PLANETARY QUARANTINE IMPACTS ON PROBE DESIGN

Robert E. DeFrees
McDonnell-Douglas Astronautics Company

MR. DEFREES: The switch in order was especially advantageous because a lot of the things that I had to presume have already been explained by Alan Hoffman. The planetary quarantine program, as far as probes are concerned, progressed in the following fashion. We designed a probe under contract to Ames for entry into Saturn and Uranus. We were asked at the start of the design to hold off any provisions for planetary quarantine, specifically. Subsequently, after completing the basic contract, we were given a contract to determine the incremental effects of imposing planetary quarantine on the probe design that we had evolved. Quite frankly, the changes are small in scope and few in number. The business of planetary quarantine begins with a probability analysis. An analogy I would like to draw is: Walt Disney usually referred to his work as an examination of plausible improbabilities. The planetary quarantine business is the inverse of that, in that it is the examination of plausible probabilities. We are constantly setting standards and, as engineers, trying to live with them. The standards that are set here are on Figure 9-6, the probability of contamination and the probability of growth.

NASA Headquarters, in particular the planetary Quarantine Officer, sets these probabilities. They have been set for each of the planets and for some of the missions. In general, the probability of contamination value is the same for these planets, including all four of the giant planets. Pluto is still expected - as is Mercury - as being of little biological interest. In effect, the probability of growth is the more significant number because a probe is intended to go into the planet; and if it does, it has a chance of releasing organisms which can grow. Therefore, this number is divided up according to the number of missions, number of times you expect something to have the potential for contaminating that planet, and the transit survival potential. A flyby can contaminate it in one of two ways, (1) by direct entry or (2) by ejecta from part of the entire launch vehicle or spacecraft. Also,

Figure 9-6. Probability of Contamination and Growth

PLANET	PROBABILITIES CONTAMINATION, P(c)[1]	GROWTH, P(g)[2]
VENUS	1×10^{-3}	1×10^{-9} (ATM) NIL (SURFACE)
MARS	1×10^{-3}	1×10^{-6}
JOVIAN PLANETS	1×10^{-3}	1×10^{-6}
MISSIONS		
1975 VIKING (ORBITER AND LANDER)	7.2×10^{-5}	1×10^{-4}
PIONEER F AND G (EACH)	6.4×10^{-5}	1×10^{-4}
PIONEER G (SATURN)	1×10^{-4}	
OUTER PLANET MISSIONS (PER FLIGHT, PER PLANET)	7.1×10^{-5}	1×10^{-4}
SATURN AND URANUS[3] (SUAEP STUDY)	2.5×10^{-5}	1×10^{-6}

1) STAVRO AND GONZALEZ, PLANETARY QUARANTINE CONSIDERATIONS FOR OUTER PLANET MISSIONS.
2) PLANETARY QUARANTINE SPECIFICATION SHEETS, FOR NASA BY EXOTECH SYSTEMS, INC., ISSUED 12 1 73
3) STUDY OF THE EFFECTS OF PLANETARY QUARANTINE ON THE DESIGN OF AN OUTER PLANETS ATMOSPHERIC PROBE, MDC E1053, 29 MARCH 1974; INTENTIONALLY MORE CONSERVATIVE.

the other factor involved is time. In the case of Mars mission, there is a fifty-year time period of reasonable non-contamination involved. In general, for the outer planets, the time span is set at about twenty years and then one has to determine how many times American, U.S.S.R., or some other country is going to send something to the vicinity of the planets. From this you get the probability of contamination and, also, fairly arbitrarily, you establish the growth probability for each of those planets.

Now, Pioneer 11, originally Pioneer G, is interesting in that it will go past Jupiter, having the potential for contaminating it, and then go on to Saturn. The analyses for both of the flights, F&G, were performed some time ago (before launch) by Ames Research Center and then the Pioneer G was extended to the Saturn case (before Jupiter encounter). This was of interest to us on the Saturn-

Uranus probe study, because our Saturn-Uranus probe has a similar mode of operation: a flyby of one planet and a deposition of a probe into the second. In general, as you can see, the value for the probability of contamination at the second planet is given a little relief (lowered) from that of the first.

We have chosen a deliberately more severe requirement than have some other authors simply because the number of flights is not well established yet, over this twenty-year time period, and we felt it was appropriate to establish the more stringent requirement on our own studies.

