined:

$$N_{es} = f(N_e, N_i, t, F)$$

where F is a complex factor representing the severity of the attack, protection available in non-shelter areas, facilities, etc.

Under a given set of circumstances, non-entrant survival will be dependent upon the number of people admitted to shelters. Thus, the demand for partial protection is decreased by the number of people admitted to the shelter, but provisions required by shelter occupants subtract from those available to non-entrants.

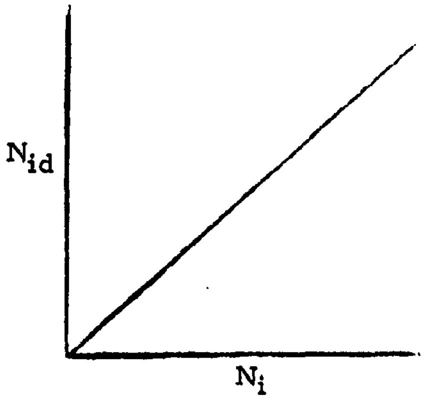
It is the major subject of this research effort to determine the nature of the survival curve and the influencing factors. For purposes of analyzing policies, however, a generalized form will be used. For a defined shelter and occupancy period, N_{is} can be expressed as a function of N_i. While the theoretical or empirically determined function can be represented by a high order polynomial, a number of simpler representations suffice for preliminary analysis. Linear, exponential and parabolic non-survival functions result in the following survival functions.

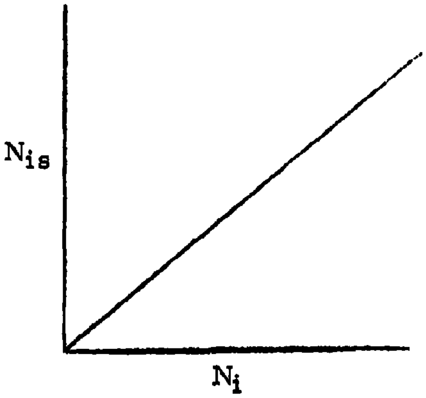
1. Assume N_{id} is a linear function of N_i

$$N_{id} = (1-a)\,N_i$$

$$N_{is} = a\,N_i$$

where a is the shelter survival fraction



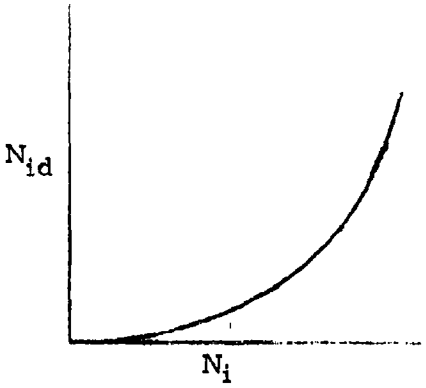


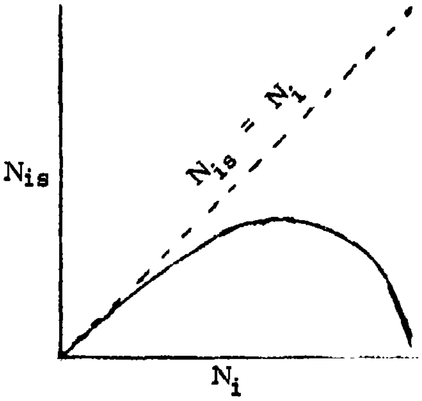
2. Assume N_{id} is an exponential function of N_i

$$N_{id} = e^{kN_i} - 1$$

$$N_{is} = N_i - (e^{kN_i} - 1)$$

where k is a constant



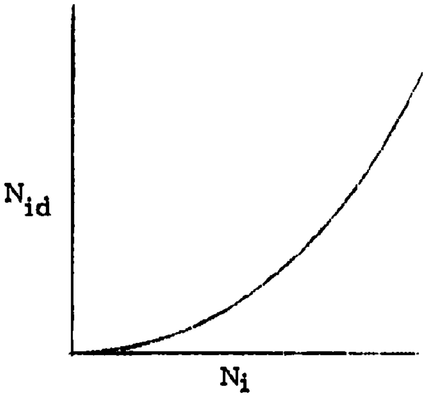


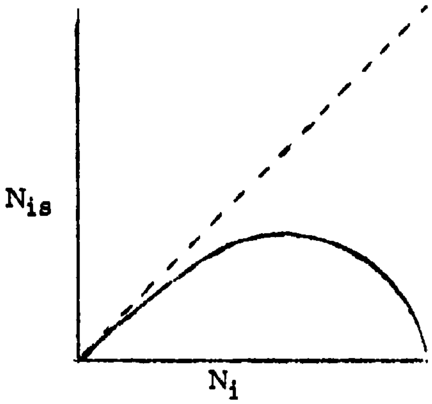
3. Assume N_{id} is a parabolic function of N_i

$$N_{id} = (N_i)^k$$

$$N_{is} = N_i - (N_i)^k$$

where k is a constant





A preliminary examination of the applicable policies will be made with an exponential function assumed for N_{is} and a constant non-entrant survival function:

$$N_{is} = N_i - (e^{kN_i} - 1)$$

$$N_{es} = b\ N_e$$

where b is the non-entrant survival fraction.

These functions are illustrated in Figure 1. The following values are obtained for the criterion:

1. Maximize the total number of survivors

$$N_i = \frac{\ln^{*} \dfrac{(1 - b)}{(k)}}{k}$$

(Note: This value is independent of N_p)

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*ln represents the natural logarithm

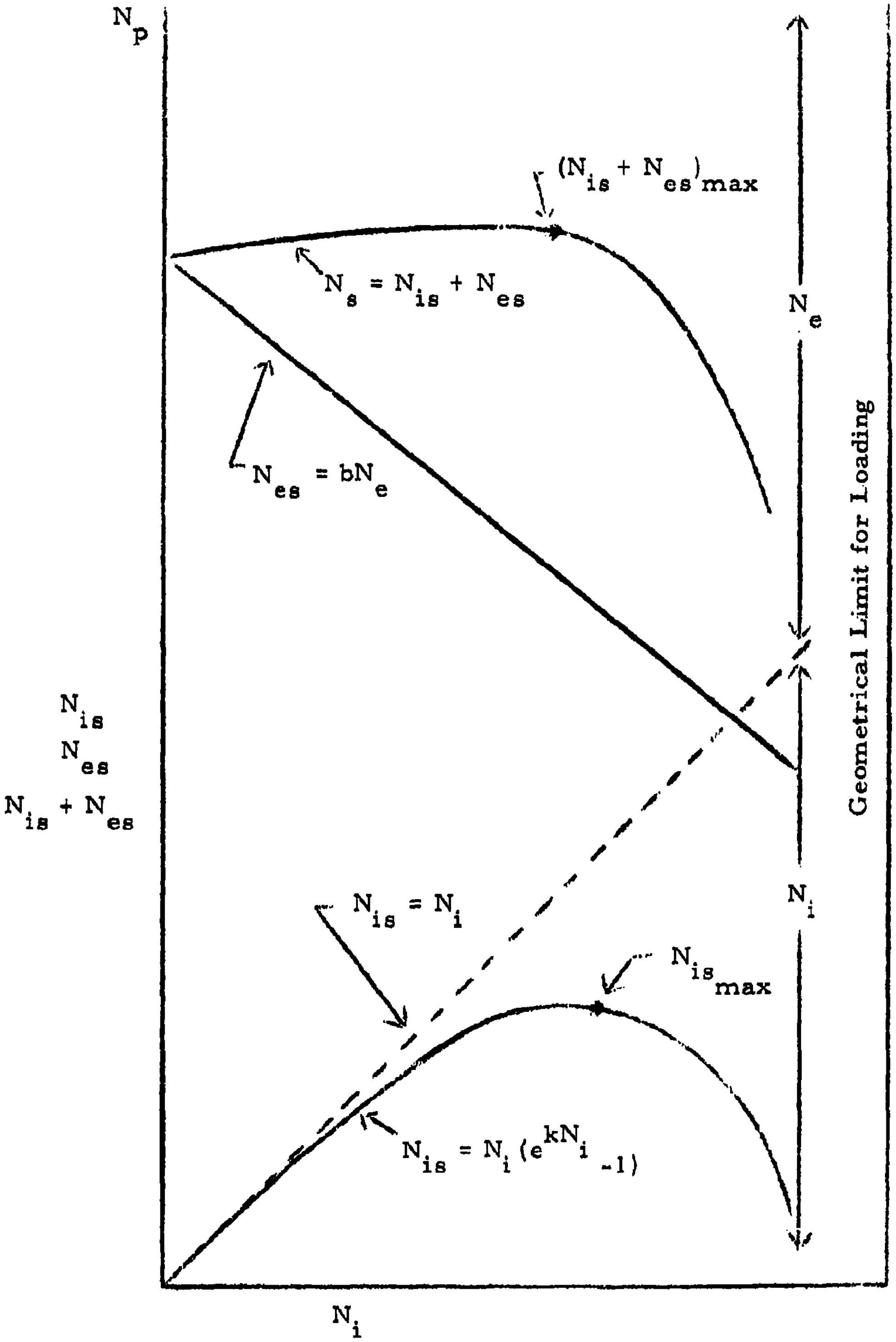


Figure 1 Survival Functions

2. Maximize shelter survivors

$$N_i = \frac{\ln\left(\frac{1}{k}\right)}{k}$$

3. Maximize the shelter survival fraction

$\frac{N_{is}}{N_i}$ is constantly decreasing function with a maximum at $N_i = 0$

4. Equal survival fractions

$$N_i = \frac{(e^{kN_i} - 1)}{1-b}$$ the value of N_i is determined by iteration

5. Minimize shelter deaths

N_{id} is a constantly increasing function with a minimum at $N_i = 0$

6. Dynamic policy

As an illustration, maximizing $(N_{is} + N_{es})$ when the non-entrant survival fraction varies as an increasing linear function of time would require N_i to assume the following value:

$$N_i = \frac{\ln\left[\frac{1-(b+gt)}{k}\right]}{k}$$

where $g = \left(\frac{1-b}{t_o}\right)$ is the rate of increase of the non-entrant survival fraction over the nominal occupancy period t_o.

Discussion

For the static models considered above, the first policy, that of maximizing the total number of survivors appears to be the most desirable.

The second policy, maximizing shelter survivors fails to take into account the non-entrant survival fraction and will result in

$$\left[\frac{(1-b)\ln(1-b)+b}{k}\right]$$

more deaths in the total population over that experienced with the first policy.

The maximization of the shelter survival fraction results in the trivial solution, $N_i = 0$.

The selection of an acceptable survival fraction requires an arbitrary judgment, difficult to justify above or below that obtained for maximizing total survival,

$$1 - \frac{(1-b-k)}{\ln(\frac{1-b}{k})}$$

The policy of admitting shelter occupants until the predicted shelter survival fraction equals the non-entrant survival fraction does not take into account the total life saving maximum which occurs prior to that point. The total survival curve in Figure 1 has a positive slope at $N_i = 0$. This indicates that the total survival fraction will increase above b before it returns to that point again when $\frac{N_{is}}{N_i} = \frac{N_{es}}{N_e} = b$. For the N_{is} function considered, such a policy would result in $\frac{1-b}{k}\left[\ln(\frac{1-b}{k}) - 1\right] -1$ deaths above that for the first policy.

Minimizing shelter deaths, as does the policy of maximizing the shelter survival fraction, results in the trivial solution of $N_i = 0$.

The dynamic policies offer life-saving advantages over fixed shelter assignments assuming the non-shelter survival function increases significantly prior to the release of all shelter occupants. As a general observation, the policy to maximize shelter survivors is superior to policies 3, 4, and 5, but the maximum total number of lives saved is achieved by considering the non-shelter environment and in particular its temporal dimension.

The exponential function used in the evaluation of criteria was selected because preliminary investigations reveal that it is characteristic of the thermal environment survival function.

The linear survival function although unlikely to be encountered in shelter occupancy is interesting in its close relation to policy 4. If the shelter survival fraction is greater than b, it should be loaded to capacity; if it is equal to b, the life saving feature of the shelter is negated.

DERIVATION OF POLICY PARAMETERS

Nomenclature

N_p = population serviced by a given shelter

N_i = shelter entrants in N_p

N_e = non-entrants in N_p

N_{is} = survivors among entrants

N_{id} = deaths among entrants (or irreversible damage)

N_{es} = survivors among non-entrants

N_{ed} = deaths among non-entrants (or irreversible damage)

a = shelter survival function

b = non-entrant survival function

g = $\frac{(1-b)}{(t_o)}$ rate of increase of non-entrant survival over time t_o

k = constant

l = constant relating the dependence of N_{es} upon N_i

t = time

t_o = nominal time period of shelter occupancy

Policy 1. Maximize the total number of survivors

$$N_{is} = N_i - (e^{kN_i} - 1)$$

$$N_{es} = b \; N_e = b \, (N_p - N_i)$$

$$N_{is} + N_{es} = N_i \; (e^{kN_i} - 1) + b \, (N_p - N_i)$$

$$\frac{d \, (N_{is} + N_{es})}{d \, N_i} = 1 - k \, e^{kN_i} - b = 0$$

$$e^{kN_i} = \frac{1-b}{k}$$

$$N_i = \frac{\ln \left(\frac{1-b}{k}\right)}{k}$$

value of (N_{is}/N_i) at this maximum

$$\frac{N_{is}}{N_i} = 1 - \frac{(e^{kN_i} - 1)}{N_i} = 1 - \frac{(1-b-k)}{\ln \left(\frac{1-b}{k}\right)}$$

Policy 2. Maximize shelter survivors

Exponential:

$$N_{is} = N_i - (e^{kN_i} - 1)$$

$$\frac{dN_{is}}{dN_i} = 1 - ke^{kN_i} = 0$$

$$N_i = \frac{\ln \left(\frac{1}{k}\right)}{k}$$

Parabolic:

$$N_{is} = N_i - (N_i)^k$$

$$\frac{dN_{is}}{dN_i} = 1 - k(N_i)^{k-1} = 0$$

$$\underline{N_i = e^{\frac{1}{k-1}\ln\left(\frac{1}{k}\right)}}$$

Policy 3. Maximize the shelter survival fraction

$$\frac{N_{is}}{N_i} = 1 - \frac{e^{kN_i} - 1}{N_i}$$

$$\frac{d(N_{is}/N_i)}{dN_i} = N_i k e^{kN_i} - 1 - e^{kN_i} = 0$$

this is true where

$$\underline{N_i = 0}$$

Policy 4. Equal survival fractions

$$\frac{N_{is}}{N_i} = b = 1 - \frac{(e^{kN_i} - 1)}{N_i}$$

$$\underline{N_i = \frac{(e^{kN_i} - 1)}{1 - b}} \quad \text{or} \quad \frac{N_{ps}}{N_p} = b$$

Note: Solution requires iteration.

