Letters

Decontamination and Sterilization of Lunar and Planetary Spacecraft

In 1959 and 1960, official policy letters were formulated by the administrator and the deputy administrator of the National Aeronautics and Space Administration declaring that it was essential that no act be performed that would irretrievably preclude the use of a celestial body as a base for scientific investigations, including the search for extraterrestrial life and the collection of information which would lead to an understanding of the origin of life. In accord with this philosophy, requirements were set forth for preventing the biological contamination of specific celestial bodies. These policy documents made it mandatory that effective procedures be established, well in advance of proposed flights, for the decontamination and sterilization of space vehicles destined for flights to the moon and planets, to a degree consistent with the established requirements for preventing the contamination of each body.

On the basis of these guidelines, procedures were established and approved for the Ranger spacecraft, the first U.S. spacecraft to be launched to the moon. The procedures were selected after a review and study of the various available decontamination techniques. Actions preceding the approval of these techniques included a thorough literature survey, a review of the procedures used by the food preservation and canning industry, and a study of the procedures and standards established by modern surgical facilities.

The procedures adopted for the Ranger spacecraft required that the majority of components and assemblies be sealed and heated to 125°C for 24 hours prior to their incorporation into the spacecraft. This was deemed sufficient to produce sterile units. For certain elements not amenable to heat sterilization, other techniques were applied to reduce contamination. Among these were aseptic assembly, the use of special sterilants, and environmental control designed to minimize the numbers of microorganisms.

After final assembly and checkout, just after installation aboard the launch vehicles, the spacecraft was soaked in an atmosphere of sterilizing gas of 12 percent ethylene oxide and 88 percent freon (by weight) for a minimum of 11 hours to produce the final surface sterilization. During and after the ethylene oxide soak, the spacecraft remained in its sealed, gas-tight cavity within the nose fairing of the launch vehicle and separated by a diaphram from the other parts of the launch vehicle. This sealed container was not opened until fairings were jettisoned during the launch ascent, after departure from the earth's atmosphere.

Although the procedures outlined represent the general approaches taken to decontaminate Ranger spacecraft, it should be pointed out that prior to the launching of each lunar impacting spacecraft (only Ranger IV actually did impact the moon), waivers were approved for certain elements which were not compatible with internal sterilization procedures. Typical examples of these, taken from the actual Ranger IV list, are: six wafer-type batteries, five germanium transistors, three acceleration switches, retro-motor main propellent, igniter, and squib. The degree of internal contamination of these items is unknown, but it is relatively certain that the resultant contamination levels of the Ranger spacecraft were low.

The decontamination procedures specified for the Ranger were purposely made more stringent than was believed necessary to prevent contamination of the moon. A fundamental objective of the procedures prescribed for Ranger was the development of the technology of decontaminating spacecraft for the benefit of later planetary-landing spacecraft.

Many significant factors evolved during the experience with the Ranger program. Some of the conclusions drawn from this experience have led to a better understanding of the nature of the problem and, in many cases, to solutions. In other cases, the difficulty of the problem was clearly established and indications were obtained that alternate solutions must be sought. A summary of some of the successful results from this experience is as follows:

1) Many parts and components used in spacecraft are amenable to heat and other effective sterilization treatments.

2) Many sterilization techniques and equipment for decontamination were developed, proved, and can be applied to the future planetary program directly.

3) Personnel gained considerable insight into the problems and methods associated with sterilization and decontamination, and their training in the complexities of the matter is now available for application to the planetary program.

Some of the discouraging results include the realization that the problem of achieving technological reliability after subjecting certain materials and components to the sterilization treatment is far more formidable than had been anticipated. For example, it was found that television tubes, solid propellant for rocket motors, and certain crystals in timers, instruments, and radios are more vulnerable to heat than had been suspected. It became very clear during the Ranger experience that treating an entire spacecraft composed of electronics and many different materials, parts, and subassemblies is a significantly different task from the problem of sterilizing a surgeon's instruments or canned foods. All of this experience results in a far greater respect for the sterilization of spacecraft than had earlier been the case.

The decontamination and sterilization requirements applied to the Ranger were put into effect after the Ranger had already reached an advanced state of development. It is now clearly understood, however, that it is essential to consider the rigors of sterilization throughout all phases of design and that considerable emphasis must be placed early in the design effort on the selection of parts and components which are compatible with the requirements of decontamination.

The sterilization procedures employed on the Ranger, particularly the heat cycle, was suspected of degrading

performance, and perhaps contributing directly to Ranger failures.