The classic requirement for sterilization has been established in the Viking program and you will hear a good deal more discussion about that in a few minutes from Bob Howell. But, classically, it is a matter of saying that if you heat something at a temperature above a hundred degrees Centigrade, you will enhance the probability of decreasing the microbe load; and, in fact, plotted on a semi-log paper it is a straight line. In effect, if you hold a certain temperature for a period of time, you will decrease the number of microbes on that object from 100% to 10% to one percent to one tenth of one percent, and so forth. This is usually referred to as decimal reduction time (D - value) and it is also sometimes referred to as decades or logs. (See Figure 9-7)

The standard D-value that is used is that for bacillus subtilus variant niger, as supplied by the U.S. Public Health Service. The temperature that was initially set for Viking was 125°C. This was later changed to 113°C. On the outer planet probes, we now understand it may go back to 125° because there tends to be more probe equipment available that has been tested at the higher temperatures. This has to be a consideration in the costing. It conceivably could be a requirement for more testing of a probe, even though there is a tremendous fund of knowledge already available in the Viking program.

In addition to that, the life of a planetary quarantine engineer is a little bit complicated by the discovery that not all microbes are willing to die at the same rate that bacillus subtilus does. This leads to a problem wherein some will follow a more-or-less

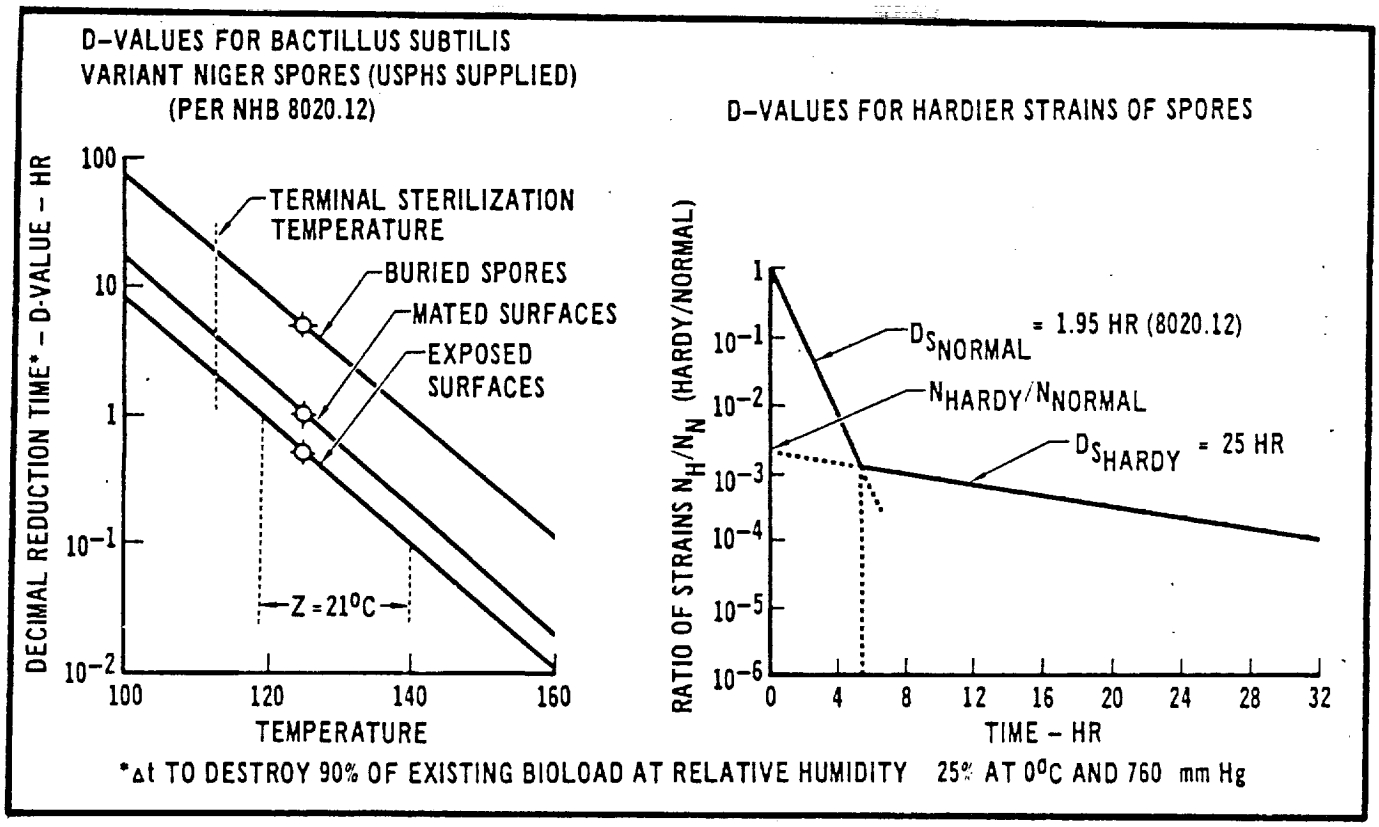

Figure 9-7. Decimal Reduction Times

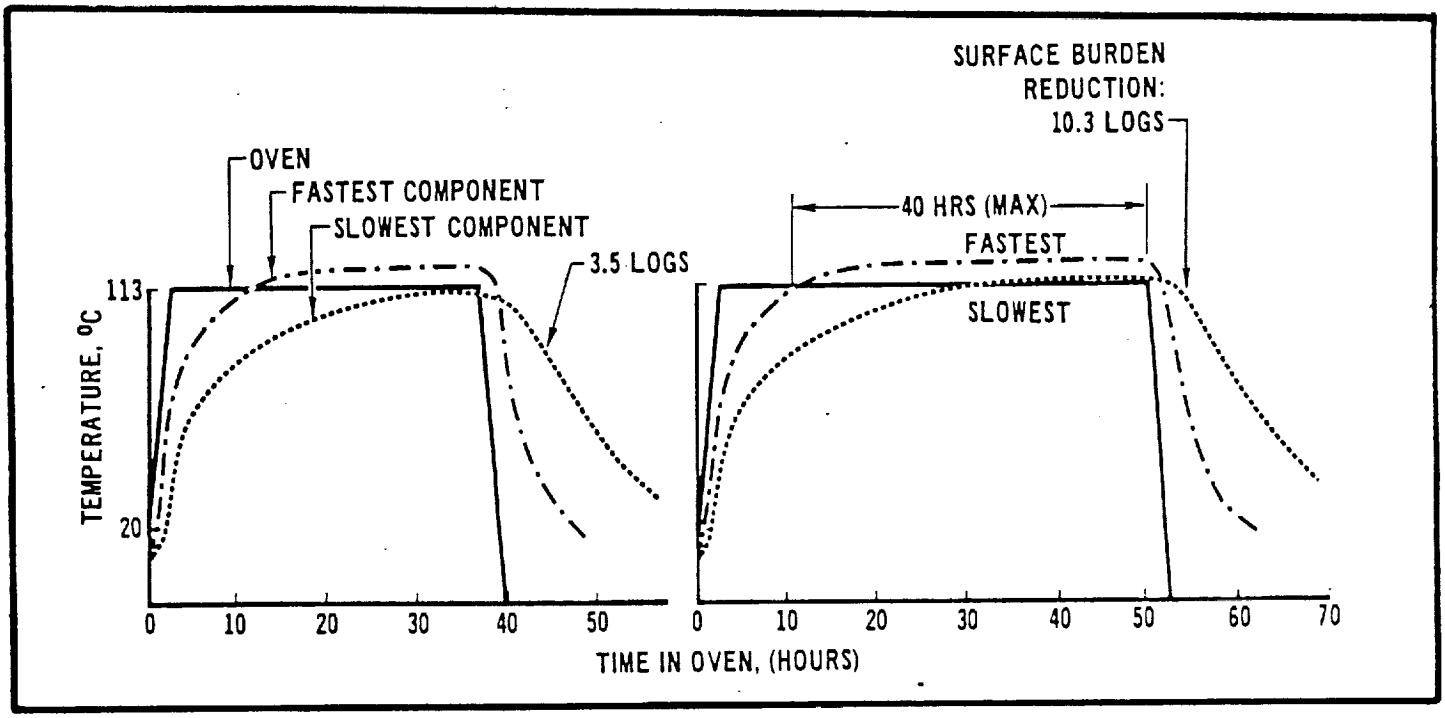

Figure 9-8. Estimated Thermal Response Characteristics

normal decay rate, whereas, others have a very prolonged decay rate. An example is on Figure 9-7. It is not the only example, others have even shallower slopes. In this example, the times were chosen fairly arbitrarily and the ratio between the two types was shown. The net effect of this is that instead of periods of the order of forty or fifty hours of terminal sterilization, we might be forced to go to longer periods to guarantee that these hardy ones are killed off. The obvious requirement on the part of cleanliness engineers and their staffs is to find out whether that type of microbe is prevalent in clean rooms. It is analogous to the problem in surgical situations after World War II where they suddenly found tremendous quantities of staphylococcus showing up in operating rooms: a rather horrible concept that they had to lick rather quickly due to excessive dependence on antibiotics and relaxed cleanliness procedures.

