CLEANROOM ROBOTICS – APPROPRIATE TECHNOLOGY FOR A SAMPLE RECEIVING FACILITY ?

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Introduction: NASA is currently pursuing a vigorous program that will collect samples from a variety of solar system environments. The Mars Exploration Program is expected to launch spacecraft that are designed to collect samples of martian soil, rocks, and atmosphere and return them to Earth, perhaps as early as 2016. International treaty obligations mandate that NASA conduct such a program in a manner that avoids cross-contamination of both Earth and Mars. Because of this requirement, Mars sample curation will require a high degree of biosafety, combined with extremely low levels of inorganic, organic, and biological contamination.

The Space Studies Board's 1997 report *Mars Sample Return: Issues and Recommendations* [1] examined many of the planetary protection issues concerning the back contamination of Earth and concluded that "no facility meeting all the requirements of sample receiving, containment, and research currently exists." Since that report a series of Mars Sample Handling Protocol workshops were held from which the *Draft Test Protocol for Detecting Possible Biohazards in Martian Samples Returned to Earth* [2] emerged. The purpose of this Protocol is to provide a methodology by which returned martian samples could be assessed for biological hazards and examined for evidence of life (extant or extinct), while safeguarding the samples from possible terrestrial contamination.

Sample Receiving Facility Requirements: The baseline requirements anticipated for a Sample Receiving Facility (SRF) to support a Mars Sample Return mission have been stated as follows: "In order to preserve the scientific value of returned martian samples under safe conditions and avoid false indication of life within the samples, the capability is required for handling and processing Mars samples while preventing their contamination by terrestrial materials and while maintaining strict biological control" [2]. The SRF will need to simultaneously provide a level of contamination control at least as high as NASA's Lunar Sample Facility, while at the same time maintaining the biological control characteristic of a high-level biosafety laboratory. In addition, the SRF must provide the capability and flexibility to execute sophisticated analyses to test the samples for evidence of life and biohazards [2].

Sample Receiving Facility Design: Three industry study teams were commissioned in 2003 to provide SRF concepts which could meet these containment and analysis recommendations. Each of the study teams concluded that the principles and techniques for the various levels of containment required in the SRF are mature and can provide the necessary levels of containment to ensure both high-level protection of Earth from potential biohazards in the returned Mars samples and protection of the samples from terrestrial contaminants. Although the methods cited for primary containment are mature, there are technology developments that must occur to realize the concepts presented by each of the study teams.

Maintaining containment and the pristine nature of the material will pose a unique challenge, as no system currently available meets all the requirements for sample handling. The final solution will likely encompass technology and standard practices from the nuclear, pharmaceutical, biohazard, and clean room industries. Handling and analyzing the material may need to be performed in containment modules that incorporate features of standard gloveboxes typically used in the nuclear industry, as well as Class III biological safety cabinets used in the biohazard industry. It may also necessitate that unique concepts, such as double wall modules, be developed. Additionally, there are many other aspects that will need to be considered during design including: development of specialized robotic handling and test equipment, sterilization and cleanliness of the modules and equipment, ultra-high purity gas delivery system, material compatibility of the equipment with martian sample material, integration of equipment in the modules, and the room environment for the modules.

Robotics: Each of the three SRF study teams called for the use of robotics within the containment vessels. Two of the teams specified the use of robots either in the entire spectrum of SRF functions, e.g., in preparing, analyzing, transferring, and housing sub-samples, or in a subset of these functions. One of the teams presented evidence of the capabilities of robots to provide very fine-scale manipulations, using a number of different 'end-effectors' to handle differently sized and shaped objects, as practiced in semiconductor manufacture and pharmaceutical manufacture.

Each of the robotics concepts would require some degree of technology development prior to use with martian samples. It will be essential to establish very early whether or not the use of robotics is to be pursued. If the answer is in the affirmative, these activities will need further definition.

We have recently completed a survey of robotics in a range of industrial and research applications. This survey demonstrates the extent to which inorganic, organic, and biological contamination can be controlled and minimized using current robotics technology in a curation environment. Such a technology assessment and development effort is key to the timely completion of a Sample Receiving Facility. In turn, this Facility is viewed as an absolute requirement for launch of a Mars Sample Return Mission.

Cleanroom Robots: ISO Class 1 (two 0.2 micron particles per cubic meter) certified robots are available in both vertically articulated and Selectively Compliant Articulated Robot Arm (SCARA) configurations (Figs. 1 and 2). The robots are factory certified for particulate generation only. Tribology dictates that interacting surfaces in relative motion produce particles. Accordingly, special coatings are used to ease cleaning of and minimize particulate generation by cleanroom robots. Certain coatings and lubricants may off-gas and produce molecular contamination. Where molecular contamination is an issue, internal vacuum systems are instead used to control particulate generation and achieve ISO Class 1 certification. Alternatively, an acceptable material may be used to sheath the robot, thereby containing particles generated through movement of the parts.

Apart from the robot itself, Class 1 certification in the semiconductor and pharmaceutical industries is achieved by using mini containment environments within which the robotics always operate below the manufacturing space. This configuration ensures that gravity assists in the removal of any particles generated from the area of concern. Air handling, including filtering to achieve laminar flow, is also used to "sweep" particulates away from the manufacturing space.

Once ISO Class 1 certification for particulates is attained, the environment is monitored to ensure the integrity of the contamination control systems. A monitoring schedule is determined by the requirements of the facility and is arrived at by historical monitoring records. In cases of extreme cleanliness environments, continuous monitoring of particulate generation is required.

Recommendations: The first samples returned from Mars will likely consist of small rocks and soils. A pristine environment will be required for storing and manipulating the Mars samples. Careful determination of the kinds and locations of activities which will occur within the sample containment environment will dictate how samples will be manipulated. A combination of robotic types could be utilized to optimize their capabilities. Certain robot types are best suited for repetitive tasks and others are best suited for operation on-the-fly. It may even be desirable to incorporate a mini-environment within a glove box environment for certain kinds of activities (i.e. rock breaking and other kinds of sub-dividing). **A dedicated program of testing should be implemented to assess whether current cleanroom robots are (1) inorganically and organically clean enough and (2) flexible and dexterous enough to be appropriate for use in a Sample Receiving Facility.**

References: [1] Space Studies Board, National Research Council (1997) National Academy Press, Wash. DC. [2] NASA/CP—2002-211842, NASA.

Figure 1. Vertically articulated (upper) and SCARA (lower) cleanroom robots.