Policy 5. Minimize shelter deaths

$$N_{id} = (e^{kN_i} - 1)$$

when $N_i = 0$, the function assumes minimum value

Policy 6. Dynamic policy

$$N_{es} = (b + gt)\ N_e \qquad \text{where } g = \frac{1-b}{t_o}$$

t_o = nominal time period

$$N_{is} = N_i - (e^{kN_i} - 1)$$

$$N_{is} + N_{es} = N_i - (e^{kN_i} - 1) + (b+gt)\ (N_p - N_i)$$

$$\frac{d(N_{is} + N_{es})}{dN_i} = 1 - ke^{kN_i} - (b+gt)$$

$$e^{kN_i} = \frac{1 - (b+gt)}{k}$$

$$N_i = \frac{\ln\left[\frac{1 - (b+gt)}{k}\right]}{k}$$

Assume non-entrant survival dependent upon number of entrants

$$N_{es} = (b - l\,N_i)\;N_e = (b - l\,N_i)\;(N_p - N_i)$$

$$N_{is} = N_i - (e^{kN_i} - 1)$$

$$N_{is} + N_{es} = N_i - (e^{kN_i} - 1) + (b - l\,N_i)\;(N_p - N_i)$$

$$\frac{d\,(N_{is} + N_{es})}{dN_i} = 1 - ke^{kN_i} - b - l\,N_p + 2\,l\,N_i = 0$$

$$e^{kN_i} = \frac{(1-b) + l\,(2\,N_i - N_p)}{k}$$

$$N_i = \frac{\ln\left[\dfrac{(1-b) + l\,(2\,N_i - N_p)}{k}\right]}{k}$$

Note: solution requires iteration

APPENDIX B

MORBIDITY STATISTICS

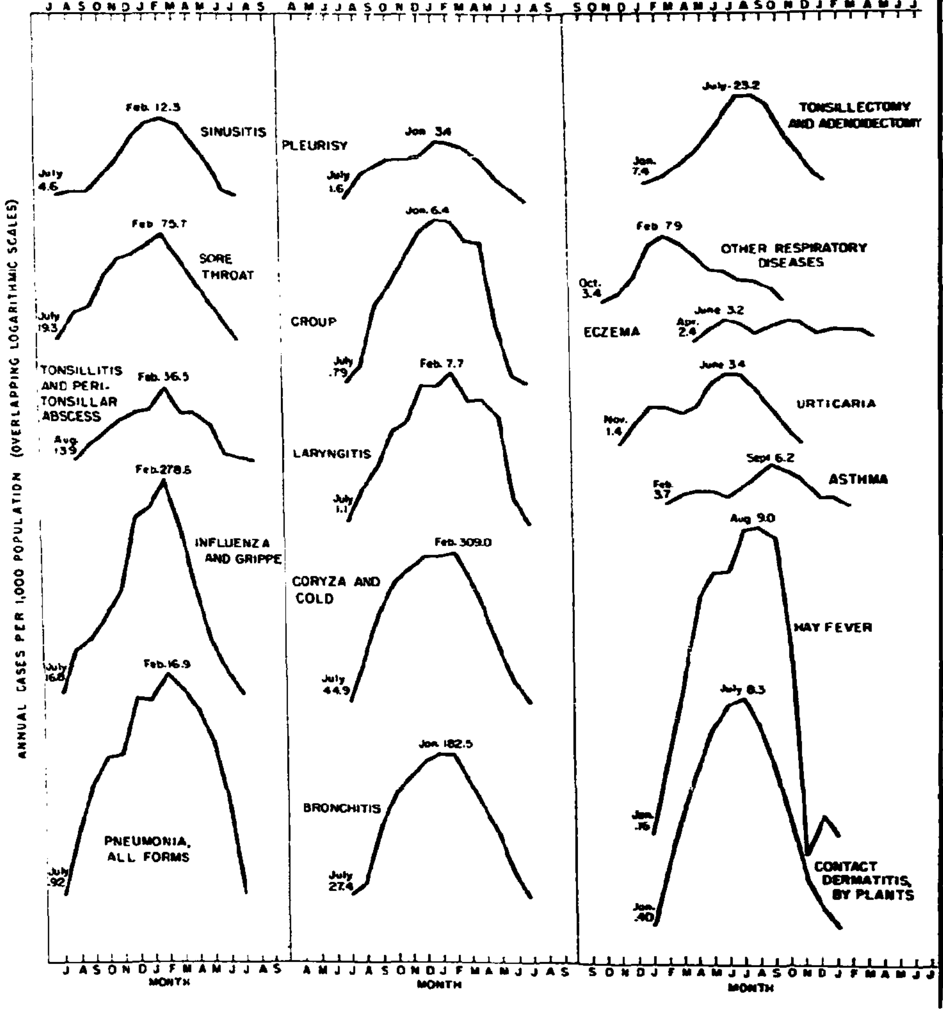
Days of disability per 1,000 population and the distribution of cases according to days of disability, with means and medians—5 surveys with 80,768 person-years of observation

[Sole and primary causes]

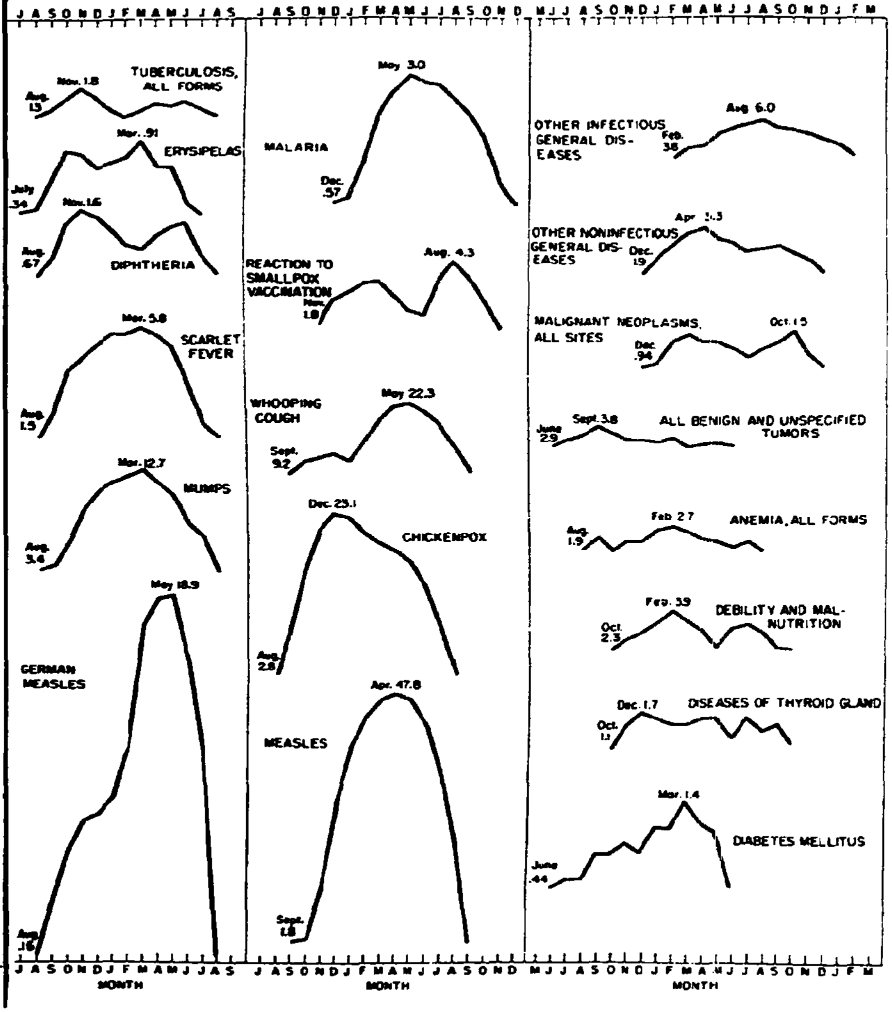
Diagnosis	Annual days of disability per 1,000 population	Mean days per case	Median days per case	Percentage of cases, by duration of disability (100% = all disabling cases)										
				1-2 days	3-5 days	6-8 days	9-11 days	12-17 days	18-24 days	25-30 days	31-45 days	46-75 days	76-349 days	350 days and over
Influenza and grippe	611.6	8.3	6.4	14.5	28.8	23.6	11.1	13.3	4.5	2.9	0.5	0.7	0.1	......
Bronchitis	370.7	7.5	5.4	20.8	30.0	24.4	8.6	9.2	2.9	2.3	.6	.7	.4	0.1
Coryza and cold	236.8	4.1	3.1	44.0	32.2	14.4	4.0	3.9	.8	.6	......	.1	......	......
Tonsillitis and peritonsillar abscess	128.3	7.4	5.6	14.7	34.2	25.0	8.3	10.5	4.0	2.3	.3	.6	.1	......
Sore throat	116.6	5.6	4.1	30.6	35.5	17.8	6.3	4.8	2.5	1.9	.2	.3	.1	......
Laryngitis	12.4	6.1	5.0	21.4	34.9	23.8	8.7	7.2	1.6	2.4	......	......	......	......
Croup	9.7	4.8	3.7	35.2	37.1	17.1	5.7	2.9	1.0	......	......	......	1.0	......
Sinusitis	41.6	10.0	5.4	28.8	22.3	15.3	6.2	12.0	6.9	3.7	1.5	2.6	.7	......
Pneumonia, all forms	183.4	27.6	21.6	2.3	3.6	7.0	7.0	18.8	19.6	17.7	8.1	9.2	6.7	......
Pleurisy	33.3	17.7	7.7	17.8	15.5	22.5	9.3	10.1	10.1	7.7	......	......	7.0	......
Tonsillectomy and adenoidectomy	134.1	8.6	7.2	8.6	25.0	29.1	16.8	15.0	2.7	1.9	.4	.5	......	......
Other respiratory diseases	39.7	22.2	6.7	21.6	22.7	14.8	10.2	9.1	5.7	4.5	2.3	2.3	3.4	3.4
Asthma	62.5	18.3	5.4	29.2	21.8	16.2	4.6	10.6	6.0	2.8	1.9	3.7	2.3	.9
Hay fever	5.9	25.1	2.5	50.0	21.5	7.1	14.3	......	7.1	......	......	......	......	......
Urticaria	2.9	4.8	4.1	27.8	41.7	11.1	11.1	5.5	2.8	......	......	......	......	......
Eczema	7.7	14.2	10.8	14.3	23.8	4.8	9.5	9.5	14.3	19.0	......	......	4.8	......
Contact dermatitis, by plants	5.2	6.1	4.8	20.4	38.9	16.7	5.6	12.9	3.7	1.8	......	......	......	......
Measles	211.1	11.4	10.4	1.9	13.7	17.0	28.0	27.5	8.0	2.7	.2	.7	.2	.1
German measles	29.3	5.7	4.9	5.0	55.7	27.3	6.3	3.9	1.3	.5	......	......	......	......
Whooping cough	275.2	31.4	30.5	4.0	3.2	5.3	2.9	8.8	9.6	16.2	30.3	17.8	1.9	......
Mumps	85.1	10.1	9.2	4.8	17.4	22.7	21.4	23.7	8.4	1.6	......	......	......	......
Chickenpox	131.9	12.3	11.5	1.6	10.1	13.8	24.2	35.3	13.0	1.6	......	.2	.2	......
Scarlet fever	114.1	24.3	22.6	1.5	5.6	5.6	5.6	11.6	28.1	38.1	1.8	1.5	.7	......
Diphtheria	19.8	20.0	18.0	2.1	4.2	2.1	4.2	35.4	29.1	18.7	2.1	2.1	......	......
Typhoid and paratyphoid fever	7.3	34.6	36.5	......	8.3	......	......	......	8.3	16.7	41.7	16.7	8.3	......
Erysipelas	8.0	18.6	15.7	7.4	3.7	7.4	18.5	18.5	26.0	11.1	......	3.7	3.7	......
Tuberculosis, all forms	495.6	194.3	163.7	1.4	3.4	3.4	.7	2.1	9.0	5.5	5.5	9.0	31.0	29.0
Smallpox	7.1	22.9	21.0	......	9.1	......	9.1	9.1	36.4	36.3	......	......	......	......
Reaction to smallpox vaccination	6.0	3.7	3.0	43.9	36.7	12.2	3.1	3.1	1.0	......	......	......	......	......
Other infectious general diseases	97.9	21.8	7.9	18.8	20.4	13.5	8.5	9.6	7.7	6.9	4.2	4.6	3.9	1.9
Malignant neoplasms, all sites	142.7	70.3	43.9	4.0	8.1	5.7	.8	7.3	5.7	4.8	15.3	16.1	27.4	4.8
Benign and unspecified tumors and cysts of female genital organs and breast	60.2	43.8	26.4	5.0	7.9	6.9	4.0	8.9	10.9	20.8	15.9	7.9	5.9	5.9
Other benign and unspecified tumors	14.7	15.6	8.0	23.7	10.9	18.2	7.3	9.1	9.1	5.4	5.4	7.3	3.6	......
Diseases of thyroid gland	43.0	30.7	8.0	25.3	16.1	10.3	2.3	8.1	10.3	4.6	5.8	10.3	4.6	2.3
Diabetes mellitus	120.9	105.0	19.3	4.4	11.8	10.3	14.7	5.9	11.8	5.9	1.4	4.4	16.2	13.2
Anemia, all forms	39.4	38.8	26.8	10.8	6.2	12.3	7.7	3.1	7.7	6.1	12.3	15.9	12.3	4.6
Debility and malnutrition	18.1	15.1	5.6	23.3	26.0	13.7	8.2	11.0	6.8	5.5	1.4	1.4	2.7	......
Other noninfectious general diseases	8.6	6.5	5.2	30.2	22.2	19.0	11.1	7.9	6.4	1.6	......	......	1.6	......
Cerebral hemorrhage, embolism, thrombosis	172.8	112.6	38.8	9.9	6.6	8.8	4.4	4.4	4.4	5.5	11.0	7.7	16.5	20.8
Neuritis and neuralgia	53.4	14.0	4.9	29.3	26.1	13.5	5.1	6.5	8.4	4.2	.9	2.3	2.8	.9
Nervousness	55.2	23.6	6.9	26.7	17.1	13.0	4.8	11.7	3.4	5.5	7.5	4.8	3.4	2.1
Psychoneurosis	130.7	54.7	11.5	15.0	13.6	17.5	3.9	8.4	3.9	3.3	8.4	10.4	11.7	3.9
Other nervous system and mental diseases	769.8	232.0	59.1	16.4	7.6	5.8	2.3	4.1	2.9	2.9	5.3	5.9	12.3	34.5
Inflammation of conjunctiva and eyelid	18.0	8.2	4.6	26.9	32.1	22.8	6.4	8.8	.6	.6	.6	1.2	......	......
Other eye diseases	65.7	41.4	12.4	19.2	14.9	10.6	3.2	13.8	9.6	7.4	3.2	4.3	10.6	3.2
Earache	10.3	5.4	4.0	32.5	34.9	14.3	6.4	6.4	3.1	1.6	......	.8	......	......
Otitis media	61.0	11.2	8.4	13.3	18.7	18.3	15.4	18.0	8.3	5.3	.7	1.0	.7	.3
Other ear diseases	4.4	7.2	5.9	16.7	30.0	26.7	13.3	10.0	......	3.3	......	......	......	......
Mastoid diseases	27.6	36.0	38.9	5.1	......	2.6	12.8	10.2	5.1	2.6	20.5	30.8	10.3	......
Rheumatic fever	255.5	125.1	32.6	4.5	7.1	9.7	3.3	8.4	7.7	7.7	11.6	11.6	21.3	7.1
Diseases of the heart	626.2	71.8	17.1	17.9	11.3	10.0	3.6	7.6	4.2	4.2	7.7	7.6	17.6	8.3
Hypertension and arteriosclerosis	158.4	82.0	18.0	16.4	13.1	9.8	4.1	5.7	12.3	3.3	4.1	13.1	10.7	7.4
Hemorrhoids	28.3	22.1	12.8	16.1	17.3	7.4	4.9	19.8	6.2	11.1	9.9	4.9	1.2	1.2
Varicose veins and ulcers	62.9	66.0	19.2	1.6	14.7	11.5	1.6	16.4	16.4	8.2	4.9	11.5	6.6	6.6
Diseases of lymphatic system	30.8	12.7	6.2	17.5	26.7	22.9	9.9	8.4	6.1	6.1	.8	.8	.8	......
Other circulatory diseases	30.3	21.1	7.4	32.6	14.7	4.2	5.3	13.7	9.5	5.3	3.1	5.3	4.2	2.1
Functional digestive disturbances	99.5	4.3	2.2	60.1	25.2	7.9	2.3	2.3	1.1	.5	.1	.2	.1	.2
Diarrhea and enteritis	76.6	4.9	2.6	48.8	28.4	12.0	2.7	3.2	2.1	1.5	.4	.5	.4	......
Diseases of teeth and gums	21.3	4.6	2.0	46.7	27.0	14.7	2.9	4.0	2.5	1.4	.4	.4	......	......
Diseases of mouth	4.2	9.2	6.2	14.8	25.9	37.1	3.7	3.7	7.4	3.7	......	3.7	......	......
Ulcer of stomach and duodenum	76.1	49.2	11.2	17.1	17.1	11.8	4.5	5.4	7.2	7.2	9.0	8.1	9.0	3.6
Appendicitis	180.3	24.1	17.7	14.1	11.4	9.7	4.2	10.1	14.7	20.3	6.4	4.6	4.1	.4
Hernia of abdominal cavity	94.5	46.8	33.7	7.3	4.9	4.1	2.4	7.3	9.8	9.8	21.1	21.1	11.4	.8
Cholecystitis and biliary calculus	75.9	19.8	5.4	34.1	16.7	7.9	3.2	9.5	5.9	5.6	5.9	6.4	3.6	1.2
Other gallbladder and diseases of liver	12.1	13.4	5.2	26.1	24.0	12.5	6.3	13.5	3.2	6.3	1.0	1.0	2.1	......
Other digestive diseases	63.3	14.4	4.7	33.0	22.9	8.9	6.4	8.5	7.6	4.7	.8	1.7	5.5	......
Nephritis	176.2	84.2	16.4	14.4	14.4	9.8	4.6	8.3	7.6	3.8	4.6	9.1	15.1	8.3
Pyelitis	20.7	15.8	12.5	8.0	14.8	17.0	6.8	20.5	14.8	13.6	1.1	1.1	2.3	
Other kidney diseases	39.8	24.2	8.2	12.1	22.3	17.2	9.1	10.1	9.1	8.1	3.0	3.0	3.0	3.0
Cystitis and urinary calculus	26.1	13.2	6.6	17.5	25.9	17.5	9.2	10.8	8.3	1.7	.8	3.3	5.0	...
Other diseases of urinary system	7.0	14.8	4.3	35.0	25.0	20.0	......	10.0	......	5.0	......	......	5.0	
Furuncle and carbuncle	24.3	9.7	5.3	22.9	29.4	11.8	[illegible]	11.8	8.5	3.9	.6	2.0	1.3	...
Abscess, cellulitis, and ulcer	13.6	10.6	7.8	10.5	21.0	23.7	11.8	18.4	4.0	4.0	2.6	4.0		
Other local infection	25.8	11.7	8.3	11.9	14.1	25.9	12.6	14.8	9.6	6.7	1.5	2.2	.7	
Impetigo	18.0	16.7	12.6	8.2	13.1	8.2	16.4	21.3	21.3	4.9		1.7	4.0	
Scabies	15.3	17.6	13.8	7.7	17.3	11.5	3.9	25.0	17.3	5.8	1.9	9.6	...	
Other skin diseases	31.8	12.8	7.4	22.2	16.8	17.5	7.4	15.4	6.7	8.0	1.3	1.3	3.4	...
Arthritis and chronic rheumatism	934.0	130.5	11.5	10.6	17.3	16.3	5.8	12.3	5.8	4.3	5.8	7.9	6.7	7.2
Lumbago, myalgia, and myositis	26.1	8.3	5.0	26.3	28.8	17.1	6.3	9.8	4.9	1.9	1.5	2.0	.5	
Other diseases of bones, joints, and organs of movement	194.0	75.3	14.2	16.3	13.3	11.9	5.2	7.4	5.2	4.4	5.9	7.4	7.1	15.6
Congenital malformations and diseases of early infancy	58.7	47.4	15.5	37.5	......	2.5	5.0	7.5	7.5	12.5	2.5	2.5	10.0	12.5
Headache	10.2	1.8	1.6	86.6	9.2	2.1	.3	1.5	.3	......	......	......	......	...
Rash, unqualified	4.0	6.0	4.5	20.6	44.1	11.8	17.7	2.9	......	......	......	2.9	......	...
Other and ill-defined diseases	74.9	10.4	2.8	47.6	21.4	13.3	3.0	3.7	3.7	2.2	1.2	2.0	1.2	.7
Prostate diseases	17.2	32.2	13.8	32.3	6.5	6.5	......	12.9	3.2	......	6.4	16.1	16.1	......
Circumcision	7.5	4.5	3.9	27.8	48.2	16.7	1.8	3.7	1.8	......	......	......	......	......
Other male genital	1.1	7.7	5.5	......	50.0	12.5	12.5	......	12.5	12.5	......	......	......	......
Diseases of ovary, oviducts, and parametrium	22.6	34.4	24.5	9.1	6.8	11.4	4.5	2.3	15.9	11.4	13.6	15.9	9.1	......
Menstrual conditions	30.3	5.4	2.2	57.9	23.3	6.8	1.6	4.2	2.6	1.3	.5	1.3	.5	......
Other female genital and breast	68.8	25.0	16.8	17.7	7.1	8.3	6.5	11.8	10.1	12.4	10.1	8.3	7.7	......
Abortions, stillbirths, ectopic pregnancy	56.6	19.0	13.9	2.0	5.9	20.1	11.8	25.5	14.7	10.8	2.9	3.9	2.4	......
Delivery with live birth	296.2	16.3	14.2	.4	1.0	3.3	27.6	39.2	16.8	9.9	.5	.9	.4	......
Puerperal diseases of breast	2.9	8.1	5.0	......	61.1	22.2	......	11.1	5.6	......	......	......	......	......
Other complications of pregnancy, childbirth, and the puerperium	23.5	18.1	7.8	14.8	21.0	18.5	6.2	11.1	9.9	7.4	2.5	2.5	6.1	......
Motor vehicle accidents	105.4	24.5	11.7	15.1	16.2	12.1	6.1	13.8	10.4	5.7	5.0	8.8	6.1	.7
Acute poisoning except by plants	8.5	4.6	3.6	34.7	43.8	14.0	2.5	1.7	1.7	.8	......	.8	......	......
Burn	19.3	12.3	6.5	20.2	24.2	10.2	8.1	9.1	7.1	11.1	......	......	4.0	......
Fall	135.2	20.2	8.8	14.9	20.3	14.2	5.0	10.8	8.0	6.2	6.2	7.8	6.2	.4
Laceration	43.7	11.8	7.0	22.5	18.9	16.7	9.5	10.4	8.1	7.2	2.2	2.7	1.8	......
Eye accident	11.6	10.2	5.1	37.3	14.7	13.3	12.0	8.0	4.0	4.0	2.7	2.7	1.3	......
Injury by animal or insect	2.2	6.7	6.0	30.0	15.0	30.0	10.0	10.0	5.0	......	......	......	......	......
Other and ill-defined accidents	347.0	18.1	7.8	22.6	17.1	13.4	7.8	9.5	8.4	8.4	4.2	4.2	4.1	.3
Total acute	5,007.1	10.3	5.9	23.7	24.3	16.9	9.4	11.6	5.7	4.2	1.5	1.6	1.0	.1
Total chronic	5,101.2	63.6	11.0	18.4	15.7	11.9	4.8	9.2	6.8	5.2	5.9	7.0	9.0	6.1
Total diagnoses	10,108.3	17.9	6.3	22.9	23.0	16.1	8.8	11.3	5.8	4.4	2.1	2.4	2.2	1.0

