BIOLOGICAL LOSSES AND THE QUARANTINE POLICY FOR MARS

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Abstract. An international committee known as COSPAR has agreed that the probability of a single viable organism aboard any unmanned spacecraft intended for planetary landing should be kept less than 10^{-3}, in agreement with work by Sagan and Coleman. At present, the U.S.A. is committed to remain consistent with this standard. Using a model which includes both expected losses from failures to collect data and from contamination to analyze the quarantine problem, evidence is given which suggests that the current quarantine requirements may be too strict if their implementation forces a program delay. U.S. policy should be re-examined, keeping more fully in mind both the types and the relative sizes of the losses which might be encountered.

The SAGAN-COLEMAN (1966) analysis of the quarantine problem had a strong influence on the recommendations set forth by the international committee known as COSPAR. It is therefore important in reviewing current U.S. policy to review it in terms of the work and parameter evaluations which instigated this policy through the COSPAR agreements.

Specifically, in the face of possible mission delays, it becomes appropriate to reassess the value which Sagan and Coleman give to the parameter v, the probability of one viable organism being aboard a landing capsule at the time of its landing on Mars. Apparently no previous attempt has been made to develop a model involving v which also takes cognizance of the type of biological risks foreseeable and which formulates conceptions of these risks in relative numerical terms.

As a basic premise we assume that a politically or financially oriented decision will determine when the first Martian manned venture will be undertaken, and thus, effectively, when the unmanned program will cease. If the latter program is delayed this decision will truncate the last missions from the program. We will, however, consider only the biological ramifications of the unmanned lander missions and their associated losses since these losses must be deemed of higher order than any others. In particular, we are concerned that any life on Mars not be subverted or changed by the introduction of terrestrial biota prior to a full study of that life, or that a condition of non-life unknowingly be supplanted with or modified by organisms from Earth to be subsequently misinterpreted as aboriginal. It is in our interest, on the other hand, to attempt to learn the true nature of the Martian biological condition before the impending invasion of Mars by contaminant-bearing human beings. This information would add to the growing body of knowledge about the nature and the origin of our existence in a dramatic way. It could also offer clues to the possibility of back contamination from Mars resulting from manned flights which might actually threaten our existence.

Space Life Sciences **1** (1969) 514–519; © *D. Reidel Publishing Company, Dordrecht-Holland*

In actual practice our conclusions will relate to the minimal form of decontamination required to achieve suggested levels of spacecraft cleanliness. These procedures vary from simple gas decontamination of exterior and mating surfaces to prolonged heating of the entire spacecraft.

In the development of our model we make the strongly conservative assumption that any significant contamination caused by one mission will spread sufficiently rapidly to adversely affect the next mission. On mission k we are concerned about an information loss $f(k)$ due to some experimental failure and a contaminating loss $g(k)$. Our mission k loss table becomes as Table I, where we presuppose that once

TABLE I

	unbiased data	biased or no data
no significant contamination	0^1	$f(k)^2$
significant contamination	$g(k)^3$	$f(k)+g(k)^4$

Mars is contaminated all information gathered thereafter is biased. Indexing the mission outcomes by the integers in the upper right of the cells, we assume a constant probability for these outcomes over missions and write the probability of that respective outcome as p_i, with $i=1, 2, 3$, or 4, the cell index.

For a single mission we compute the values of the parameters p_i from the following considerations, where C = significant contamination; $\bar{C}$ = no significant contamination; D = unbiased data; $\bar{D}$ = biased or no data:

$$p_1=P(\bar{C}, D)=P(D|\bar{C})\cdot P(\bar{C})\doteq P(D)\cdot P(\bar{C})=P(D)\cdot(1-P(C)) \text{ when } P(C) \text{ is small}$$
$$\text{since } P(D)=P(D|C)\cdot P(C)+P(D|\bar{C})\cdot P(\bar{C})\doteq P(D|\bar{C}) \text{ when } P(C) \text{ is small.}$$
$$p_2=P(\bar{C}, \bar{D})\doteq(1-P(D))\cdot P(\bar{C})=(1-P(D))\cdot(1-P(C)).$$
$$p_3=P(C, D)=P(D|C)\cdot P(C).$$
$$p_4=P(C, \bar{D})=(1-P(D|C))\cdot P(C).$$

where, in particular,

$$P(C)=P(\text{viable organism aboard})\ P(\text{release}|\text{aboard})\ P(C|\text{release, aboard}),$$
$$P(\text{release}|\text{aboard})=P(\text{soft land})\cdot P(\text{release}|\text{soft land, aboard})$$
$$+P(\text{crash land})\cdot P(\text{release}|\text{crash, aboard}).$$
$$P(D)=P(D|\text{soft land})\cdot P(\text{soft land}) \text{ and}$$
$$P(D|C)=P(D|C, \text{soft land})\cdot P(\text{soft land})$$