The requirements for heat sterilization are shown on Figure 9-8 as they affect the equipment designer, the man who provides the oven, and also the design engineer, who is designing the probe. If you make a probe to go through space where there is very little sunlight, it is going to get cold. So, in general, we have provided a rather effective barrier to reduce the rate of loss of heat in space. The net effect of this as far as an oven is concerned is that you can turn the oven on and run it up to 113° Celsius in a matter of hours. Some of the components will heat up rather rapidly. This is shown as exceeding the oven line. Obviously, it wouldn't exceed the oven unless it is something like the radio isotope heater unit inside which would go beyond the oven temperature and will get to that temperature rather quickly.

Other components in the case of the probe, the battery is a good example, are buried inside of multiple-layer insulation and inside some foam insulation on one side or some powder insulation on the other. It may also have deliberately poor heat

conductive paths to the framework. The net effect is that some component is going to take a long while to get up to this temperature. But, if you determine this fact by analysis and confirm it later by tests, that this particular component only go to 113°C at the time you shut off the oven, you still can expect some reduction in microbes by the fact that it exceeded 100°, more particularly 110°, before the oven was turned off. But the problem as far as the probe designer is concerned is how long will it be subjected to that temperature and how frequently. Again, this goes back to the fact that most units are designed to the qualification test requirements and not to the true environment; thus, you have to determine the total length of time this temperature exposure is held if you wish to calculate microbe kill capability.

The classic equation was inferred by Al Hoffman when he showed that the probability of contamination is a function of the number that is present at the start of the terminal sterilization period, divided by the probabilities for survival, for release, and for growth. This determines the number of microbes that will remain when the probe enters the planet.

Now in a forty-hour period we can decrease the number of microbes from, say, three and a half, typically, to ten logs. This is in effect even if you start with a million microbes onboard, you cut them to 10^5, 10^4, 10^3, 10^2, 10^1, and even below; to get a probability less than one that there are any living microbes.

A further reason for doing this is that we are looking for the flight acceptance test requirements, trying to set them for the components and for the probe itself. This branched system, Figure 9-9, shows components on the upper branch and the assembled probe with a presumed bioshield and test requirements requiring from fifty-four hours of exposure at 110° to 113°C. In a discussion yesterday with Bob Howell and Leo Daspit of Langley, the acceptance test temperature for components is usually the upper limit of 125°. What we are after is a determination of how many