(From: Collins et al, 1955; Table 9)

Relative seasonal variation in detailed diagnoses of respiratory diseases and allergy. (Based on annual case rates for each month for periods in each survey of 12 consecutive months or multiples thereof; all except the respiratory diseases were smoothed by a 3-month moving average.)

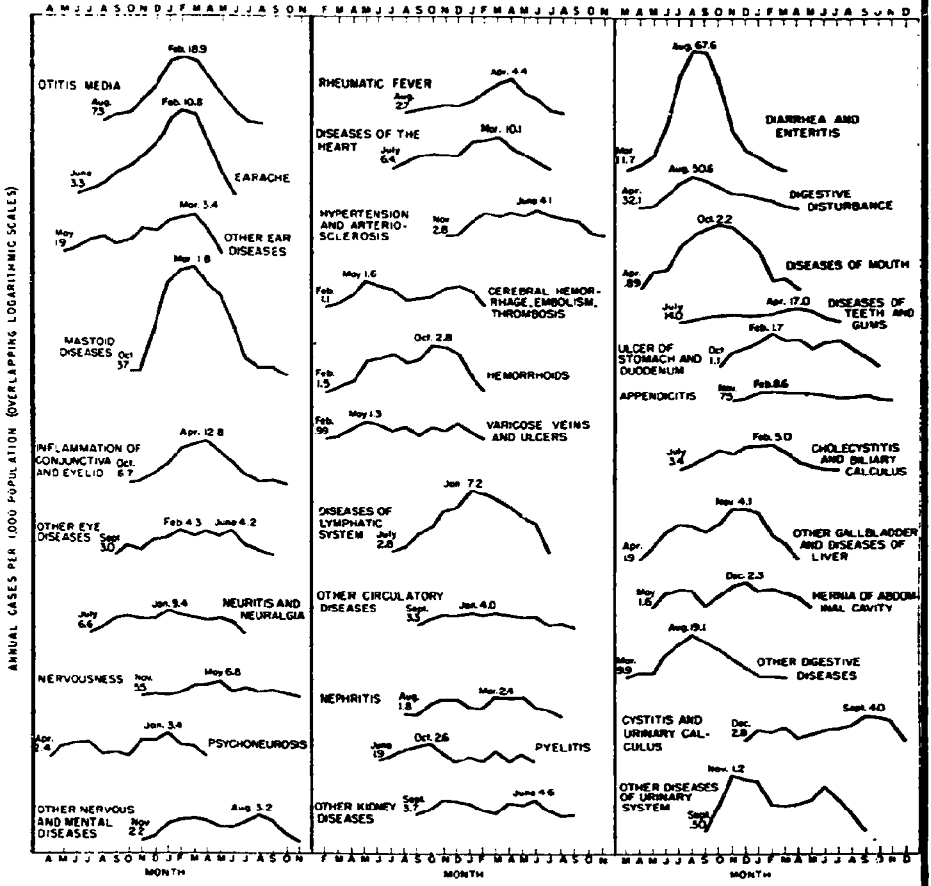


Relative seasonal variation in detailed diagnoses of infectious general and noninfectious general diseases.

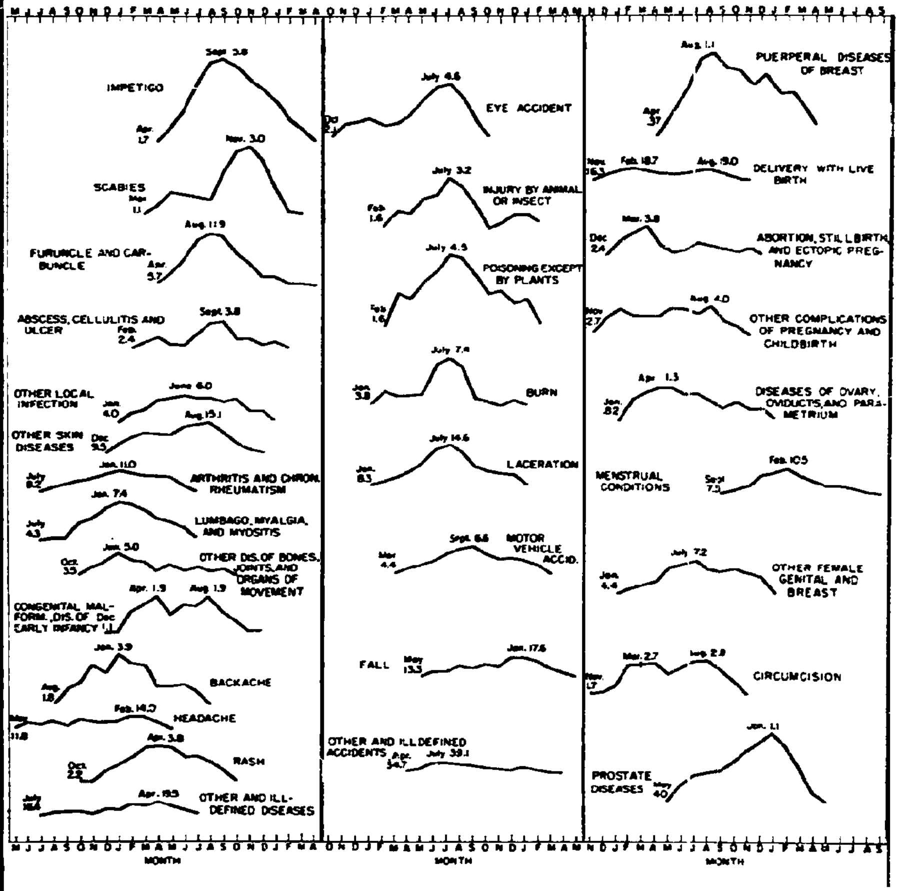


(From: Collins et al, 1955; Figures 17 and 18)

Relative seasonal variation in detailed diagnoses of mental and neurological diseases, ear, eye, heart and circulatory, kidney, urinary, and digestive diseases.



Relative seasonal variation in detailed diagnoses of diseases of the skin, organs of movement, aches, and ill-defined diseases, accidents, female genital and puerperal diseases, and male genital diseases.