To assign numerical values to these probabilities, we use the Sagan-Coleman values wherever theirs fit into the framework of our model. We employ their probability of significant contamination of Mars given the release of a single organism as $P(C|\text{release, aboard})=10^{-2}$, but under our conservative assumption that the spread of contamination occurs rapidly in the interval of time between missions if it occurs at all. Their release probability $P(\text{release}|\text{aboard})=1$ and their $P(\text{crash})=0.1$ (whence $P(\text{soft land})=0.9$) are also accepted. We take $P(D|\text{soft land})$ as 0.9 to indicate a high probability of successful data collection after a soft landing, and $P(D|C$, soft land$)=10^{-2}$, to reflect the belief that data collected on a contaminating mission will likely be biased. Letting $v=P$(viable organism aboard), we obtain $p_1=0.81(1-v\cdot 10^{-2})$, $p_2=0.19(1-v\cdot 10^{-2})$, $p_3=0.009\cdot v\cdot 10^{-2}$, $p_4=0.991\cdot v\cdot 10^{-2}$.

Sagan and Coleman give the estimate of 30 missions to be flown during the United States unmanned lander program. It is appropriate to consider only the United States program in this paper for the following reasons:

(1) We must presume a lack of information from Russia on its plans and accomplishments, as indicated in the article by MURRAY *et al.* (1967).

(2) Decisions made to delay or not delay missions are made at the national level and relate to an individual country's ability to achieve prescribed decontamination levels.

Finally we must choose loss functions. We take three different forms for the informational loss function:

$$f_1(k) = a\cdot k$$
$$f_2(k) = b$$
$$f_3(k) = c/k,$$

where a, b, and c are constants chosen such that $\sum_{k=1}^{N} f_j(k)=100$, $j=1$, 2, and 3. For $N=30$, $a=0.21505376$, $b=3.33333333$, and $c=25.0313696$. These $f(k)$ functions represent different possible forms of sequential data loss and are increasing, constant, and decreasing, or alternatively, their cumulatives are respectively concave, linear, and convex in k. We stress that the numerical values assigned the $f(k)$ functions are dimensionless, with the choice of $\sum_{k=1}^{N} f(k)=100$ arbitrary and indicating only its value relative to the contamination loss $g(k)$. It is solely the relative size of the two losses which is of importance, and without considering their comparative size meaningful losses could not be assigned.

For the present let us adopt a $g(k)$ function which is constant and of size 100 so that the loss for the act of contaminating Mars is independent of the mission with which it occurred.

Combining each of the possible losses by weighting each by the probability that it is incurred and then summing over all such losses gives the total risk. Table II gives values for the risk with $v=P$(viable organism aboard) ranging from 1 down to 10^{-6} and for delays of 0, 1, 3, and 6 missions, where a delay is the number of missions that the start of the program must be postponed to achieve satisfactory reliability of all spacecraft components under sterilization methods required to obtain probability level v. We see that for a fixed delay the risk values necessarily decrease with decreasing v. A complete and detailed account of the derivation of the form of the risk function may be found in STEG and CORNELL (1968).

For a v value of 1 under f_1, the risks tell us to unconditionally delay the lander program. The same result holds true for a one mission delay and $v=10^{-1}$, but no other table values exhibit this behavior. Essentially this behavior implies that the chance of contamination under this large v probability is too great compared to the value of the information which might be collected when f_1 describes that value.

TABLE II

A table of the risk values

v	f_1	f_2	f_3	f_1	f_2	f_3
		No Delay			One-Mission Delay	
1	59.819	56.444	50.689	58.577	57.694	69.459
10^{-1}	23.585	23.199	22.560	23.583	25.723	42.658
10^{-2}	19.464	19.425	19.360	19.620	22.107	39.618
10^{-3}	19.046	19.043	19.036	19.219	21.741	39.310
10^{-4}	19.005	19.004	19.004	19.179	21.704	39.279
10^{-5}	19.000	19.000	19.000	19.175	21.700	39.276
10^{-6}	19.000	19.000	19.000	19.174	21.700	39.275
		Three-Mission Delay			Six-Mission Delay	
1	56.581	60.233	83.809	54.827	64.138	92.901
10^{-1}	24.101	30.776	59.249	26.187	38.376	71.344
10^{-2}	20.455	27.472	56.483	23.014	35.521	68.944
10^{-3}	20.086	27.137	56.203	22.694	35.232	68.702
10^{-4}	20.049	27.104	56.175	22.661	35.203	68.677
10^{-5}	20.046	27.100	56.172	22.658	35.200	68.675
10^{-6}	20.045	27.100	56.172	22.658	35.200	68.675

