A HISTORIC CHOICE OF NUMBER: THE PLANETARY-PROTECTION REQUIREMENT FOR OCEAN WORLD EXPLORATION

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1. Introduction

Despite existing international requirements, planetary protection is a new field. Robotic exploration of our solar system's ocean worlds – especially certain icy moons of Jupiter and Saturn that contain vast interior oceans – is imminent in the coming decades. Around Earth's seafloor hydrothermal vents and in the thick ice of its cryosphere (our best analogues for these ocean worlds) life abounds. Our space flight instruments may encounter alien microbial life within two decades. Being on the cusp of breaching faraway habitable environments makes the risk of "forward contamination" real. How ready are we for this unique event? What are humanity's obligations?

2. The requirement

Today's governing requirement for avoiding the contamination of an alien habitable environment with terrestrial organisms rests on a single value: limiting to one in ten thousand the probability that a single viable Earth organism enters an alien liquid water reservoir. Enforceable under international treaty, this 10^{-4} forward-contamination requirement constrains NASA, JAXA, ESA, and private companies alike. It strongly drives mission concepts, implementation procedures, technologies, and costs. But where did this value come from, and what makes it correct?

The 10^{-4} requirement originated in the US at the time of Viking mission planning, and ultimately reflects 1940s capability for sterilizing hospital equipment rather than a de novo consideration of appropriate avoidance of contaminating other worlds. Furthermore, the requirement originally pertained to a series of missions but is now applied on a per-mission basis. The 10^{-4} value may still be appropriate for the missions we now contemplate for the coming decades. But it is also possible that the requirement is technically or socio-culturally outdated, or both. Without validation by an explicit conversation among a broad, international cross-section of stakeholders, mission plans could be expensively derailed once in development. If the requirement should be modified, starting the renovation of international consensus now would be timely.

3. Technological and conceptual developments

Many changes in the half-century since Viking justify revisiting the requirement's rationale: 1) vastly improved technology for assaying biomolecules and organisms; 2) expansion of the definition of self-replicating organisms; 3) recognition of a wide range of environments now known to be habitable; 4) deeper understanding of how multi-cellular communities behave differently from single organisms; 5) expansion of the astrobiology target list from just Mars to a plethora of ocean worlds; and 6) a sociological and international context for setting technology policy quite different from the mid-20th century. In this analysis, we describe how the current requirement arose: its source; how it was deemed appropriate for humanity's first contact with Mars; and its verifiability. We then summarize the current state of fields affecting our understanding of how life might take hold in ocean-world environments: biology of extremophiles; specific scenarios for the origin of life; self-replication of non-life macromolecules; rapid evolution in changing environments; and how microbial communities sustain habitability. All these factors affect how we might quantify the probability of survival and replication in a given alien environment.

4. Risk-assessment and ethical decision making

We then summarize contemporary methodology for developing technology policy surrounding low-probability, high-consequence risks, including ways to compensate limitations in human cognition about improbable events; and how perceptions of risk are normalized and acculturated. We consider the applicability of these methods to the risk of contaminating another world: an irreversible event that would affect every person and subsequent generations, albeit without personal physical hazard. We assess how decision responsibility might be distributed across diverse stakeholders. This leads directly to consideration of the ethical basis for developing workable guidelines and requirements for forward contamination. As with other techno-ethical decisions facing humanity today, we must weigh consequences, compare ethical values, and accept uncertainty based on the comparison. We contrast a meta-ethical discussion about absolute values with reliance on an arbitrary number for governing the necessity of preserving opportunities for scientific discovery or of avoiding interference with alien life. The ethical decision-making process in this special case is not comparable to other ethical discourses, and needs a different ethical model. Models based on utility, suffering or other features of sentience can not be applied. Value-based models face us with the problem of ascribing value to contamination of other worlds, something that is highly hypothetical and very hard to communicate. Risk-based models leave us with the same problem of assessing the value of non-contamination while at the same time complicating the communication process. As these problems can not be solved by an objective ethical decision making process, as we show in the discussion of ethical models, we propose a stakeholder discussion that should try and establish a meta-consensus including a broad range of societal agents. We describe how an enlightened understanding and evolving consensus could flow into governing policy. If the 10^{-4} requirement does not deserve automatic perpetuation, how could a reasoned conversation advance to achieve consensus?

Short Summary

Today’s governing requirement is a single value: limiting to 10-4 the probability of a viable Earth organism entering a liquid water reservoir.The paper gives a history of the requirement, it's source and describes scientific progress since then. It argues decision responsibility and the ethical basis for developing forward-contamination requirements.