(From: Collins et al, 1955; Figures 19 and 20)

Annual age-specific disabling case rates for detailed diagnoses—white families canvassed periodically in 5 surveys [1] covering 80,768 person-years of observation

Serial No.	Diagnosis	All ages: Number of cases	All ages: Rate	Age: Under 5	5-9	10-14	15-19	20-24	25-34	35-44	45-54	55-64	65 and over
				Annual case [2] rate per 1,000 population									
	Respiratory diseases:												
	Minor respiratory:												
1	Influenza and grippe:												
	Both sexes	6,009	74.4	83.6	82.5	70.6	55.8	64.1	82.2	77.6	69.9	69.4	72.1
	Male	2,718	68.0	84.6	77.3	68.3	54.3	55.4	73.5	67.6	61.5	60.0	57.8
	Female	3,291	80.6	82.5	87.8	73.0	57.3	71.5	89.6	87.6	79.2	78.9	84.1
2	Bronchitis:												
	Both sexes	4,128	51.1	99.2	81.2	42.3	33.5	36.7	36.0	35.2	30.0	53.2	51.4
	Male	1,929	46.3	99.1	83.7	39.4	34.8	31.5	32.2	28.6	39.0		42.0
	Female	2,199	53.9	99.2	78.7	45.2	32.1	41.1	40.4	41.8	49.7		50.2
3	Coryza and cold:												
	Both sexes	4,747	58.8	104.9	112.1	81.9	47.8	36.7	35.7	35.1	34.3	39.2	39.1
	Male	2,189	54.8	102.3	103.4	79.3	45.0	29.5	29.4	31.5	29.6	35.8	39.7
	Female	2,558	62.7	107.6	120.8	84.6	50.7	42.8	41.2	38.7	39.6	42.6	38.6
4	Tonsillitis and peritonsillar abscess:												
	Both sexes	1,438	17.8	32.7	32.9	20.0	15.0	13.6	17.4	12.9	8.73	5.01	2.13
	Male	631	15.8	35.4	29.2	17.4	12.5	11.3	15.3	10.2	4.55	2.92	2.92
	Female	807	19.8	29.9	36.5	23.0	17.7	15.5	19.1	15.6	13.30	7.10	1.47
5	Sore throat:												
	Both sexes	1,700	21.8	26.9	39.0	40.0	25.8	15.3	15.3	14.5	12.6	10.2	6.92
	Male	753	18.9	26.0	38.4	39.2	18.6		12.1	10.0	7.4		2.33
	Female	1,007	24.7	27.9	42.8	40.8	23.0		18.0	18.9	16.2		10.70
6	Laryngitis:												
	Both sexes	173	2.14	1.73	2.27		1.40		2.62		2.39	1.88	1.86
	Male	63	1.56	1.71	2.19		.51		1.64		1.47		1.75
	Female	110	2.69	1.76	2.35		2.25		3.52		2.99		1.90
7	Croup:												
	Both sexes	164	2.03	9.41	6.10	1.31	.08		.17		.12		
	Male	93	2.33	10.44	7.20	1.64			.09		.12		
	Female	71	1.74	8.34	4.98	.97	.16		.24		.12		
	Other respiratory diseases:												
8	Sinusitis:												
	Both sexes	394	4.88	1.41	4.26		5.10		6.73	8.23	4.03		1.86
	Male	170	4.26	1.92	3.62		5.07		5.40	6.83	3.53		1.17
	Female	224	5.49	.88	4.91		5.14		7.86	9.62	4.56		2.45
9	Pneumonia, all forms:												
	Both sexes	625	7.74	24.1	10.0	4.76	3.84	3.35	3.16	4.07	4.91	6.05	16.2
	Male	334	8.36	27.7	11.1	5.63	3.72		3.00	4.00	5.89		11.1
	Female	291	7.13	20.4	8.9	3.87	3.53		2.77	4.15	4.72		20.5
10	Pleurisy:												
	Both sexes	200	2.48	.22	1.55		2.90		3.28		3.12		3.40
	Male	88	2.20	.43	1.21		2.37		3.11		2.94		2.92
	Female	112	2.74		1.90		3.53		3.44		3.30		3.91
11	Tonsillectomy and adenoidectomy:												
	Both sexes	1,282	15.9	23.4	49.6	24.9	10.3	11.0	9.97	6.98	3.83	1.04	1.00
	Male	618	15.5	22.4	52.4	23.0	9.3	9.3	8.83	6.83	2.96	.83	
	Female	664	16.3	24.4	46.7	26.8	11.4	12.4	10.94	7.13	4.79	1.25	1.96
12	Other respiratory diseases:												
	Both sexes	165	2.04	3.46	2.58	2.26	1.92	1.12	1.70		1.75		1.33
	Male	88	2.20	4.26	2.08		1.80		1.90		1.91		1.75
	Female	77	1.80	2.63	2.79		1.28		1.52		1.57		.98
	Allergy and related disorders:												
13	Asthma:												
	Both sexes	320	3.96	2.92	5.68	4.05	2.80	2.61	2.49	4.02		6.90	
	Male	164	4.11	4.26	6.17	6.80	1.35		1.80	3.46		7.54	
	Female	156	3.82	1.54	5.10	1.21	4.01		3.08	4.00		6.31	
15	Urticaria:												
	Both sexes	64	.79	1.62	1.65	1.31	.74	.37	.33	.33	.48	.35	
	Male	25	.63	1.40	1.44	1.17	.51		.36	.17			
	Female	39	.96	1.76	1.87	1.45	.64		.31	.50	.83		
16	Eczema:												
	Both sexes	55	.68	2.27	.62	.60	.25		.25	.42	.71		
	Male	28	.71	2.98	.33		.17		.36	.50	.50		
	Female	27	.66	1.54	.80		.32		.15	.33	.83		
17	Contact dermatitis, by plants:												
	Both sexes	70	.87	....	1.24	3.45	.89	.75	.58		.38		....
	Male	40	1.00	....	.82	4.22	1.16	.81	.69		.59		....
	Female	30	.73	....	1.66	2.06	.60	.69	.48		.16		....
	Infectious general diseases:												
18	Measles:												
	Both sexes	1,514	18.7	66.3	68.1	17.4	5.78	2.24	2.49	.06	.41		
	Male	760	19.0	66.9	69.7	16.7	4.65	2.42	.87		.47		
	Female	754	18.5	65.6	66.4	18.1	6.90	2.07	2.24		.36		
19	German measles:												
	Both sexes	416	5.15	9.19	17.4	13.4	4.57	.75	.60	.33	.18		
	Male	214	5.30	8.53	18.9	14.1	3.48	.40	.69		.12		
	Female	202	4.98	9.88	15.8	12.8	5.70	1.04	.32		.24		
20	Whooping cough:												
	Both sexes	721	8.93	34.7	32.6	7.50	1.33	.10	.33	.33	.18		
	Male	350	8.76	31.5	33.3	7.04	1.74	.40	.17		.12		
	Female	371	9.09	38.0	32.0	7.97	.90	......	.48		.24		
21	Mumps:												
	Both sexes	695	8.60	12.2	33.5	17.8	4.28	2.24	2.99	1.91	.41		
	Male	328	8.21	11.5	31.7	17.4	4.07	2.83	1.82		.47		
	Female	367	8.99	12.9	35.3	18.4	4.50	1.73	3.04		.36		

See footnotes at end of table.

Public Health Monograph No. 25, 1955 (Collins et al, 1955; Appendix Table 2)

Annual age-specific disabling case rates for detailed diagnoses—white families canvassed periodically in 5 surveys [1] covering 80,768 person-years of observation—Continued

Serial No.	Diagnosis	All ages		Age									
		Number of cases	Rate	Under 5	5-9	10-14	15-19	20-24	25-34	35-44	45-54	55-64	65 and over
			Annual case [2] rate per 1,000 population										
	Infectious general diseases - Con.												
22	Chickenpox:												
	Both sexes	880	11.0	29.6	50.4	10.4	1.62	.93	1.33	.33	.06		
	Male	425	10.6	29.2	47.1	9.6	1.74	.40	.87		.12		
	Female	461	11.3	30.1	53.8	11.1	1.60	1.38	.80		...		
23	Scarlet fever:												
	Both sexes	385	4.77	8.97	17.6	10.2	2.36	.56	1.08	.75	.30		
	Male	201	5.03	10.44	17.9	11.5	2.32	.40	.43		.24		
	Female	184	4.51	7.40	17.2	8.9	2.40	.69	1.36		.36		
24	Diphtheria:												
	Both sexes	81	1.00	2.60	3.20	1.43	.74		.17	.17	.06		
	Male	41	1.03	2.77	3.70	1.41	.34		.17		...		
	Female	40	.98	2.41	2.70	1.45	1.12		.16		.12		
26	Erysipelas:												
	Both sexes	37	.40	.32	.28		...		37		.99		1.60
27	Tuberculosis, all forms:												
	Both sexes	213	2.64	1.19	2.07	1.90	2.36	4.66	3.41	2.74	2.63	3.39	
	Male	91	2.28	1.28	1.42		2.20		2.70	2.66	2.73	3.89	
	Female	122	2.99	1.10	2.57		4.50		4.01	2.82	2.52	2.93	
28	Smallpox:												
	Both sexes	25	.31	.11	.50		.49		.25	.08	.30		
29	Reaction to smallpox vaccination:												
	Both sexes	135	1.07	2.49	6.71	2.86	.74	.56	.46		.18		
	Male	71	1.78	3.20	6.58	3.52	.58	.40	.43		.12		
	Female	64	1.57	1.70	6.85	2.17	.90	.69	.48		.24		
30	Other infectious general diseases:												
	Both sexes	364	4.51	5.10	6.14		4.94		3.99	3.91	3.35	2.92	3.13
	Male	188	4.71	4.48	7.01		6.42		3.55		2.80		2.92
	Female	176	4.31	5.93	5.25		3.53		4.32		3.62		1.47
	Noninfectious general diseases:												
31	Malignant neoplasms, all sites												
	Both sexes	164	2.03	.32	.06		.08		.17	1.75	4.19	6.47	18.6
	Male	62	1.55				...		...	.83	3.04	6.25	15.2
	Female	102	2.50	.06	.11		.16		.31	2.65	4.79	6.68	21.5
32	Benign and unspecified tumors and cysts of female genital organs and breast [3]	121	2.98			.24	.00	3.11	5.09	6.64	5.80	4.18	1.47
33	Other benign and unspecified tumors:												
	Both sexes	97	1.20	.43	.22		1.41			1.99	1.82		1.86
	Male	42	1.05	.43	.22		1.22			2.00	1.41		
	Female	55	1.35	.44	.22		1.57			1.99	2.26		
34	Diseases of thyroid gland												
	Both sexes	120	1.00		.31	.36	1.23		1.99	3.91	3.71	.70	
	Male	10	.25				.51		.52		.15		......
	Female	119	2.91		.67		1.93		2.77	7.80	7.82	1.13	
35	Diabetes mellitus.												
	Both sexes	96	1.19	.32	.33		.25		.42	.75	2.15	6.26	5.85
	Male	33	.83	.45	.33		.17		.36	.50	2.50	2.92	2.33
	Female	63	1.54	.22	.34		.32		.46	1.00	1.77	9.60	8.81
36	Anemia, all forms.												
	Both sexes	137	1.70	.32	1.71		1.81		1.59	1.83	1.68	2.50	3.40
	Male	18	.70	.21	.44		.34		.52		1.47		2.33
	Female	109	2.67	.44	3.02		3.21		2.80		2.62		4.40
37	Debility and malnutrition:												
	Both sexes	122	1.51	1.51	1.11		1.07		1.79		1.56	2.10	
	Male	40	1.00	1.49	.77		.17		.87		1.37	1.94	
	Female	82	2.01	1.54	1.45		1.93		2.64		1.77	2.25	
38	Other noninfectious general diseases:												
	Both sexes	141	1.75	3.24	1.45	.24	.44	1.12	1.41	2.16		2.92	
	Male	77	1.93	3.20	.99		.51		1.26	2.60		3.89	
	Female	64	1.57	3.29	.78		.96		1.54	1.70		2.03	
	Nervous system and mental diseases:												
39	Cerebral hemorrhage, embolism, thrombosis:												
	Both sexes	164	2.03	.22	.33		.08		.33	.83	2.51	3.90	21.6
	Male	79	1.98	.43	.44		...		.36	.83	2.50		[illegible]
	Female	85	2.08		.22		.16		.31	.83	3.62		25.4
40	Neuritis and neuralgia:												
	Both sexes	376	4.66		.52	1.19	1.48	3.35	5.15	7.31	8.85	12.72	11.7
	Male	99	2.48		.21	.94	.51		1.80	3.66	6.48		8.8
	Female	277	6.79		.83	1.45	4.01		8.02	10.95	14.31		14.2
41	Nervousness:												
	Both sexes	225	2.79	......	.93	1.31	1.33	2.24	3.90	4.65	5.60	4.17	3.73
	Male	40	1.00	......	.62	1.41	.87	.81	1.08	.67	1.77		2.33
	Female	185	4.53	...	1.25	1.21	1.80	3.46	6.32	8.63	8.83	7.93	4.89
42	Psychoneurosis:												
	Both sexes	217	2.69	..	.10	.36	1.33	2.98	4.20		5.74	5.21	3.73
	Male	58	1.45	..	.21	.23	.58	1.72	2.08		4.10	2.08	1.75
	Female	159	3.89	....		.48	2.10	4.15	6.15		7.56	8.35	5.35
43	Other nervous system and mental diseases:												
	Both sexes	355	4.40	7.68	3.62	4.05	3.98	3.54	2.16	4.41		6.08	
	Male	193	4.83	8.95	4.71		3.89		1.80	4.71		6.08	
	Female	162	3.97	6.37	2.90		3.69		2.47	4.10		6.08	

See footnotes at end of table.