Since experience with the earlier Rangers, as outlined previously, indicated that a reliable sterilized spacecraft could not be built and launched based on the present state-of-the-art, NASA procedures for future lunar spacecraft have been changed. In spite of the low probability for contamination (as calculated by CETEX and Sagan), NASA's current procedures require that the microbial load of the spacecraft be reduced to a minimum by assembly and check-out in bacteriological clean rooms and also be treated with surface sterilants after final assembly and check-out. In this way, contamination, if any, will be localized to very small areas on the moon; there will be very low probability of microbial proliferation; and the moon will continue to offer a source of sub-surface samples from which to seek the desired clues as to the existence of life forms or the origin of life.

NASA has definite plans for the eventual landing of a capsule on the planet Mars. The procedures being established for Mars missions require that the capsule or spacecraft which might encounter Mars be sterilized, after complete assembly and check-out, using effective methods and sealed units which will not be opened. The earlier flying spacecraft will be aimed in such a manner that the probability of encountering the planet is less than 10^{-4}. Laboratory facilities are being prepared which will provide, with a high degree of assurance, the necessary sterilization. Assay techniques and survey methods for determining that the sterilization techniques have been applied properly and effectively, with a high degree of certainty, are being developed.

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Mutations and Aging

Aging processes have only recently attracted the attention of large numbers of biologists and, since meaningful data are still quite scarce, a multitude of theories can be advanced at no great risk. Occasionally, when one of these views appears to be proved untenable, it is brought back in full strength to bemuse the next generation of investigators. Curtis (*1*) has thus attempted to explain aging on the basis of somatic mutations. I would like to make three points based on that report: (i) There is essentially no evidence from irradiation experiments linking mutations causally with aging. (ii) Curtis's own data present a strong argument against the view that mutations cause aging. (iii) Organ reserve capacity would overcome loss of function due to mutations.

The main reasons advanced for suspecting a role for mutations arise from experiments utilizing irradiation—treatment known to cause both mutations and life shortening. However, it is extremely unlikely that the life-shortening effect is due to accelerated "normal" aging in that irradiation does not accelerate the onset of some specific age-related lesions (*2*), nor does it cause age-changes in collagen which are the most precise measurements of biologic age (*3*). It has also not been shown that the life shortening effect of irradiation is due to mutations. It is more likely to be caused by degenerative changes in the vascular system (*4*).

Curtis has shown that an increasing number of chromosomal aberrations occur in liver cells with increasing age. However, the animals do not die from, or with, liver failure, and there do not appear to be any important age-related changes in liver. This suggests that even though chromosomal aberrations occur in that organ, they have little functional significance and certainly can not be used to explain aging. Curtis's irradiated animals had a greatly increased number of chromosomal aberrations but they appeared to recover their vigor with time and get rid of altered cells as well. This would certainly argue against the role of chromosomal changes in aging, as noted by Curtis. His explanation of why these animals were not conspicuously aged could be used, with some modifications, to explain why "normal" chromosomal aberrations do not cause "normal" aging. The data showing that the strain of short-lived mice had more chromosomal changes are, at best, a correlation. Questions arise as to whether or not these mice really age faster, are more susceptible to specific diseases, or have some altered metabolism which affects liver cells.

Finally, the functional reserve of most organs is enormous—well over 100 percent in the case of liver. A fraction of most organs can handle the demands of the body, at least for short periods. When parts of many organs are damaged or lost, they can undergo regeneration, hyperplasia, or hypertrophy to meet body demands. This can occur even in old age and is particularly true in the case of liver. This knowledge tends to minimize the importance of not only mutations, but of cells in general in aging processes. Reasons for implicating connective tissue and the vascular system in aging have been summarized elsewhere (*5*).

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References

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I was interested in Kohn's comments on my recent paper even though I cannot agree with his objections to it. When we observed a single correlation between mutations and aging, we were not impressed; but after we had observed many such correlations quantitatively relating these two phenomena, we became convinced that there is a causal relation between them.

I submit that there is a wealth of information indicating that irradiated animals contract the same kinds of fatal illnesses as do normal animals, but that they do so sooner. The exceptions to this statement are minor and can easily be explained on other grounds. Since the only quantitative definition of aging which has any degree of acceptance states that aging is something which leads to death, it does not seem unreasonable to speak of radiation-accelerated aging. The objection raised by Kohn that radiation does not cause the same changes in collagen as does natural aging is quite minor, since, like greying of the hair, changes in collagen are almost certainly symptoms rather than causes of aging. Likewise, degenerative changes in the vascular system are symptoms of aging in the mammal. It should be pointed out that animals without a vascular system and without collagen also age.

Second, the liver was examined in these studies because it is the most convenient organ for this purpose. Other cell systems have been studied by other investigators. There is every reason to believe that deductions from these studies about the behavior of the cells of other organs will be valid, and it is