If we compare the $v=10^{-1}$ value for the no-delay entry with the $v=10^{-2}$ three-mission delay value, we see that if through improvements in design we can achieve the lower level of spacecraft contamination while maintaining spacecraft reliability during the delay, but not before, we should take the delay with its consequent lower risk. Six 'no-delay' entries admit smaller 'delay' risks of the next lower order of v, but the 'no-delay' risks are smallest for $v \leqslant 10^{-3}$ under f_1, $v \leqslant 10^{-2}$ under f_2, and $v \leqslant 10^{-1}$ under f_3.

We have also found the risks using the constant loss $g(k)=1000$, and the variable loss, depending on the contaminating mission B, which varies from 200 down to 100 with increasing B, making it more costly for a more prolonged period of contamination prior to manned landings. In the second case the results were like those we have already cited, but in the first case the 'no-delay' risks were smallest only for v values of around one order of magnitude smaller. However, assuming 18 total lander missions on the basis of an average of three missions at each opportunity between 1973 and 1984, the risks indicated, under the three forms of f and of g previously considered, calling for a delay if the best achievable level is $v > 10^{-1}$, but none if $v \leqslant 10^{-2}$. Values between 10^{-2} and 10^{-1} gave varying results depending on the forms of the losses assumed.

Perhaps an easier way to conceptualize our results is found by asking what constant g value would lead to equal risks for not delaying at level $v=10^m$ and delaying one mission to obtain level $v^*=10^{m-1}$. These g values are given for each of the three f loss functions in Table III. Since rather large values of g are thought to be inconsistent with the importance of obtaining data on Mars before manned landings, that is with

TABLE III

Table of constant g losses yielding equal risks, where the v^* level requires a one-mission delay.

v	v^*	f_1	f_2	f_3
1	10^{-1}	−56.392	−32.591	65.338
10^{-1}	10^{-2}	−48.652	59.037	739.511
10^{-2}	10^{-3}	9.392	955.908	7473.121
10^{-3}	10^{-4}	587.914	9922.717	74808.436
10^{-4}	10^{-5}	6372.942	99590.616	748161.516
10^{-5}	10^{-6}	64223.320	996269.582	7481692.310

$\sum_{k=1}^{N} f(k) = 100$, this table indicates less risk for going forward with the lander program rather than delaying it, at least for a level $v \leqslant 10^{-4}$ under f_1, $v \leqslant 10^{-3}$ under f_2, and $v \leqslant 10^{-2}$ under f_3. If a two- or more-mission delay were required to attain v, these values can be made an order of magnitude larger or more.

All of these results are almost certainly conservative, since release of contaminating organisms, as well as their growth and spread to the point of representing significant planetary contamination, appears to be much less likely to occur than we have assumed. Under the Sagan-Coleman model using $N = 30$, the value of v is 1.86×10^{-3}. Using an increasing f_1 function we agree with this value, even in the face of a one mission delay. In the event of a three- or more-mission delay, however, a loss function like f_1 implies that the appropriate quarantine level is $v = 10^{-2}$. Under a constant f_2 or decreasing f_3 function a value of $v = 10^{-2}$ should suffice, in fact of $v = 10^{-1}$ in the latter case. A decreasing loss would seem most appropriate, since this corresponds to assigning larger losses to the failure to gain data early in the program than during later missions. Such a loss would require truncation of the last, more complex missions due to a lack of preliminary Martian data acquisition. Under this form of loss as given by f_3, the current international level of $v = 10^{-3}$ (HOROWITZ *et al.*, 1967), as well as the modified Sagan-Coleman value, assigns little weight to f relative to g. It would seem reasonable to weight these losses more equally. United States policy should be re-examined, it appears, with interest focused on the forms and relative sizes of data collection failure and contamination losses.

Acknowledgments

During the work on this paper support was received from training grant No. 5T1 GM-913 from the National Institute of General Medical Sciences and from grant No. NGR-10-004-029 from the National Aeronautics and Space Administration. Partial support for the Florida State University Computing Center, whose facilities were used extensively in this research was received from the National Science Foundation.

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