(Collins et al, 1955; Appendix Table 2)

Annual age-specific disabling case rates for detailed diagnoses—white families canvassed periodically in 5 surveys[1] covering 80,768 person-years of observation—Continued

Serial No.	Diagnosis	All ages: Number of cases	All ages: Rate	Age: Under 5	5-9	10-14	15-19	20-24	25-34	35-44	45-54	55-64	65 and over
			Annual case[2] rate per 1,000 population										
	Diseases of eye and ear:												
44	Inflammation of conjunctiva and eyelid:												
	Both sexes	266	3.29	4.87	9.09	7.38	2.36	.56	1.58	1.16	.96	1.04	1.33
	Male	132	3.30	4.26	10.49	7.74	1.35		1.62	1.17	.40	.24	
	Female	134	3.28	5.49	7.08	7.01	1.77		1.54	1.16	1.51	2.03	
45	Other eye diseases:												
	Both sexes	152	1.88	.97	2.17	1.90	.74		.91	1.75	2.30	2.92	7.45
	Male	65	1.63	.43	1.85	1.41	.68		1.08	1.83	2.50	3.40	
	Female	87	2.13	1.54	2.40	2.42	.80		.77	1.06	2.27	6.31	
46	Earache:												
	Both sexes	295	3.65	9.84	10.7	4.76	2.36	.93	1.08	1.00	.84	.82	
	Male	128	3.20	9.38	9.7	4.22	1.74	.40	.72	.50	.68	.40	
	Female	167	4.09	10.32	11.8	5.32	3.00	1.38	1.39	1.49	1.01	1.13	
47	Otitis media:												
	Both sexes	641	7.94	29.8	18.4	5.83	3.69	2.24	3.41	2.93	2.15	.94	
	Male	311	7.79	31.3	18.1	6.57	4.07	1.21	2.16	1.83	.69	1.22	
	Female	330	8.08	28.3	18.7	5.07	3.30	3.11	4.47	3.82	3.78	.68	
48	Other ear diseases:												
	Both sexes	93	1.15	1.95	2.17	1.79	1.33	.93	.79		.30		.53
	Male	46	1.15	1.92	2.19		.84		.78		.29		.58
	Female	47	1.15	1.98	1.79		1.45		.80		.31		.49
49	Mastoid diseases:												
	Both sexes	77	.95	2.49	2.69	.48	.58		.42	.58	.36	.23	
	Male	38	.95	3.20	1.53		.34		.38	.50	.23	.24	
	Female	39	.96	1.76	1.79		.80		.46	.66	.50	.23	
	Heart and circulatory diseases:												
50	Rheumatic fever:												
	Both sexes	156	1.93	.43	2.89	5.36	1.77	1.49	1.00	1.67		1.52	
	Male	66	1.65	..	3.08	4.69	1.16	1.62	.54	1.25		1.70	
	Female	90	2.20	.88	2.70	6.04	2.40	1.38	1.39	2.10		1.35	
51	Diseases of the heart:												
	Both sexes	829	10.3	.65	1.45	2.38	3.39	2.98	3.49	6.23	15.3	35.5	87.3
	Male	322	8.1	.64	1.97		1.86		1.80	4.00	9.3	33.8	77.0
	Female	507	12.4	.66	1.79		4.50		4.93	8.46	21.9	37.2	95.9
52	Hypertension and arteriosclerosis:												
	Both sexes	342	4.23		.22		.25		.66	2.16	7.54	16.5	42.3
	Male	127	3.18							1.50	5.01	12.1	39.1
	Female	215	5.27		.45		.48		1.23	2.82	10.34	20.9	45.0
53	Hemorrhoids:												
	Both sexes	115	1.42				.44	1.12	2.16	3.49	2.51	2.71	1.00
	Male	66	1.65				.68		2.70	4.16	2.65		2.33
	Female	49	1.20				.80		1.70	2.82	2.52		
54	Varicose veins and ulcers:												
	Both sexes	98	1.21					.37	.83	1.33	2.39	3.98	8.25
	Male	30	.75				.17		.18	1.00	1.77		5.83
	Female	68	1.67				.10		1.39	1.06	4.24		10.27
55	Disease of lymphatic system:												
	Both sexes	314	3.89	10.6	12.1	8.07	1.81		.75	.83	.60	.23	
	Male	152	3.81	11.3	12.5	4.69	1.35		.54	.67	.46	.24	
	Female	162	3.97	9.9	11.6	7.49	2.25		.92	1.00	.76	.23	
56	Other circulatory diseases:												
	Both sexes	178	2.20	.32	.83	2.26	1.92	.93	1.06	2.91	3.35	4.17	7.18
	Male	80	2.00	.21	.99		1.35		1.02	2.00		6.32	
	Female	98	2.40	.44	2.01		1.61		1.70	3.00		4.73	
	Digestive diseases:												
	Minor digestive diseases:												
57	Functional digestive disturbance:												
	Both sexes	2,155	26.7	45.0	44.0	38.7	17.7	14.3	15.7	15.8	19.4	24.6	33.5
	Male	931	23.3	41.6	41.7	40.6	11.6	12.9	13.0	14.2	12.8	16.7	19.8
	Female	1,224	30.0	48.5	46.3	36.7	24.0	15.5	18.0	17.4	26.7	32.6	45.0
58	Diarrhea and enteritis:												
	Both sexes	1,359	16.8	49.2	19.3	13.2	9.00	9.31	10.5	10.4	13.0	12.9	18.4
	Male	636	15.9	51.4	20.1	14.3	9.00	7.08	7.6	8.0	10.0	9.6	15.8
	Female	723	17.7	47.0	18.5	12.1	9.00	10.71	13.1	12.8	16.4	18.3	20.5
	Other digestive diseases:												
59	Diseases of teeth and gums:												
	Both sexes	473	5.86	7.68	6.10	8.33	9.15	5.40	5.90	4.90	4.07	2.92	.80
	Male	212	5.31	6.81	5.55	6.80	8.42	4.04	5.19		3.53		1.17
	Female	261	6.39	8.78	6.64	9.91	9.90	6.57	5.59		3.77		.49
60	Diseases of mouth:												
	Both sexes	46	.57	1.95	1.24	.71	.30	.19	.21		.15		
	Male	16	.40	.85	.99		.17		.09		.15		
	Female	30	.73	3.07	1.01		.32		.32		.16		
61	Ulcer of stomach and duodenum:												
	Both sexes	132	1.63				.15	1.12	2.74	3.66	2.87	3.13	1.86
	Male	101	2.53				.68		4.68	5.66	4.71		2.33
	Female	31	.76				.48		1.08	1.00	1.10		1.47
62	Appendicitis:												
	Both sexes	680	8.42	1.19	7.13	11.2	16.8	15.6	13.5	7.40	3.71	3.96	1.38
	Male	207	5.18	1.28	5.35	8.4	9.3	7.7	7.6	4.06	2.50	2.50	.58
	Female	473	11.59	1.10	8.93	14.0	24.6	22.5	18.7	10.12	5.04	5.43	1.96

See footnotes at end of table.

Annual age-specific disabling case rates for detailed diagnoses—white families canvassed periodically in 5 surveys [1] covering 80,768 person-years of observation—Continued

Serial No.	Diagnosis	All ages		Age									
		Number of cases	Rate	Under 5	5-9	10-14	15-19	20-24	25-34	35-44	45-54	55-64	65 and over
			Annual case [3] rate per 1,000 population										
	Digestive diseases—Continued												
	Other digestive diseases Con.												
63	Hernia of abdominal cavity:												
	Both sexes	176	2.18	2.70	.93	.48	1.65		1.95		2.51	5.63	6.12
	Male	142	3.55	3.84	1.21		2.70		3.29		5.89		11.09
	Female	34	.83	1.54	.22		.64		.72		1.20		1.06
64	Cholecystitis and biliary calculus:												
	Both sexes	330	4.09	.....	.06		.30	2.24	3.06	6.89	7.78	11.47	8.52
	Male	40	1.00	.....	.11		.29	.40	1.26	2.31		1.40	
	Female	290	7.10	.....	.....		.30	3.80	5.70	16.01		18.25	
65	Other gallbladder and diseases of liver:												
	Both sexes	128	1.58	.65	1.11		.09		.91	1.41	3.59	3.75	3.73
	Male	47	1.18	.85	1.10		1.52		.90	.67	1.62		2.33
	Female	81	1.08	.44	1.12		.48		.92	2.16	5.35	6.26	4.89
66	Other digestive diseases:												
	Both sexes	447	5.53	6.38	5.37	3.81	4.20		4.57	6.18		8.07	
	Male	227	5.68	7.25	6.99	3.52	4.05		5.40	5.77		7.05	
	Female	220	5.39	5.49	3.74	4.11	4.34		3.85	6.60		9.01	
	Kidney and urinary diseases:												
67	Nephritis:												
	Both sexes	194	2.40	.22	.21	.36	.49		.83	2.33	3.23	7.92	20.8
	Male	76	1.90	.43	.22		.51		.39	1.09	2.06	4.17	19.8
	Female	118	2.89	.....	.34		.48		1.23	2.99	3.53	11.69	21.5
68	Pyelitis:												
	Both sexes	120	1.49	1.81	1.00		1.23		1.50	1.52		1.82	
	Male	15	.38	.21	.....		.51		.30	.58		.73	
	Female	105	2.57	2.85	3.24		1.93		2.47	2.50		2.25	
69	Other kidney diseases:												
	Both sexes	197	2.44	1.30	1.55	1.19	.74	1.49	1.91	3.58		5.01	7.18
	Male	61	1.53	1.07	1.23	.94	.51		.72	2.21		2.92	5.25
	Female	136	3.33	1.54	1.87	1.45	1.61		2.93	5.00		7.10	8.81
70	Cystitis and urinary calculus:												
	Both sexes	187	2.32	.11	.28		.82		2.58	3.90	4.55	5.03	6.92
	Male	85	2.13	.....	.33		.51		2.60		5.30		7.58
	Female	102	2.50	.22	.22		1.12		3.92		4.80		6.36
71	Other diseases of urinary system:												
	Both sexes	56	.69	.54	.22		.08		.06	.91	1.20	1.99	
	Diseases of skin and cellular tissue:												
72	Furuncle and carbuncle:												:NN
	Both sexes	220	2.72	2.38	2.43		3.70		3.24	2.58	2.03	2.29	.80
	Male	127	3.18	2.34	2.74		3.72		3.89		3.39		.58
	Female	93	2.28	2.41	2.12		3.69		2.00		1.57		.98
73	Abscess, cellulitis, and ulcer:												
	Both sexes	122	1.51	1.41	1.34	2.74	1.50		1.16	1.25	1.52		1.33
	Male	66	1.65	.85	1.85	3.28	2.20		1.47		1.00		
	Female	56	1.37	1.98	.83	2.17	.96		.96		1.90		
74	Other local infection:												
	Both sexes	231	2.86	1.73	3.10	3.69	2.88		2.91		2.97		2.39
	Male	138	3.46	1.07	4.32	4.22	3.04		3.55		3.98		4.08
	Female	93	2.28	2.41	1.87	3.14	2.73		2.82		1.89		.98
75	Impetigo:												
	Both sexes	92	1.14	2.38	4.13	2.74	.41		.08	.08	—		
	Male	40	1.00	2.13	3.07		.17		.09		--		
	Female	52	1.27	2.63	3.91		.64		.08		..		
76	Scabies:												
	Both sexes	70	.87	.43	3.10	2.98	1.33	.19	.02				
	Male	20	.50	.21	2.06	1.17	.68		—				
	Female	50	1.22	.66	4.15	4.83	.96		.05				
77	Other skin diseases:												
	Both sexes	226	2.80	3.24	3.04		2.63		1.66	1.58	3.60		5.85
	Male	116	2.90	2.77	3.29		3.04		1.44	1.83	3.83		5.25
	Female	110	2.69	3.73	2.70		2.25		1.85	1.33	3.14		6.36
	Diseases of bones and organs of movement:												
78	Arthritis and chronic rheumatism:												
	Both sexes	690	8.54	.43	2.38		2.22		6.15	9.39	17.0	20.5	42.0
	Male	309	7.74	.43	2.74		1.69		5.58	10.15	16.2	17.9	37.9
	Female	381	9.33	.44	2.01		2.73		6.63	8.63	17.9	35.1	45.5
79	Lumbago, myalgia, and myositis:												
	Both sexes	282	3.49	.22	.93	1.31	1.48	1.08	2.06	6.65	7.30	7.30	7.98
	Male	140	3.50	.21	.99		2.03		5.10		7.07		6.42
	Female	142	3.48	.22	1.23		1.12		4.24		7.55		9.30
80	Other diseases of bones, joints, and organs of movement:												
	Both sexes	250	3.10	1.51	1.75	3.46	2.55		2.65	3.87		5.01	6.12
	Male	123	3.08	1.28	1.64	3.62	2.37		2.88	4.04		5.42	5.25
	Female	127	3.11	1.76	1.87	3.38	2.73		2.47	3.70		4.59	6.85
	Other and ill-defined diseases:												
81	Congenital malformations and diseases of early infancy:												
	Both sexes	116	1.44	10.4	.93	.60	.16		.12		.06		
	Male	63	1.58	12.1	.44		.17		.09		—		
	Female	53	1.30	8.6	1.12		.16		.16		.12		

See footnotes at end of table.

(Collins et al, 1955; Appendix Table 2)

Annual age-specific disabling case rates for detailed diagnoses—white families canvassed periodically in 5 surveys [1] covering 80,768 person-years of observation—Continued

Serial No.	Diagnosis	All ages: Number of cases	All ages: Rate	Age: Under 5	5-9	10-14	15-19	20-24	25-34	35-44	45-54	55-64	65 and over
			Annual case [2] rate per 1,000 population										
	Other and ill-defined diseases—Con.												
82	Headache:												
	Both sexes	451	5.58	.22	2.79	7.02	3.84	4.10	6.73	8.81	9.69	8.34	1.33
	Male	113	2.83		2.47	7.51	4.36	2.83	2.34	2.16	2.28	3.75	1.17
	Female	338	8.28	.44	3.11	6.52	3.30	5.18	10.48	15.43	17.90	12.94	1.47
83	Backache:												
	Both sexes	75	1.27	.....	.27		.80		1.81	2.82	1.00	2.50	3.19
	Male	30	1.23	.	.27		.25		2.71		1.89		
	Female	30	1.30	.....	.14		1.42		2.00		2.57		
84	Rash, unqualified:												
	Both sexes	72	.89	2.70	2.48	1.31	.30	.19	.25	.25	.12	.23	
	Male	34	.85	2.56	2.26	1.41	.17		.17		.24		
	Female	38	.93	2.85	2.70	1.21	.32		.32		.12		
85	Other and ill-defined diseases:												
	Both sexes	579	6.83	7.24	5.56		5.23		5.50	4.58	5.58	9.33	25.0
	Male	187	4.35	5.12	4.44		3.47		2.48		3.06	4.01	18.8
	Female	392	9.26	9.44	7.68		6.93		7.35		7.67	14.71	30.2
	Male genital diseases (nonvenereal): [3]												
86	Prostate diseases	53	1.33	.....	...	......	.17		1.12		1.77		15.8
87	Circumcision	157	3.93	27.1	3.91	1.88	......		.09		.24		
88	Other male genital	17	.43	1.07	.33		.34		.30	.33	.46	.24	
	Female genital (nonvenereal) and puerperal conditions, except neoplasm: [4]												
89	Diseases of ovary, oviducts, and parametrium	68	1.07	.....	......	.24	2.10	4.84	4.47	2.82			...
90	Menstrual conditions	503	12.3	.....	....	11.6	25.2	19.7	15.0	16.1	23.4	9.60	1.47
91	Other female genital and breast	300	7.35	.88	.62	.48	2.10	9.08	20.0	13.3	7.08	3.31	3.91
92	Abortions, stillbirths, ectopic pregnancy	246	6.03	.....	......	.....	2.40	19.0	18.2	10.1	.76		....
93	Delivery with live birth	1,470	36.0	....	....	.24	24.3	124.7	113.8	46.0	2.27		.
94	Puerperal diseases of breast	41	1.00	...	......	......	.00	3.80	3.08	1.33	..	..	...
95	Other complications of pregnancy, childbirth, and the puerperium	242	5.93	......	...	...	4.20	19.0	19.1	7.63	.76	...	...
	Accidents and poisonings:												
96	Motor vehicle accidents:												
	Both sexes	348	4.31	2.81	3.82		5.19		4.15	4.81		4.68	
	Male	195	4.88	2.77	5.59		6.42		4.32	4.81		4.13	
	Female	153	3.75	2.85	2.01		4.01		4.01	4.80		5.18	
97	Acute poisoning except by plants:												
	Both sexes	154	1.91	1.73	1.60		1.56		2.33		2.05		1.86
	Male	73	1.83	1.49	1.53		1.69		2.34		1.77		1.75
	Female	81	1.98	1.98	1.68		1.45		2.32		2.36		1.90
98	Burn:												
	Both sexes	132	1.63	2.06	2.07	1.31	1.89		1.50		1.56	1.17	
	Male	60	1.50	1.71	2.47	1.41	1.69		1.04		.91	.24	
	Female	72	1.76	2.41	1.66	1.21	2.09		1.36		2.27	2.03	
99	Fall:												
	Both sexes	551	6.82	4.22	5.68	5.59	3.39	3.91	5.98	6.07	7.78	16.7	19.4
	Male	203	5.08	4.48	7.20	6.10	3.19	2.83	4.14	3.50	3.42	7.9	13.4
	Female	348	8.52	3.95	4.15	5.07	3.60	4.84	7.56	8.63	12.61	25.5	24.5
100	Laceration:												
	Both sexes	300	3.71	2.27	6.10	5.71	4.28		3.74	3.16	2.43		1.33
	Male	213	5.33	3.41	7.40	8.44	6.76		7.03	4.83	2.36		.58
	Female	87	2.13	1.10	4.78	2.90	1.93		.92	1.49	2.52		1.96
101	Eye accident:												
	Both sexes	92	1.14	.76	1.22		1.48		1.74	1.08	.72	.63	.63
	Male	70	1.75	.85	1.64		2.53		2.88	2.00	1.37	.49	
	Female	22	.54	.66	.78		.48		.77	.17	......	.08	
102	Injury by animal or insect:												
	Both sexes	27	.33	.87	.93	.24	.17				.15	.12	
	Male	19	.48	1.28	.77		.17				.29	.21	
	Female	8	.20	.44	.45		.16				—	—	
103	Other and ill-defined accidents:												
	Both sexes	1,557	19.3	6.49	19.9	24.0	22.7	15.1	18.7	22.2	23.3	20.3	
	Male	994	24.9	7.46	25.9	29.6	33.7	24.2	24.5	30.3	27.6	21.4	
	Female	563	13.8	5.49	13.9	18.4	11.4	7.2	12.7	14.1	18.7	19.4	
			Population (years of life)										
	Both sexes	80,768		9,248	9,680	8,402	4,778	[illegible]	12,038	12,034	8,258	4,795	3,758
	Male	39,944		4,692	4,864	4,263	2,444	2,478	5,551	6,007	4,292	2,400	1,714
	Female	40,824		4,556	4,816	4,139	[illegible]	[illegible]	6,487	6,027	3,966	2,395	2,044

