QUANTITATIVE PLANETARY PROTECTION FOR SAMPLE RETURN FROM OCEAN WORLDS. M. Neveu1, A. D. Anbar1, J. A. Baross2, D. P. Glavin3, C. P. McKay4, C. C. Porco5, B. Sherwood6, Y. Takano7, and H. Yano8. 1Arizona State University, Tempe, AZ, USA, email: mneveu@asu.edu. 2University of Washington, Seattle, WA, USA. 3NASA GSFC, Greenbelt, MD, USA. 4NASA ARC, Moffett Field, CA, USA. 5CICLOPS, Space Science Institute, Boulder, CO, USA. 6Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA. 7JAMSTEC, Yokosuka, Japan. 8Institute of Space and Astronautical Science, JAXA, Sagamihara, Japan.

Introduction: Volcanism on ocean worlds [1-3] facilitates sample return missions, enabling flexible, sensitive, and specific analyses on Earth to study how far chemistry has evolved in these oceans. Such mission concepts have yet to quantitatively address planetary protection (PP) [4,5]. They fall in Cat. V-Restricted Earth Return [6], as icy world oceans contain chemical energy [7] and organics [8], are shielded from exogenic radiation by ice, and ocean material has likely not been naturally exchanged with Earth [9].

Quantifiable forward PP: The probability of introducing a single viable terrestrial microbe into a liquid-water environment must be <10^-4, an arbitrary but manageable value [10]. Current policy [9,11] requires that this probability be estimated from bioburden at launch (F1), organism survival to radiation during the cruise (F2) and near the target (F3), the probabilities of encountering the target (F4) and surviving landing/impact (F5), and subsurface transport mechanisms, timescales (F6), and survival (F7). The compliance and cost of specific designs could be assessed from measurements of molecular contaminants as robust proxies for microbial particulates [12] (F1); known microbial radiation tolerance [13] and planetary radiation budgets [14] (F2-F3); trajectory design (F4); projected impact velocities [15] (F5); ice transport timescales [16] (F6), and growth rates in ice [17] (F7).

As an alternative to the difficult quantification of these factors, a binary decision tree has been proposed [10]: Do current data indicate that the target body lacks (1) liquid water? (2) bioessential elements? (3) physical conditions in the range of extreme conditions for Earth life? (4) chemical energy? (5) complex organic nutrients? (6) Is the likelihood of contact with the habitable environment less than 10^-20? (7) Can treatment at 60°C for 5 h eliminate physiological groups that can propagate on the target body? If one or more of these decision points is evaluated negatively, the spacecraft must be heated above 110°C for 30 h for sterilization.

In contrast, current PP requirements are only qualitative: Current policy [9,11] prohibits destructive impact upon return, and in the absence of sample sterilization, requires fail-safe sealing of the sample container with a method to verify its operation before Earth return (B1); containment until transfer to a receiving facility (B2); “breaking the chain of contact” with the target (B3); no return to Earth of uncontained hardware that contacted the target (B4); reviews and approval of mission continuation prior to launch from Earth, leaving the target for return, and commitment to Earth reentry (B5); and life detection and biohazard testing prior to any sample distribution (B6).

These provisions and their means of evaluation could be quantified. A maximum leakage rate could be specified for particles above 10 nm (the size of prions, the smallest known pathogens [18]) (B1-B2), even for impact at terminal velocity, accidental or intended (bypassing the risk of failure of the reentry system, but requiring monitoring of sample integrity). For leak detection, He is commonly used [23], but its van-der-Waals radius of 0.14 nm could place too stringent a constraint for containment of pathogens over 70 times larger. To meet (B3)-(B4), uncontained parts in contact with ocean world material could be jettisoned prior to reentry with maximum allowed probabilities of Earth/Moon impact, or of microbial survival upon reentry. (B6) could require life detection prior to or after opening the sealed container [19].

Next steps to set policy: An ongoing European effort, Planetary Protection of Outer Solar System, is seeking to make recommendations for the definition, improvement, and implementation of PP policy [20], and could help quantify provisions (B1)-(B6).