Development of Space Cabin Tolerance Criteria To Trace Contaminants

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FROM the very inception of contemplated space flight, the Air Force has been vitally interested in research directed toward provision of a safe and habitable environment under the hostile conditions of space. The idea of safely sustaining man in a closed system for relatively long periods of time is not particularly new or unique. The Navy has been confronted with this problem for many years and has performed many successful missions requiring prolonged periods of submergence in the nuclear powered submarine. Approximately 40 years of research effort have been necessary to attain the underwater capabilities of today's submarine with regard to atmospheric control. Fortunately, the experience and data compiled on submarine habitability problems have direct application to space cabin function. One soon realizes, however, that although the problems are essentially alike in the two systems, environmental control problems in space craft will be greatly accentuated by both the external and internal environments of the vehicle.

Just as with the submarine, one can anticipate that short, manned space missions from one to 14 days will present no major difficulties with regard to trace concentrations of toxic contaminants. The major toxicity hazard would only be of an acute nature such as in the case of a leaky refrigeration system, an accidental spill of some noxious material, or complete failure of the air filtering system. In most cases, the astronauts could protect themselves with closed circuit breathing of oxygen and, if necessary, abort the mission. The cardinal problems, then, appear to be associated with missions of greater than two weeks, and also with those which could not be aborted easily into the friendly atmosphere of earth.

Here, one faces problems much greater than those presented by long term submergence in a submarine. Cabin materials which can give rise to noxious gases and vapors will probably not be too much different from those found in undersea craft. However, this is the end of the similarity. For long term space flights, payload limitations will require a closed ecological system for supplying a habitable environment. This adds chemical, algael, bacterial and perhaps fungal subsystems to the craft. Further, the cabin will be operating somewhere between 5 and 14 psi pressure which will enhance greatly the problems of "boil-off" from such common substances as paints, varnishes, adhesives, plastics, plasticizers, oils, solvent fluids and even metals, to mention just a few. Zero gravity conditions will also present problems with particulate matter such as dusts and aerosols which would have a tendency to clump into larger and larger aggregates and be harmful to both man and filtering systems.

Another, and probably the most important limitation is electrical and mechanical power. Submarine engineers really didn't solve many of their problems until the advent of nuclear power plants which allowed almost unlimited power for air conditioning systems, air filtering beds, air pollution instrumentation, and contaminant warning systems. Even with unlimited power, it was found that cabin air was still loaded with large amounts of hydrocarbons and aerosols. For instance, hydrocarbon contamination from cooking and smoking was so high that within two to three days activated carbon filtering systems were saturated, and only the higher boiling

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compounds were adsorbed, allowing for total displacement of the lower boiling compounds. Aerosol concentration was also elevated, and although there is little data on long term toxicity of these particles, they certainly did produce a deleterious effect on delicate instrumentation.

TABLE I. SUMMARY OF MORTALITY RATES IN THREE SPECIES OF ANIMALS

Compounds	Monkeys		Rats		Mice	
	Per Cent Deaths	Number Dead/Used	Per Cent Deaths	Number Dead/Used	Per Cent Deaths	Number Dead/Used
Control	0	0/19	4	2/50	19	38/200
Indole	20	2/10	10	5/50	22	22/100
Methyl mercaptan	40	4/10	10	5/50	43	43/100
Hydrogen sulfide	0	0/10	24	12/50	26	26/100
Mixture†	80	16/20	64	32/50	99	99/100
Carbon tetrachloride	10	1/10	0	0/50	0	0/100
Phenol	0	0/10	0	0/50	0	0/100

†Indole, skatole, methyl mercaptan and hydrogen sulfide.

Naval scientists, then, have made enormous strides toward the development of atmospheric controls for the ideal or true submarine. However, they are still finding and solving problem areas. How then can we approach the solution to environmental control with the added restrictions placed upon the situation by factors mentioned above?

Space cabin engineers have been requesting information regarding criteria or guidelines with which to work in solving these problems. Of course, the ideal system would remove completely all contaminants, but practical considerations show this may not be feasible. 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.[4] Unfortunately, the Threshold Limit Value is only designed to be used for eight-hour exposures for a five-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.