---

[1] The 5 surveys were: Baltimore 21,505; Syracuse, N. Y., 6,341; Cattaraugus Co., N. Y., 10,142; Committee on the Costs of Medical Care—full-time 38,544; part-time, 4,230.

[2] Cases include sole, primary, and contributory causes of illness so are not addable to a total for all causes. Recurring attacks of chronic disease within the period of observation are counted along with the original attack or illness. Thus for chronic diseases it represents the number of attacks of chronic disease in the same sense as attacks of acute disease.

[3] Based on female population.

[4] Based on male population.

APPENDIX C

1. A SIMPLIFIED METHOD FOR MAKING ROUGH APPROXIMATIONS OF STEADY-STATE SHELTER AIR TEMPERATURE

2. PREDICTED EFFECT OF OVERLOADING ON STEADY-STATE, SATURATED AIR TEMPERATURE FOR A HYPOTHETICAL 100 MAN UNDERGROUND SHELTER

APPENDIX C

1. A SIMPLIFIED METHOD FOR MAKING ROUGH APPROXIMATIONS OF STEADY-STATE SHELTER AIR TEMPERATURE

To assess the effects of overloading on the thermal environment within the shelter, it became necessary to establish a means for rapid estimation of shelter air temperatures under different conditions of loading. Starting with a model formulated by Achenbach, et al., (1962), a number of simplifying assumptions were made. The input data to the simplified model were taken from a study by Drucker and Chang (1962) who, in turn, reported on empirical data from other references. Some of the data for this study were taken from studies by Achenbach, et al., (1960) and from Heiskell (1960).

The 100 man shelter for the current study was assumed to be 25' x 40' x 8', constructed of concrete, and located underground. The heat balance equation within the shelter is:

Sensible Heat Balance

$$Q_{gs} = Q_{vs} + Q_{ws} \qquad (1)^{*}$$

Latent Heat Balances

$$Q_{gl} = Q_{vl} + Q_{wl} \qquad (2)$$

$$Q_{gs} + Q_{gl} = Q_{vs} + Q_{vl} + Q_{ws} + Q_{wl} \qquad (3)$$

$$= n\, q_g$$

$$\therefore\ nq_g = Q_{vs} + Q_{vl} + Q_{ws} + Q_{wl} \qquad (4)$$

$$Q_{vs} = 0.0018V\,(t_a - t_v) \qquad (4a)$$

$$Q_{vl} = 0.075V\,(W_a - W_v)\,\lambda \qquad (4b)$$

$$Q_{ws} = Ah_m\,(t_a - t_{sm}) \qquad (4c)$$

$$Q_{wl} = Ah_{dm}\,(W_d - W_{Am})\,\lambda \qquad (4d)$$

$$\therefore\ nq_g = 0.018V\,(t_a - t_v) + 0.075V\,\lambda\,(W_a - W_v) + Ah_m(t_a - t_{sm}) + Ah_{dm}\lambda(W_d - W_{Am}) \qquad (5)$$

---

[*] A list of symbols is given at the end of Section 1 of this Appendix.

Empirical data have shown that the amount of heat flux through the walls of a shelter becomes relatively constant, and that 5 Btu/hr ft^2 is a good approximation to a fairly wide range of cases. Assuming $Q_{ws} + Q_{wl}$ to be constant, k, obviates the necessity of attempting to solve the multidirectional heat flow into, through, and within the walls and soil. A comprehensive solution of this problem was not considered to be within the scope of this study, since extensive computer calculations are required for each set of input conditions to be analyzed. The analysis presented here is approximate, and can be refined where necessary as a larger body of shelter heat transfer data becomes available.

Thus Equation (5) becomes

$$nq_g = 0.018V\,(t_a - t_v) + 0.075\lambda\,(W_a - W_v) + k \tag{6}$$

$$nq_g = 0.018Vt_a - 0.018Vt_v + 0.075V\lambda\,(W_a - W_v) + k \tag{6a}$$

$$0.018Vt_a = 0.018Vt_v - 0.075V\lambda\,(W_a - W_v) + nq_g - k \tag{6b}$$

$$t_a = t_v - \frac{0.075\lambda\,(W_a - W_v)}{0.018} + \frac{nq_g - k}{0.018V} \tag{6c}$$

$$t_a = t_v - 4.167\lambda\,(W_a - W_v) + \frac{55.56}{V}\,(nq_g - k) \tag{6d}$$

The value of λ can be approximated for a small enough temperature range, by taking the average of the values within the range:

t_a	λ
80	1048
85	1045
90	1042
95	1039

The average for the range of interest thus becomes 1044. This, in turn, changes Equation (6d) to:

$$t_a = t_v - 4350\,W_a + 4350\,W_v + \frac{55.56}{V}\,(nq_g - k) \tag{7}$$

In order to express all terms which vary with t_a in terms of t_a, it becomes desirable to find a conversion factor from W_a to $k_t t_a$. For the range of interest, 3.6×10^{-4} allows a good evaluation of W_a in terms of t_a.

Therefore, Equation (7) can be re-expressed as

$$t_a = t_v - 4350 \times 3.6 \times 10^{-4}\, t_a + 4350\, W_v + \frac{55.56}{V}(nq_g - k) \qquad (7a)$$

$$t_a = t_v - 1.57\, t_a + 4350\, W_v + \frac{55.56}{V}(nq_g - k) \qquad (7b)$$

$$2.57 t_a = t_v + 4350\, W_v + \frac{55.56}{V}(nq_g - k) \qquad (7c)$$

$$t_a = \frac{t_v + 4350\, W_v + \frac{55.56}{V}(nq_g - k)}{2.57} \qquad (8)$$

The use of Equation (8) requires knowing only the temperature (wet and dry bulb) of the input ventilation air and the rate at which it is entering to determine the shelter air temperature. This technique makes the further assumptions that

1. Ventilation air stays at a constant temperature and flow rate,
2. The heat generated by the occupants remains constant,
3. All surfaces are at the same temperature,
4. The shelter air at "steady state" is essentially at 100 percent humidity.

SYMBOLS

q_g = heat generated by one average occupant*

Q_{gs} = sensible heat transferred to the shelter air and surfaces from all occupants

Q_{gl} = latent heat transferred to the shelter air and surfaces from all occupants

Q_{ws} = sensible heat exchanged between shelter air and shelter surfaces

Q_{wl} = latent heat exchanged between shelter air and shelter surfaces

Q_{vs} = sensible heat exchanged between shelter air and ventilation air

Q_{vl} = latent heat exchanged between shelter air and ventilation air

V = ventilation rate (ft^3/min)

t_a = shelter air temperature

t_v = ventilation air temperature

λ = latent heat of condensation of water vapor

W_a = humidity ratio of shelter air

W_v = humidity ratio of ventilation air

A = surface area (3040 ft^2)

h_m = surface heat transfer coefficient

t_{sm} = shelter surface temperature

h_{dm} = mass transfer coefficient

W_{Am} = humidity ratio of saturated air at t_{sm}

n = number of occupants

k = heat flux through shelter walls

k_t = a conversion constant

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*All heat terms expressed in Btu per hour.

2. PREDICTED EFFECT OF OVERLOADING ON STEADY-STATE, SATURATED AIR TEMPERATURE FOR A HYPOTHETICAL 100 MAN UNDERGROUND SHELTER

To assess the effects of shelter overloading on shelter air temperature, using the simplifying assumptions discussed in the foregoing section, steady state conditions were predicted for hypothetical 100 man shelters located in Pomona, California and New York City using the 2 1/2 percent design criteria (according to the ASHRAE Guide and Data Book for 1961); those conditions were:

Pomona, California	100°F dry bulb 72°F wet bulb	intake air
New York City, New York	91°F dry bulb 76°F wet bulb	intake air

Figure 1 in this Appendix shows the results of those computations. As can be noted, the shelter steady state temperatures (assumed to be at 100 percent humidity) in the New York City cases are higher than for Pomona for ventilation rates of both 300 and 600 cubic feet per minute. Empirical data predict that the shelter temperature will be essentially steady state before the third day. Further, decreasing the average heat flux through the walls from 5 $Btu/ft^2\ {}^{\circ}F$ to 4 $Btu/ft^2\ {}^{\circ}F$ causes the steady state temperature to be between two and four degrees higher, depending on the ventilation rate.

As can be noted, the minimum ventilation design cases (300 ft^3/min or 3 ft^3/min per person for the design load) for the two geographical areas allow for little overloading, the doubled minimum ventilation rate allowing for more than twice as many additional people before reaching critical temperatures.

Figures 2, 3, and 4 of this Appendix show shelter temperatures versus various loadings for various hypothetical cases.

Figure 2 deals with three different dry bulb temperatures, 71°, 81°, and 91°F with a wet bulb temperature of 60°F and two different ventilation rates. As can be seen, the doubled ventilation rate allows a higher overload capability than the lesser. Further, as is expected, the lower the temperature of the ventilation air, the greater the overload capability.

The statements applicable to Figure 2 are also applicable to Figure 3, which contains similar plots for a wet bulb temperature of 70°F. The amount of overloading allowable in this set of cases is less (for a given ventilation rate) for each of the 70°F wet bulb cases than for any of the 60°F cases. Figure 4 shows the effects of two different ventilation air wet bulb temperatures on shelter steady state temperature while holding the ventilation air dry bulb constant.

Figure III-3 (p. 36, given previously) is a plot of the maximum overload capability for various wet-dry bulb combinations while keeping the steady state shelter temperature $\leq 95^\circ$F.

Curve	Intake Air	Vent Rate	Wall Flux
1	100°F d. b. 72°F w. b.	600 cfm	5 Btu/ft^2°F
2	100°F d. b. 72°F w. b.	600 cfm	4 Btu/ft^2°F
3	91°F d. b. 76°F w. b.	600 cfm	5 Btu/ft^2°F
4	100°F d. b. 72°F w. b.	300 cfm	5 Btu/ft^2°F
5	100°F d. b. 72°F w. b.	300 cfm	4 Btu/ft^2°F
6	91°F d. b. 76°F w. b.	300 cfm	5 Btu/ft^2°F

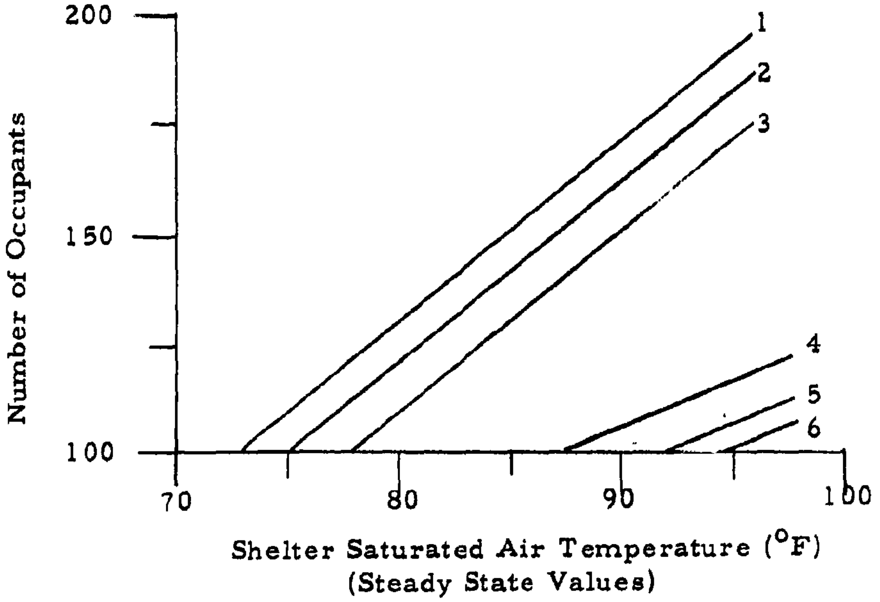

Figure 1 Effect of overloading on saturated air temperature for a hypothetical, 100 man underground shelter.