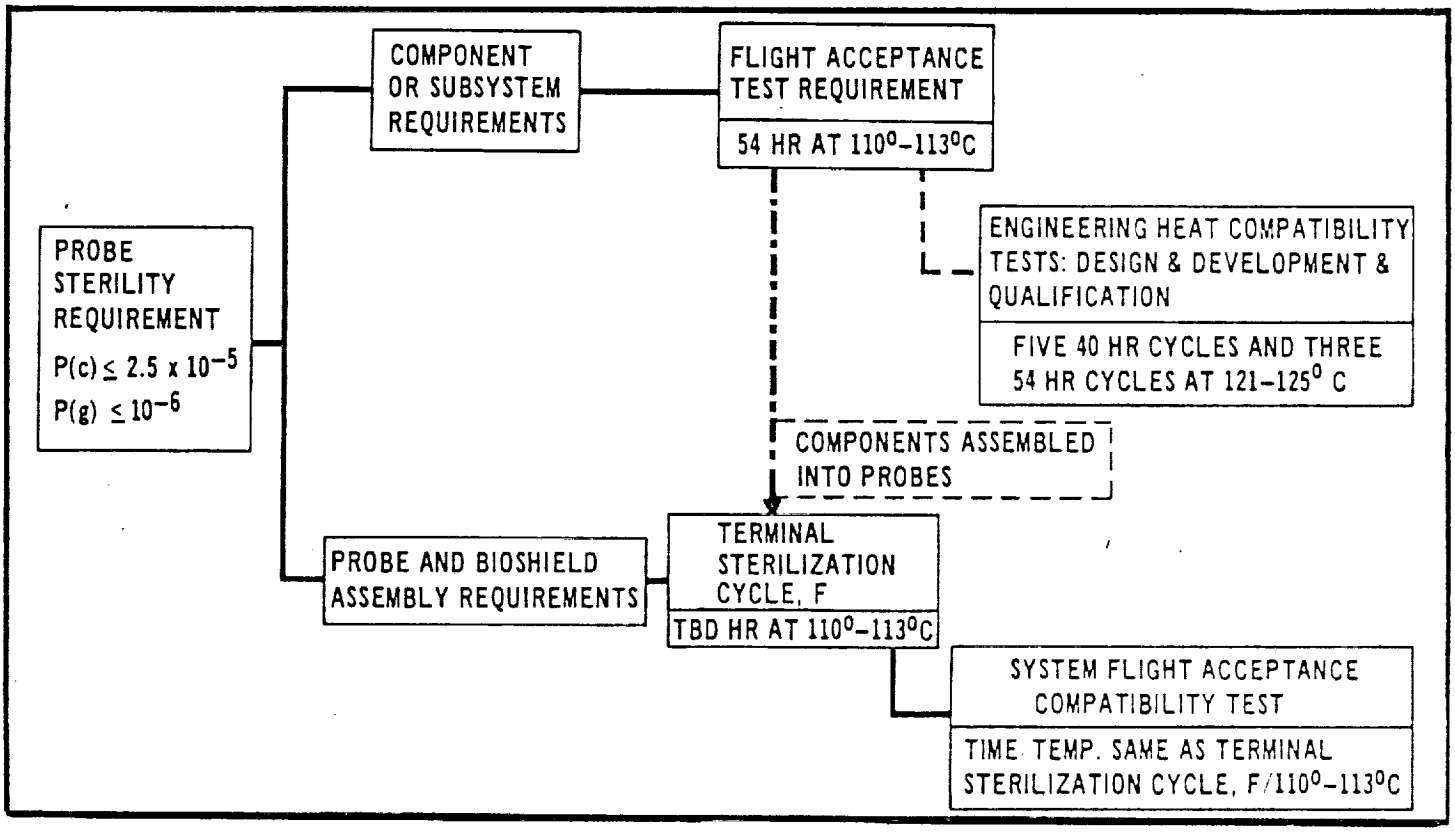

Figure 9-9. Sterilization Development Testing

times will the component be subjected to the worst case terminal sterilization cycle. This is of interest because one of the side benefits of going through this type of cycling is that you performed an excellent accelerated life test, because you have raised the component or probe to a high temperature repeatedly. That, of course, is deleterious to plastics, to rubbers, and to other materials whose physical properties are temperature dependent.

A total of eight cycles was negotiated in the Viking program. We initially adopted this in our probe studies. We feel the number is a negotiable item relative to a probe design. A lower number of cycles are preferred simply because the probe is orders of magnitude less complex than the Viking lander.

For internal equipment sterilizations, we have to determine a time. This is performed at 110° to 113° on Viking. It may go back up to 125°C on the probes, according to Larry Hall, and if so, that fact will have to be taken into account both in writing of procedures and in the costing of the probe.

The net result of all this is that there are changes that were required in probe configuration. The accompanying figure, Figure 9-10 lists them. The significant ones are that a bio-shield is necessary or some other form of prevention of contamination after the unit is assembled. There may be changes in the adapter. Inside the probe, the chief changes are in thermal control (a substitution of one plastic for another); the electrical