In order to test the validity of extrapolations, a number of experiments were designed. Physiological changes in rats, mice and monkeys were studied during 90-day continuous exposure to controlled atmospheres of toxic vapors and gases. Concentrations of test chemicals were those recognized as Industrial Theshold Limit Values and included: (a) carbon tetrachloride (25 ppm); (b) phenol (5 ppm); (c) indole (10 ppm); (d) skatole (3 ppm); (e) hydrogen sulfide (20 ppm); (f) methyl mecaptan (50 ppm), and (g) a mixture of *c*, *d*, *e* and *f*. Clinical laboratory and terminal stress tests (swimming time)[5] were followed by necropsy with gross and microscopic pathology.

Compounds c through *f* were selected because they are known compounds derived from human excreta. Carbon tetrachloride was tested because it represents a compound whose TLV has been steadily decreasing as more toxicological data have been gathered. Phenol represents a compound whose TLV has remained firm for many years. For the purpose of this discussion, only part of the pertinent results will be reported. Detailed results can be found in two papers by Sandage.[2,3]

Table I presents a summary of the mortality rates observed from each of the contaminants.

Methyl mercaptan, indole and the mixture of compounds caused the greatest mortality in monkeys. Hydrogen sulfide caused no deaths in monkeys, but did cause a significant mortality in rats and mice, denoting a possible species sensitivity. Carbon tetrachloride produced no significant number of deaths; however, all three species showed a loss in weight and at necropsy all showed liver damage which had progressed to a stage where the term 'chirrhosis' was justified. Although the mortality was low in rats and mice exposed to indole, a phenomenon known as Heinz Body formation was observed from the hematological study of the red blood cells. This blood dyscrasia, together with a hemolytic response, was also observed in the animals from the room containing the mixture of compounds.

In another 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. This could be due to a synergistic action of the compounds.

These experiments have proven a number of points. It is fairly obvious that Industrial TLV-s cannot be used for long term exposure criteria. Further, there are physiological actions and interactions between different contaminants which may be categorized as additive, synergistic or possibly even antagonistic, which preclude any extrapolation. Fairchild, Murphy and Stokinger have demonstrated antagonism between pollutants by showing that hydrogen sulfide can protect against the toxicity of ozone and nitrogen tetroxide.[1] Other possibilities also include atmospheric interactions of trace contaminants which could produce entirely new species. In these experiments, we monitored only the concentration of the compounds being used and we did not attempt to identify possible reaction products.

Another interesting finding was the phenomenon of tolerance. The four monkeys which survived the mixture were in apparent good health and showed no decrement of performance in their stress tests. On necropsy, there was no pathology, while their cage mates which had succumbed to the exposure showed definite microscopic pathology. However, not all died from a common cause, implying that perhaps the contaminants were stress agents. Death was due to a number of secondary causes such as hemopoietic disturbances, infection, lesions of parenchymatous organs, and neurological damage.

Since our data show that Industrial Threshold Limit Values cannot be extrapolated to provide criteria for long term exposure, one much search for new methods of obtaining such criteria. It is not enough to consider only untoward physiological and toxicological effects but it is imperative that functional ability be also safeguarded. This necessitates experimentation utilizing trained animals and recording performance during exposure to noxious materials for long, continuous periods of time. Some preliminary studies have already been performed under a joint project with the Aeromedical Laboratory at Holloman AFB. Trained chimps and monkeys were exposed to acutely toxic concentrations of noxious materials and decrement of performance was measured. This work can be extended to a similar study for low level continuous long term exposures. Perhaps adequate data can be gathered during three-month exposure times which will allow us to extrapolate criteria for up to one year. If not, longer exposure times may be necessary.

As a parallel approach which also may save time, early efforts will be directed toward the evaluation of materials which are scheduled to be used in research prototype capsules. Small-scale mock-up tests will be run utilizing proportional quantities of raw materials representative of the finished products. Animals and sensing devices will be placed in this environment so that toxicological and qualitative and quantitative chemical data will be obtained. Environmental profiles identical with those anticipated in space will be duplicated, with the exception of zero gravity. In addition, toxicological screening of new useful materials will be accomplished as these become available.

One of the most difficult problems which we can forecast in this research effort involves the lack of specific analytical methodology and instrumentation for the qualitative and quantitative chemical determination of these contaminants. Many of our questions will not be answered until better analytical techniques become available for monitoring exposure chamber concentrations of complicated mixtures. As new and specific capsule instrumentation is developed, it should be used to obtain first-hand information from the early stage, non-manned long term flights. This will provide concrete evidence of contaminants and their levels under actual flight conditions and will dictate the course of future experimental protocol.

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