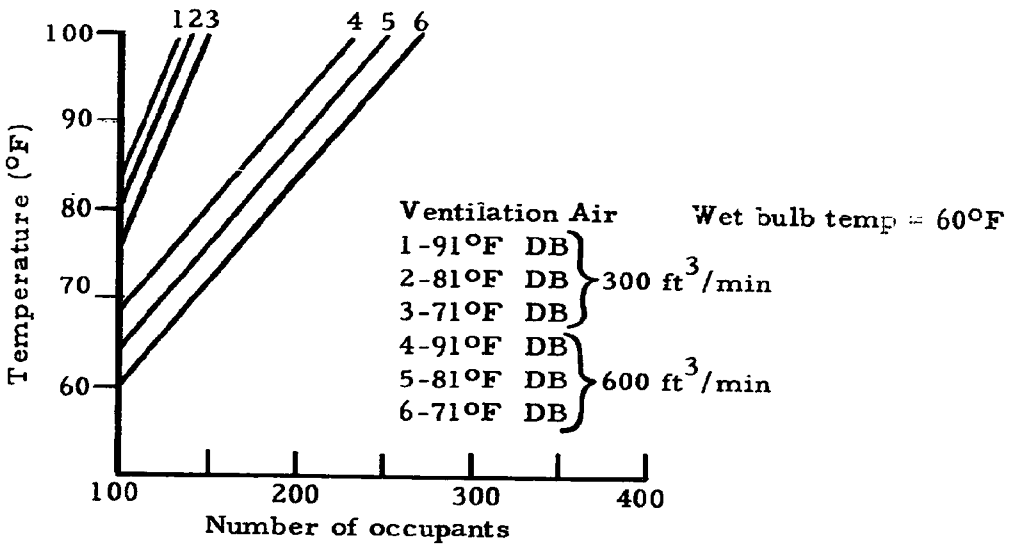

Figure 2 Shelter steady-state saturated temperature vs. loading.

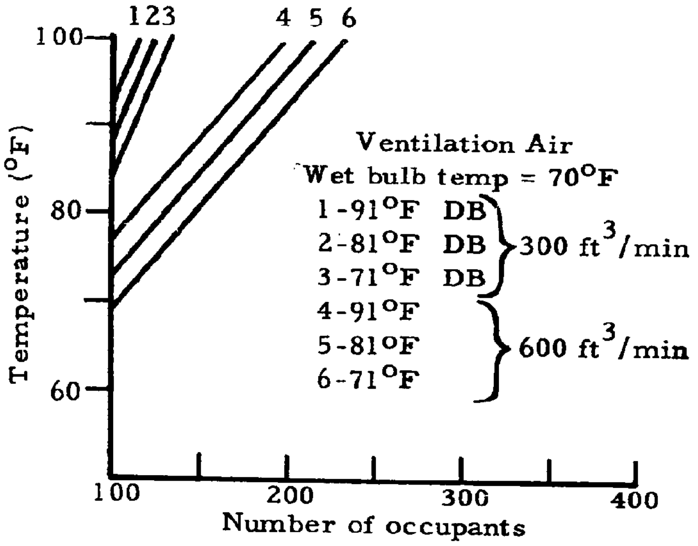

Figure 3 Shelter steady-state saturated temperature vs. loading.

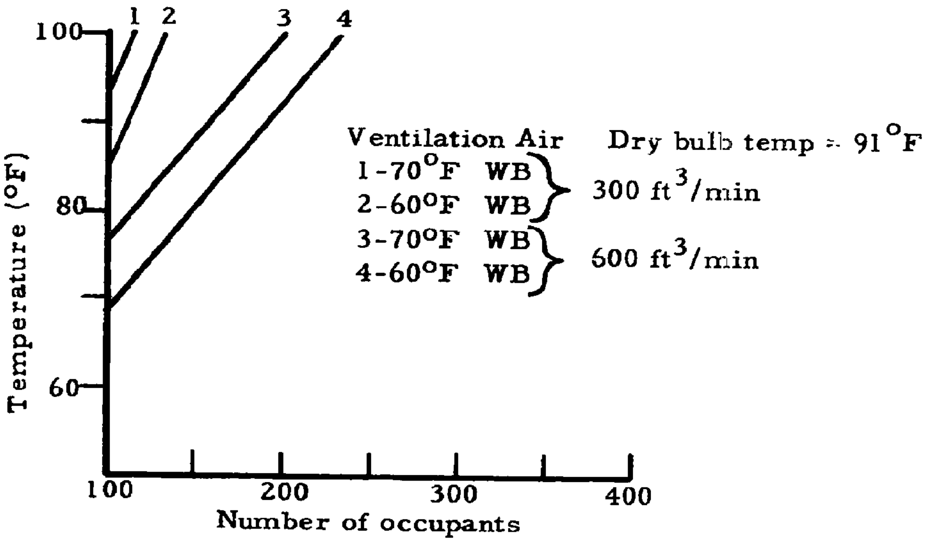

Figure 4 Shelter steady-state saturated temperature vs. loading.

APPENDIX D

DERIVATION OF EQUATIONS FOR GASEOUS CONCENTRATIONS IN VENTILATED SPACES

APPENDIX D

DERIVATION OF EQUATIONS FOR GASEOUS CONCENTRATIONS IN VENTILATED SPACES

The following derivation provides a set of equations for predicting the fraction of any gas in a shelter as a function of time given shelter volume, rate of ventilation by outside air, rate of release of the gas into shelter air from internal sources (e. g. , people), and fraction of the gas in outside air. Air inside the shelter is assumed to be homogeneous at any given time.

Definition of Terms:

G represents any gas which behaves in accordance with the general gas laws.

G_{V_i} = volume of G (cu. ft.) in shelter air at any given time, t_i

G_{V_o} = initial volume of G in shelter at $t_i = 0$

G_{V_s} = steady-state or "equilibrium" volume of gas in shelter at $t_i = t_s$

G_{f_i} = fraction of G in shelter air at any given time t_i

G_{f_o} = initial fraction of G in shelter at $t_i = 0$

G_{f_s} = steady-state or "equilibrium" fraction of gas in shelter at $t_i = t_s$

G_{f_e} = fraction of G in air external to the shelter, identical to fraction of G in ventilation air

ϕ = fraction of the steady-state value, G_{f_s}

V_s = total air volume of shelter, cu. ft.

$\dot{V}_R = \frac{dV_R}{dt}$ = rate of ventilation, cu. ft. per hr. (at shelter temperature and pressure)

$\dot{G}_{V_p} = \frac{dG_{V_p}}{dt}$ = rate of flow of G into shelter air from internal sources (people, etc.), cu. ft. per hr. (at shelter temperature and pressure)

t = elapsed time in hours

Let

$\frac{dG_{V_i}}{dt}$ = rate of change of volume of G in shelter air at t_i

$\frac{dG_{V_e}}{dt}$ = rate of flow of G into the shelter from external air via ventilation

$\frac{dG_{V_r}}{dt}$ = rate of removal of G from the shelter due to ventilation and/or leakage.

Derivation of Equations:

Since the rate of change of G in the shelter must be equal to the rate of flow of G into the shelter minus the rate of flow of G out of the shelter:

$$\frac{dG_{V_i}}{dt} = \frac{dG_{V_p}}{dt} + \frac{dG_{V_e}}{dt} - \frac{dG_{V_r}}{dt} \qquad \text{Equation 1}$$

Assume $\frac{dG_{V_p}}{dt} = \dot{G}_{V_p}$ is independent of other terms or constant and that

$\frac{dG_{V_e}}{dt} = \dot{V}_R G_{f_e}$ is also independent of other terms or constant.

Furthermore, the rate of removal of G from the shelter at any time t_i must be:

$$\frac{dG_{V_r}}{dt} = \dot{V}_R G_{f_i} = \frac{\dot{V}_R G_{V_i}}{V_s}$$

Then

$$\frac{dG_{V_i}}{dt} = \dot{G}_{V_p} + \dot{V}_R G_{f_e} - \frac{\dot{V}_R G_{V_i}}{V_s} \qquad \text{Equation 2}$$

This is a first order linear differential equation of the form

$$\frac{dy}{dx} + Py = Q$$

where

$y = G_{V_i}$

$x = t$

$Q = \dot{G}_{V_p} + \dot{V}_R G_{f_e}$

$P = \dot{V}_R / V_s$

Integrating, we obtain:

$$y = e^{-Px} \left(\frac{Q}{P} e^{Px} + C\right)$$

Solving for C, the constant of integration, we obtain:

$$C = ye^{Px} - \frac{Q}{P} e^{Px}$$

Since at $t = 0$, $G_{V_i} = G_{V_o}$

then at $x = 0$, $y = y_o$ (where $y_o = G_{V_o}$, the initial value of G_{V_i}).

Therefore,

$$C = y_o - \frac{Q}{P}$$

and

$$y = \frac{Q}{P} + \left(y_o - \frac{Q}{P}\right) e^{-Px}$$

Substituting original terms and the equivalences $G_{V_i} = G_{f_i} V_s$ and $G_{V_o} = G_{f_o} V_s$, we obtain:

$$G_{f_i} = \left(\frac{\dot{G}_{V_p}}{\dot{V}_R} + G_{f_e}\right) + \left[G_{f_o} - \left(\frac{\dot{G}_{V_p}}{\dot{V}_R} + G_{f_e}\right)\right] e^{-\frac{\dot{V}_R}{V_s} t} \qquad \text{Equation 3}$$

$G_{V_i} = G_{V_s}$ (steady-state) is obtained when $\dfrac{dG_{V_i}}{dt} = 0$

Then, from Equation 2 and setting $G_{V_i} = G_{V_s}$:

$$\dot{G}_{V_p} + \dot{V}_R G_{f_e} - \frac{\dot{V}_R}{V_s} G_{V_s} = 0 \qquad \text{Equation 4}$$

or

$$G_{V_s} = V_s \left(\frac{\dot{G}_{V_p}}{\dot{V}_R} + G_{f_e} \right) \qquad \text{Equation 5}$$

Since $G_{V_s} = G_{f_s} V_s$

$$G_{f_s} = \frac{\dot{G}_{V_p}}{\dot{V}_R} + G_{f_e} \qquad \text{Equation 6}$$

Equation 6 can also be obtained by inspection of Equation 3.

As $t \rightarrow \infty$, $e^{-\frac{\dot{V}_R}{V_s} t} \longrightarrow 0$ and $G_{f_i} \longrightarrow \left(\dfrac{\dot{G}_{V_p}}{\dot{V}_R} + G_{f_e} \right)$. Therefore,

the asymptote (which is also the steady-state value for G_{V_i}) is:

$$G_{f_i} = G_{f_s} = \frac{\dot{G}_{V_p}}{\dot{V}_R} + G_{f_e}$$

which is identical to Equation 6.

It is frequently convenient to determine the time required to reach a given C_f. Solving Equation 3 for t, we obtain:

$$t = \frac{V_s}{\dot{V}_R} \log_e \left\{ \frac{\left[G_{f_o} - \left(\frac{\dot{G}_{V_p}}{\dot{V}_R} + G_{f_e} \right) \right]}{\left[G_{f_i} - \left(\frac{\dot{G}_{V_p}}{\dot{V}_R} + G_{f_e} \right) \right]} \right\} \qquad \text{Equation 7}$$

The time, t_ρ, required to reach a given fraction ρ of the steady-state value, G_{f_s}, is found by substituting $\rho G_{f_s} = \rho \left[\frac{\dot{G}_{V_p}}{\dot{V}_R} + G_{f_e} \right]$ for G_{f_i}, which gives us:

$$t_\rho = \frac{V_s}{\dot{V}_R} \log_e \left\{ \left(\frac{1}{1-\rho}\right) \left[1 - \frac{\dot{V}_R G_{f_o}}{(\dot{G}_{V_p} + G_{f_e} \dot{V}_R)} \right] \right\} \qquad \text{Equation 8}$$

If there is no gas in the outside air ($G_{f_e} = 0$) and there is no gas in the shelter initially ($G_{f_o} = 0$), then the foregoing equations simplify as follows:

$$G_{f_i} = \frac{\dot{G}_{V_p}}{\dot{V}_R} \left(1 - e^{-\frac{\dot{V}_R}{V_s} t}\right) \qquad \text{Equation 9}$$

$$G_{f_s} = \frac{\dot{G}_{V_p}}{\dot{V}_R} \qquad \text{Equation 10}$$

$$t = \frac{V_s}{\dot{V}_R} \log_e \left(\frac{\dot{G}_{V_p}}{\dot{G}_{V_p} - \dot{V}_R G_{f_i}} \right) \qquad \text{Equation 11}$$

$$t_\rho = \frac{V_s}{\dot{V}_R} \log_e \left(\frac{1}{1-\rho} \right) \qquad \text{Equation 12}$$

For the special case where the ventilation has been shut down and no leakage exists ($\dot{V}_R = 0$), then (neglecting increase in pressure or volume of shelter):

$$\frac{dG_{V_i}}{dt} = \dot{G}_{V_p} \qquad \text{Equation 13}$$

and

$$\int dG_{V_i} = \dot{G}_{V_p} \int dt$$

$$G_{V_i} = \dot{G}_{V_p} t_i + C$$

at $t_i = 0, \; G_{V_i} = G_{V_o}$

Therefore

$$C = G_{V_o}$$

and

$$G_{V_i} = \dot{G}_{V_p} t_i + G_{V_o}$$

Since $G_{V_i} = G_{f_i} V_s$, and $G_{V_o} = G_{f_o} V_s$

then:

$$G_{f_i} = \frac{\dot{G}_{V_p}}{V_s} t_i + G_{f_o} \qquad \text{Equation 14}$$

and in terms of t_i:

$$t_i = \frac{V_s}{\dot{G}_{V_p}} (G_{f_i} - G_{f_o}) \qquad \text{Equation 15}$$

APPENDIX E

SOME DRUGS POTENTIALLY USEFUL FOR ADMINISTRATION TO OCCUPANTS OF FALLOUT SHELTERS

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SOME DRUGS POTENTIALLY USEFUL FOR ADMINISTRATION TO OCCUPANTS OF FALLOUT SHELTERS

Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
TRANQUILIZERS				
1. ELAVIL (Amytriptyline HCl) [2]***	"Particularly useful in those with predominant symptoms of anxiety and tension... Prompt relief of anxiety and insomnia associated with depression."	Oral	Contraindicated in persons with glaucoma (8, p. 369)****	"Side effects are usually mild."
2. MELLERIL (Thiordazine) [2]	"Almost a pure psychosedative. Controls "disturbed overactive behavior, marked anxiety, and agitation." (4, p. 25)	Oral	N.M. **	"Side effects are minimal and infrequent consisting in drowsiness, dryness of mouth, sweating, breast enlargement." (3, p. 21)
3. TRANPOISE LENETRAN (Mephenoxalone) [2]	Treatment of anxiety, muscle tension, nervousness, irritability, and emotional strain.	Oral (Tablets)	No significant clinical toxicity noted and "no known contraindications." (8, pp. 1094, 1872)	May rarely produce dizziness, nausea and/or drowsiness.
4. Amphenidone & Emycamate [2]	Treatment of anxiety and tension states.	Oral	Toxic effects low (4, p. 127)	May produce drowsiness.

Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
SEDATIVES				
5. Phenobarbital* [3]	Treatment for insomnia, anxiety, hyperexcitability, hysteria, cardiac and gastric neuroses.	Oral (Capsules)	[Habit forming] (6, 11. 965f)	May cause "hangover." Hypersensitive persons may develop restlessness, excitement, skin rash, fever.
6. Chloral Hydrate [3]	For inducing sleep "A safe drug" for children. (4, p. 52)	Oral (Capsules)	Harmful to people with liver disease. (8, p. 1872)	Infrequently, gastric irritation and vomiting. (8, p. 1872)
7. LORYL Chloral Hydrate + Phenyltoloxamine [3]	For inducing sleep; may be used during pregnancy.	Oral (Capsules)	Contraindicated for people with hepatic, renal, or serious cardiac disease. (8, p. 1872)	May cause gastric disturbances on empty stomach.
8. DORIDEN (Glutethimide) [2]	For sedation and insomnia.	Oral (Capsules)	Rare toxicity.	"Side effects are minimal" with occasional skin rash (8, p. 368), and possible nausea (4, p. 52).
9. PERICLOR (Perichloral) [1]	Sedative and hypnotic	Oral	N. M.	No side effects - safe. (9, pp. 416f)
10. LEVANIL or NOSTYN (Ectyluria) [1]	Sedative; no effect on blood pressure, pulse, respiration, acidity, muscle relaxation, or pain; mild tension reliever.	Oral	No toxicity even with large doses. (9, pp. 411f)	N. M.
11. Acetylbromodiethylacetyl Carbamide [1]	For daytime sedation.	Oral	Toxicity rare. (4, p. 49)	N. M.

Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
12. COMPAZINE DIMALEATE (Prochlorperazine Maleate) [2]	Treatment of "mild emotional disturbances in which anxiety, tension and agitation predominate." Reduces agitation and excitment and diminishes aggression and destructiveness; has a "general calming effect." Also useful in cases of "marked apathy and lethargy." In addition, is a mild antiemetic; controls nausea and vomiting.	Oral	Not to be used by children under 20 lbs. (9, pp. 440f)	Infrequent side effects - sedation, dizziness, hypotension, tachycardia.
13. Peraldehyde [2]	Effective and safe sedative; alleviates the fear and exhaustion as well as the hysteria resulting from catastrophic experiences." Will produce sleep in the presence of pain.	Oral	Contraindicated for people with diseases of the liver or bronchopulmonary tract. (2, pp. 13/10ff)	It is slightly irritating to the throat and stomach.
ANTI-HYPERTENSIVES				
14. METATENSIN (Trichlormethiazide and reserpine) [3]	Relieves hypertension; reduces salt requirements; allays anxiety & tension; relieves headache and palpitation.	Parenteral	Reduces heart "severe mental depression may occur." (8, pp. 1478ff)	Initial drowsiness or lassitude; nasal stuffiness.
15. Nylidrin HCl [3]	"Peripheral vasodilator used to lower blood pressure."	Oral (Tablets)	Toxic potential not fully established. (7, p. 93)	N.M.

Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
ANOREXIANTS				
16. CYDRIL (1-phenyl 2-aminopropane succinate) ALSO Diethylpropion [2]	Appetite depressant, with "action equivalent to that of amphetamine, but with lower toxicity and little, if any, central nervous system stimulation."	Oral (Capsule)	Contraindicated in people with severe hypertension or acute states (8, p. 15).	N. M.
17. Benzphetamine d-Amphetamine d-Methamphetamine [3]	Appetite depressants, CNS stimulators, decrease fatigue.	Oral (Capsule)	Contraindicated in people with hypertension, hyperthyroidism, or coronary disease; also in hyperexcitable, agitated, or elderly people. (1, p. 389)	"Talkativeness, irritability tremors, confusion, delirium, hallucinations panic states, suicidal or homicidal tendencies. Fatigue and depression commonly follow the central stimulation."
STIMULANTS				
18. Ammonia [2]	Cardiac and respiratory stimulant (by reflex from upper respiratory tract).	Inhaled or Oral	Toxic effects rare. (4, p. 40) (This statement is contradicted elsewhere; see text)	(See text)
19. Deanol [2]	Mild stimulant for chronic fatigue, mild depression and psychogenic headaches.	Oral (Tablets)	Toxicity low, if any at all. (4, p. 41)	N. M.

	Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
20.	SPARTASE (Potassium and Magnesium aspartates) [2]	Management of all fatigue problems of any origin. ["Further investigation" needed (7, p. 110)]	Oral (Tablets)	No known contraindications. (8, p. 595)	Very occasionally, abdominal discomfort and diarrhea.
21.	NIALIFT (Pentylenetetrazol + vitamins) [2]	Symptomatic relief of non-specific fatigue or general debility; relieves confusion, memory loss, and depression of the aging.	Oral (Tablets)	Not to be used by epileptics. (8, pp. 1673f)	Unharmful, flushed face may occur.
22.	Pipradrol HCl [2]	To counteract depression.	Oral (Tablets)	Toxicity apparently low. (4, p. 43)	N. M.
23.	MARSILID (Iproniazid Phosphate) [2]	A nervous system stimulant.	Oral (Tablets)	"Apparently low toxicity not to be used by overactive, agitated people. (4, p. 130)	N. M.
COMMON COLD THERAPIES; DECONGESTANTS					
24.	RHINEX TY-MED (aspirin, salicylamide, phenyl propaneolamine HCl, chlorpheniramine, Maleate, aluminum and magnesium hydroxides) [3]	Symptomatic relief of congestion and postnasal drip associated with vasomator and allergic rhinitis & common cold.	Oral (Tablets)	Not to be used by people with hypertension, heart disease, diabetes, or thyroid disease. (8, pp. 1977f)	Drowsiness may occur.

Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
25. PHARAGESIC (benzocaine, chlorpheniramine maleate, phenylpropanolamine HCl, + acetaminophen) [3]	Relief of pharyngitis associated with allergies and common colds.	Oral (Tablets)	Not to be used by people with hypertension, heart disease, diabetes, or thyroid disease. (8, p. 1772)	Drowsiness may occur.
26. URI Liquid (phenylpropanolamine HCl, phenylephrine HCl, pyrilamine maleate, + chlorpheniramine maleate) [3]	Symptomatic relief of the common cold and nasal allergies.	Oral (Tablets)	Not to be used by people with hypertension, heart disease, diabetes, or thyroid disease. (8, p. 446)	N. M.
27. TRISTACOMP (chlorpheniramine maleate, phenyltoloxamine citrate, pyrilamine maleate, phenylephrine HCl, + phenylpropanolamine HCl) [3]	Relieves sinusitis, hay fever, allergies, sinus congestion, nasal stuffiness, postnasal drip, sneezing.	Oral (Tablets)	Not to be used by people with hypertension, heart disease, diabetes, or thyroid disease. (8, p. 1470)	May cause drowsiness.
28. ISOCLOR (chlorpheniramine maleate + d-isoephedrine HCl) [3]	Relieves hay fever, allergic conjunctivities, allergic rhinitis, coryza, sinusitis.	Oral (Tablets)	Not to be used by people with hypertension, heart disease, diabetes, or thyroid disease. (8, p. 1570)	May cause drowsiness.

	Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
COUGH MEDICATIONS					
29.	Carbetapentane Citrate [2]	Treatment of acute coughing with upper respiratory infections.	Oral (Tablets)	Low order toxicity. (4, p. 113)	N. M.
30.	Cocillana; Linctus; Wild Cherry [2]	Increase expectoration and decrease coughing.	Oral (Liquids)	Toxicity rare. (4, pp. 114f)	N. M.
ANTIBIOTICS					
31.	Pencillin* [3]	Kills most gram negative bacteria.	Oral (Tablets)	The only toxic symptom is allergy.(4, p. 11)	N. M.
32.	Chlortetracycline Hydrochloride [3]	"A broad spectrum antibiotic."	Oral (Tablets)	N. M. (4, p. 11)	May cause gastrointestinal disorders, and possibly diarrhea.
33.	Colistin [2]	For infantile diarrhea and wound infections.	Oral (Tablets)	Toxicity low. (4, p. 14)	N. M.
34.	Erythromycin [1]	"Effective against a wide variety of organisms... does not destroy colon bacillus... Also effective against many... large virus effects... especially valuable in staphyloccic infections because so many are now pencillin resistant."	Oral (Tablets)	"No evidence of toxic effects." (7, p. 48)	N. M.

Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
35. Oleandomycin [1]	"Wider spectrum" antibiotic than pencillin, but similar use.	Oral (Tablets)	Toxicity "rare".(4, p. 15)	N. M.
36. Oxytetracycline and Tetracycline [3]	"Broad spectrum" antibiotics.	Oral (Tablets)	N. M. (4, pp. 15f)	"May produce slight gastrointestinal disorders including diarrhea."
ANTIBACTERIAL				
37. Sulfadiazine* [4]	An anti-infectant (including pneumonia).	Oral (Tablets)	(Diverse reports; possible renal complications; see context for discussion).	Nausea, vomiting, dizziness, headache, confusion, depression. (15, pp. 125f).
DERMATOLOGIC				
38. DRONACTIN (Dexamethasone + Cyproheptadine HCl) [2]	Relief of dermatitis, exzema, neurotic excoriations, insect bites, and pruritis ani et vulvae.	Oral (Tablets)	N. M. (8, p. 1462)	Drowsiness.
LOCAL ANESTHETICS				
39. Isoamylhydrocupreine Dihydrochloride [2]	To relieve itching and sunburn "for a number of hours."	Surface Application (Liquid)	Low toxicity; sensitivity develops with repeated use. (2, p. 9/13)	N. M.

Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
40. SALIGENIN (Salicyl alcohol) [2]	Moderately strong local anesthetic; for surface or mucous membranes.	Local Application (Liquid Solution)	Toxicity low. (2, p. 9/13)	N. M.
SURFACE ANESTHETIC				
41. EUGENOL * (From oil of Cloves) [1]	Reduce pain resulting from tooth cavities.	Surface Application (Liquid)	"Overdosage may produce intestinal irritation." (7, p. 51)	N. M.
ANALGESICS				
42. Dextro-Propoxyphene [1]	General relief from pain.	Oral (Tablets)	Nonaddictive and low toxicity. (4, p. 47)	N. M.
43. Ethoheptazine Citrate [1]	Uses similar to aspirin.	Oral (Tablets)	N. M. (4, p. 48)	Minimal
44. Sodium Gensalate [2]	Similar to aspirin-analgesic, antirheumatic diaphoretic, antiseptic.	Oral (Tablets)	N. M. (4, p. 48)	Minimal
45. "Aspirin"* (acetylsalicilic acid) [3]	Analgesic and antipyretic.	Oral (Tablets)	[Recommend combining with Menadione (Vitamin K) (1, p. 406 and 499)]	Infrequent side effects - dizziness, anxiety, disorientation (15, p. 207) vomiting (1, p. 406). (See content)

Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
ANTIEMETICS				
46. Dimenhydrinate [1]	To overcome vertigo, dizziness, nausea.	Oral (Tablets)	Toxicity rare. (4, p. 85)	N. M.
47. Hydroxyzine HC1 [1]	Overcome motion sickness mild sedative; relief of headaches and muscle spasms.	Oral (Tablets)	"Toxicity rare." (4, p. 85)	N. M.
DIARRHEA TREATMENT				
48. KAOPECTATE * (Kaolin + Pectin) [1]	Relief of diarrhea.	Oral (Liquid)	N. M. (6, p. 639)	N. M.
LAXATIVES, ANTIFLATULENTS, AND ANTACIDS				
49. "Gentlax" (Guar Gum + Gennosides A&B) [2]	Relieves "functional constipation of all types."	Oral (Granules in water)	Contraindicated if there are symptoms of appendicitis. (8, p. 1463)	N. M.
50. Cascara Sagrada* [1]	"Mild laxative, acting mainly on the colon." (7, p. 26)	Oral (Liquid)	Toxicity is rare. " "Should be given at bedtime." (4, p. 91). Is a "preferable" preparation. (3, p. 234)	N. M.
51. COLACE; DOXINATE (Dioctyl Sodium Sulfosuccinate) [1]	Treatment of constipation.	Oral (Tablets)	Toxicity negligible. (9, pp. 543-9)	None

Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
52. METHOCEL: HYDROLOSE (Methylcellulose) [1]	Treatment of constipation.	Oral (Tablets)	Toxicity negligible. (9, pp. 549-50)	None
53. COSIL (Dimethylpolysiloxane + Magnesium Hydroxide) [2]	Treatment of constipation, especially with gas distress due, e. g., to age, anxiety and pregnancy.	Oral (Tablets)	Not for children under six years. Contraindicated in presence of abdominal pain, nausea, or vomiting. (8, p. 1460)	N. M.
54. MYLICON (Methylpolysiloxane) [1]	Relieves flatulence; especially for children.	Oral (Liquid)	(Should be taken with feeding.) (6, p. 639)	N. M.
55. CO-GEL (Anylolytic, protiolytic, & celulolytic enzymes + calcium carbonate + glycine)	Reduces gas, bloating, and gastric hyperacidity.	Oral	N. M. (8, p. 1460)	None
56. DIMACID GEL (Aluminum Hydroxide + Magnesium Hydroxide) [1]	Temporary relief of gastric hyperacidity.	Oral (Tablets)	N. M. (8, p. 1462)	N. M.
57. Sodium Bicarbonate* [3]	Relief of gastric hyperacidity; to alkalinize urine; antidiote to acide burns and poisoning. (7, p. 1256)	Oral (Powder or Tablets)	"Neutralizing action is very short-lived." (3, p. 224) Rebound effect is questionable. (See context for discussion.)	(See context)

Drug	Use	Mode of Introduction	Toxicity and Contraindications	Side Effects
58. Morphine Syrette [2]	Severe pain	Hypodermic	Cannot be given to asthmatics or those known to be allergic to morphine	Occasional nausea-respiratory depressant
59. Xylocaine Solution 2% with adrenalin 1:100,000 [2]	Topical and local anesthesia	Surface or Hypodermic	Severe hypertension, shock, heart block	Rarely dizziness, visual blurring, nausea, tremor
60. Intromycin Powder [1]	Control of common bacterial dysentaries	Oral	Only allergy to neomycin	None
61. Neomycin, 500 mg [1]	Control of common bacterial dysentaries	Oral (Tablets)	Only allergy	Occasional nausea
62. Sulfisoxazole (GANTRISIN) 500 mg [2]	Systemic or urinery injections due to streptococci, pneumococci, meningococci, H. influenza, K. pneumoniae, E. coli, B. proteus, B. pyocyaneus, A. aerogenes, B. peracolon	Oral (Tablets)	Allergy to sulfonamides	Usually none agranulocytosis, rash, fever, rarely renal obstruction
63. Tapazole	Reduce output of thyroid hormone	Oral (Tablets)	Drug sensitivity pregnant or lactating females	Enlargement of thyroid (reversible) skin rash
64. L-Triiodothyronine	Replaces thyroid hormone	Oral (Tablets)	Virtually non-toxic in proper dosage	Tachycardia, increase perspiration, tremor

FOOTNOTES TO TABLE

*Included in "Kit C" (See Reference 16, p. 18).

**No mention made in references used.

***The numbers in the brackets indicate the apparent level of safety with which the drugs can be used.

- [1] indicates the highest level of safety.
- [2] indicates a minimum degree of caution must be observed when administering the drug.
- [3] indicates that special caution needs to be observed.
- [4] indicates that a high degree of caution must be observed.

****The reference source for all the information regarding a drug will generally be located in the column headed "Toxicity and Contraindications."

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