• STRUCTURAL/MECHANICAL	– BIOSHIELD (IN NEW ADAPTER) – FIELD JOINT (IN NEW ADAPTER) – DESIGN FOR 1 ATM DIFFERENTIAL PRESSURE – SEPARATION OF BIOSHIELD COVER AT EARTH – HONEYCOMB THAT IS SELF-VENTING IN CHANGING PRESSURES
• THERMAL CONTROL	– KAPTON SUBSTITUTED FOR MYLAR INSULATION BLANKET – SILVERIZE RATHER THAN GOLDIZE THE EXTERNAL MLI
• ELECTRONICS	– EQUIPMENT LIMITS ARE 160°F (OPERATING) – SOME WEIGHT AND COST PENALTIES
• ELECTRICAL	– MAIN BATTERY UP 33% IN WEIGHT – MAIN BATTERY UP 28% IN VOLUME – CELL CASES MUST USE HI-TEMP PLASTICS – NEW SEPARATORS REQUIRED – PLATE POROSITY CHANGES IN NiCd BATTERIES – SUBSTITUTION OF KAPTON OR TEFLON INSULATION ON WIRES – CLAMPS CUSHIONED BY TEFLON
• SPACECRAFT	– CABLE CUTTER MOVED INSIDE BIOSHIELD – CHANGES IN WEIGHT: SEQUENCING EQUIPMENT
• MASS PROPERTIES	– 16.5 LB INCREASE, MOSTLY IN BIOSHIELD AND POWER SUBSYSTEM

Figure 9-10. Design Impact Summary

system, (the batteries tend to get bigger, which means heavier); and very little change for the electronics. The chief reason for the increased battery weight is that silver peroxide will break down to silver oxide at the temperatures involved, so you can't count on that particular fifty-percent plateau of energy. Thus, the size of the plates just about double. There are some

other changes in the spacecraft, which are not too significant. The result is an increase in the case of a Pioneer-attached probe of about sixteen and a half pounds. In a Mariner installation this could be a little bit heavier because we have built the bio-shield into the adapter and taken advantage of that structural unit. So on Mariner the increment would be about eighteen and a half pounds.

There are some cost increments involved. The cost estimates that were made were based on contractor-furnished science instruments and, also, they pertain only to the direct costs of planetary quarantine related to the cost of the probe itself, and not to the overall program costs which would include spacecraft, launch and NASA mission operations costs. The analyses showed that most of the increase is in the design analysis and in the test phases. The basic probe cost is $40 million and the cost increment equals $13 million. This incremental increase is about twenty-one percent of direct contracted probe costs (about 5-6% of all costs).

In conclusion, there are really only two overriding conclusions, although I have included a list of some general and specific ones on Figure 9-11. The overriding ones are: (1) that a probe can be built in a sterile condition with no insurmountable problems to the design engineer, and (2) that the cost increments are predictable, which usually means that they are controllable. It is usually only unpredictable ones that are uncontrollable.

MR. TOMS: Our third speaker will be Bob Howell from Martin who has been working on the Viking Program and will show us just how the implementation problems have been solved for Viking.

- PLANETARY QUARANTINE REQUIREMENTS DO NOT AFFECT TIME NEEDED TO DEVELOP THE PROBE; BUT DO INCREASE MANUFACTURING STEPS AND HANDLING DIFFICULTY
- COSTS WILL INCREASE ABOUT 21% DUE TO MINIMIZING CONTAMINATION AT EVERY STAGE OF FABRICATION AND PRE-LAUNCH OPERATIONS
- DRY HEAT STERILIZATION WITHIN A BIOSHIELD IS COMPATIBLE WITH PLANETARY QUARANTINE OBJECTIVES AND WITH THE CURRENT STATE OF TECHNOLOGY. STUDIES OF OTHER TECHNIQUES ARE UNDERWAY FOR ATMOSPHERIC PROBE MANUFACTURE TO LOWER THE INCREMENTAL COSTS FURTHER.
- THE PROBE COULD BE ASSEMBLED IN A LARGE LAMINAR FLOW BENCH FACILITY AND, THEREBY, LIMIT MICROBE GROWTH. A CLASS 100 ROOM, IF AVAILABLE, FACILITATES ACCESS.
- RETAINED (AFT) PART OF BIOSHIELD CAN BE INTEGRATED INTO A NEW SPACECRAFT-TE364-4 ADAPTER; FORWARD COVER CAN BE RELEASED ALONG WITH THE JETTISONED TE364-4 STAGE AFTER IT INJECTS THE SPACECRAFT AND PROSE INTO A TRANSIT ORBIT.
- PROBE COLLAPSE IS NOT IMMINENT AT PRESSURES UP TO 30 ATM; ELECTRICAL EQUIPMENT IS DESIGNED FOR OPERATION IN A 160°F AMBIENT TEMPERATURE ENVIRONMENT. FAILURES WILL OCCUR PROGRESSIVELY AS THE FORWARD COMPARTMENT TEMPERATURE EXCEEDS THIS VALUE.

Figure 9-11. Summary of Conclusions