Verification on Earth

Primary TEST-RAD verification will be based on its ability to repel different sizes and charges of regolith particles, and how well these results transfer to a vacuum environment. Implementing and testing the system on Earth would require the use of a regolith simulant, with similar size, electrostatic nature, and abrasive characteristics as lunar dust and a moon-like vacuum pressure container. Our team would also test the prototype's ability to withstand large variations in temperature, though we will not be able to achieve the extreme low temperatures present on the Moon (-243℃) due to laboratory and safety limitations.

Creating comparable environmental pressure can be done with a vacuum chamber reaching 10^{-6} mmhg (3^{-15} bar; Beale and Bonometti, 2008). The testing environment will be simulated using a glove box vacuum chamber (Figure 2; Thomas Scientific), though it can only reach pressures on the order of 10^{-1} mmhg. This is the lowest pressure our team will be able to realistically achieve, and should be suitable for dynamic lunar regolith drop tests and other static tests. Thus, evaluating TEST-RAD in a vacuum environment is possible.

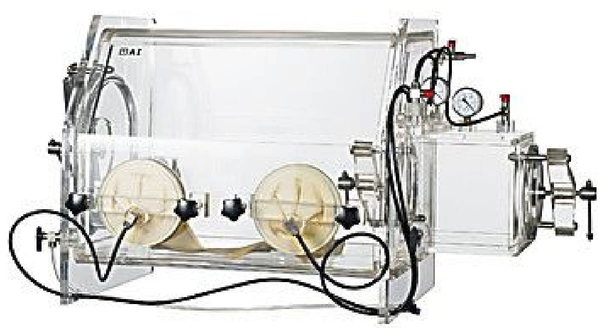

Figure 2. Acrylic vacuum glove box from ©Thomas Scientific, capable of reaching pressures of 10^{-1} mmhg.

Our team will be unable to create a microgravity environment, and this may have effects on the functionality of TEST-RAD. Though the discrepancy in gravity's influence on the system between Earth’s testing environment and the Moon can be minimized. This will be done partly through the aforementioned low pressure testing, which accounts for a majority of levitated regolith (in conjunction with dust electrostatics; McKay et al., 1991). However, given the limitations of testing and simulation equipment that is commercially available, it can be concluded that achieving a higher degree of accuracy in simulation is not reasonably possible.

The abrasive nature and size of lunar dust can be matched by a few regolith simulants. LHS-1 and LMS-1 both contain particles in the size range the project requires (50 to .50 µm). LMS-1 however has a mean size that resembles that range closer at 63 µm (CLASS). The mean size of both of these simulants is over the maximum size of the lunar soil, so our team would filter the regolith simulant to get only the desired size particles. Regolith collisions and entanglement within TEST-RAD can be modeled with MATLAB to display any and all weak points in the system.

The above two regolith simulants do not, however, have electrostatic capabilities. The electrostatic nature of the moon regolith can be replicated by way of a process that drops the regolith (could be the LHS-1, the LMS-1) and transfers a charge to the simulant through contact charging. Sternovsky et al. showed contact charging can be achieved by transferring the charge from metal to metal (2002), though they used a different simulant (JSC-1A). Since both the LHS-1 and the LMS-1 contain a significant amount of metal, the method of induction should carry over to these simulants (CLASS). TEST-RAD's electrostatic interactions with the regolith can further be analyzed by ANSYS Maxwell, a computer modeling software.

In order to test the system, prototypes of the tufted fibers and electrostatic system would be built separately to confirm that they are both able to carry a charge and to refine any aspects of the design. This would establish a TRL of 3 for each part of TEST-RAD. Then the integration phase would begin; a TRL of 3 would be established for the entire system, at this point we would move into the testing in the lab environment. There are two methods of testing the effectiveness of the system: one to simulate movement around the moon without direct contact, and one to simulate direct contact (equivalent to kneeling, falling, ect).

Inside a glove box vessel capable of achieving a vacuum (Figure 2), three iterations of prototypes will be tested. The first iteration will be a 1.5 x 3" patch using stainless steel fibers to carry charge, a wire mesh backing and a secondary non flammable adhesive backing as well as the electrical components. The second iteration will be two 1 x 4" patches using PEDOT fibers to carry charge, catching fibers to line the abutting edges, a wire mesh backing, a secondary non flammable adhesive backing and electrical components. The third iteration will use the same materials as the second but the strips will be approximately 0.5 x 10" and applied to a seal. Iteration three will be a mock-up of a joint on the space suit, of the same approximate size and shape. During testing there will be a removable piece of fabric with adhesive in the place of the outside of the pressure suit. All three iterations will reach TRL 4. The third iteration is intended to reach TRL 5, undergoing more rigorous testing and functioning on a scale prototype of a sealed joint.

Our team would conduct trials in which we would measure the amount of regolith simulant on the adhesive layer with TEST-RAD in place and with it absent, as well as in a vacuum environment and in normal Earth-like conditions. There are subsequently two methods of regolith interaction with the joint simulant. The first method will consist of dropping a predetermined amount of regolith onto the joint as to simulate indirect contact with regolith. The second method intends to simulate direct contact in which the joint, achieved by placing the system into a container filled with a predetermined amount of regolith simulant. Then a predetermined amount of weight would be placed on the joint to simulate direct contact with the lunar surface. In both of these cases the amount of regolith simulant attached to the adhesive would be measured and compared in order to determine effectiveness. After this stage of testing the TRL of 4 for the entire system will be established.

Path to Flight

Regarding the path-to-flight to the moon, a critical modification of TEST-RAD would be the application of the fibers on the Artemis space suit. For our prototype, our team will conduct tests on the flexibility and strength of the fibers and the textiles they are attached on. However the fibers are unable to be tested when attached to a seal. Therefore, the size and shape of the fiber patches attached to seals may vary from the prototype to minimize movement restrictions and maximize regolith repulsion.

Additionally, while simulant can account for the properties of lunar regolith, it does not possess the same irregular shape of regolith, and this would be a crucial component to test prior to missions using the fibers. We concluded that the fibers would be a permanent attachment to the space suit, as it was the cheapest and most volume-efficient solution, but in exchange, we need to make sure the system maintains its integrity for a long period of time. Furthermore, the simulant used will not cover the smaller particle sizes between 0.5 µm to 10 µm, which may result in more regolith bypassing the electrostatic shielding and more regolith getting caught in the fibers even after cleaning. For the event that the fibers deteriorate at a faster rate or regolith proves more difficult to clean off than expected, the fibers may be modified to be replaceable instead.

Next, our fibers will not be tested at the temperature range of -49℃ to -243℃ specified in the design constraints. However, the fibers can theoretically function in a lunar environment as we specifically chose materials that will not lose their functionality at those temperatures. Nevertheless, modifications may be required to guarantee the functionality of the fibers beyond the theoretical level. Our team will be able to test the fibers in a medium-strength vacuum, which should give a reasonable approximation of TEST-RAD's effectiveness. Future testing at more extreme temperatures and pressures will be required to reach TRL 6, which can be done at various government laboratories designed for more rigorous evaluations.

Furthermore, charge held by the fibers may complicate and interfere with electronics on the space suit. Therefore, design parameters of TEST-RAD may need to be modified to account for interference with other electronics on the space suit. In addition, we are also proposing that the fibers are powered from the life support system of the space suit. In the experiments, the life support system of the Artemis space suit will be unable to be replicated, so a modification may need to be made to accommodate for a different current running through the fibers or for a connection to the power supply of the life support system.