HARVARD
School of Engineering
and Applied Sciences

Frank N. Keutsch
*Stonington Professor of Engineering and Atmospheric Science*
*Professor of Chemistry and Chemical Biology*
keutsch@seas.harvard.edu

**Harvard John A. Paulson School of Engineering and Applied Sciences**
**Department of Chemistry and Chemical Biology**
**Department of Earth and Planetary Sciences**
12 Oxford Street, Cambridge, MA 02138 USA
Phone: 617-495-1878 / Fax: 617-495-4902

January 17, 2021

Dear SCoPEx Advisory Committee,

In response to your written request, we submit a document that provides the details you have requested for the technical soundness review of the platform test. These responses were written in consultation with Swedish Space Corporation.

We appreciate the Committee's review of the platform test's engineering integrity and safety and will be happy to provide additional information on request.

Sincerely,

Frank Keutsch
Stonington Professor of Engineering and Atmospheric Science
Harvard John A. Paulson School of Engineering and Applied Sciences
Department of Chemistry and Chemical Biology
Department of Earth and Planetary Sciences

**Responses to Review of the Engineering Integrity and Safety of SCoPEx**

**Question 1. Has SCoPEx research team identified any *potential risks and/or matters relating to safety* associated with the engineering flight?**

**Response:** The SCoPEx research team has identified the following potential physical risks associated with building, testing, and transporting equipment and personnel to the engineering flight:

- Personnel traveling (car crashes, illness)
- Lifting and moving heavy objects (load crushing injuries, falls, physical strain)
- Batteries and electronics (electrocution, explosion, burn)
- Propellers (strike risk from improper operation)
- Crane (load crushing injuries, structure tipping).

The launch and flight services, systems and materials for the launch (helium gas, flight train, parachute), and payload recovery by helicopter will all be provided by Swedish Space Corporation (SSC). Risk management associated with these aspects of the flight will fall under their purview.

**Question 2. Has SCoPEx undertaken a risk assessment of the engineering launch? If affirmative, we are requesting a copy of same and a proposed mitigation plan.**

**Response:** No, but we are working with Harvard Environmental Health & Safety to conduct a job hazard analysis to evaluate and manage the risks detailed in the bullet point list in question 1. We would be happy to share hazard analysis with the committee when it is available.

**Question 3. Please describe the process by which the balloon and gondola will be returned safely and intact to the ground following completion of the engineering test.**

**Response:** After a sufficient float period is acquired, the termination of the flight will be performed. The payload and flight systems will be separated from the balloon envelope and descend to the ground with a parachute designed to maintain a decent velocity of ~ 4-6 m/s. The balloon envelope will return to the ground separately. SSC will provide recovery of the payload. Recovery will be performed after the flight using a helicopter. The payload will normally be back at Esrange within 24 hours.

**Question 4. Can Swedish Space Corporation *safely abort the launch without posing a danger to people and structures on the ground and retrieve the gondola,* in the unlikely event that something appears to be going wrong, or has actually gone wrong?**

**Response:** The launch will take place at Esrange Space Center, which is a restricted site for third persons. Thus, problems during a launch attempt would be kept in an area where no third persons are present. The personnel involved in the launch are positioned so they will not be harmed if something goes wrong.

The balloon launch will take place at the Balloon Launch Area at Esrange Space Center, which is surrounded by infrastructure at the facility. Though it is highly unlikely that something would hit any buildings or equipment on the base, it is not impossible. All infrastructure is insured in case something happens. SSC also has third party insurance in the highly unlikely case that any third party would be hurt during any phase of the balloon operation.

The recoverability of the gondola is dependent on the type of launch failure. If, for example, the balloon and gondola has been launched and is flying at a low altitude, and then a balloon burst occurs, the parachute may not have time to inflate and decrease the landing speed of the payload resulting in substantial damage to the gondola. If the balloon bursts on the spool the gondola is secure on the launch vehicle. If the balloon has a problem at higher altitude the gondola would descend with the parachute.

As the precise landing spot cannot be determined, due to wind drift of the parachute in the end, there may be damage to the gondola when it lands.

**Question 5. What degree of control does Swedish Space Corporation have over times when and the locations where the balloon and gondola return to land? Are there particular areas where this usually occurs?**

**Response:** SSC will command the cut-down of the gondola and balloon via radio link so that is done to a high degree of control. The landing spot for the gondola will first be predicted with the help of a trajectory analysis looking at the winds before the launch. After launch, and during the flight, the actual position and thus the predicted landing spot will be continuously monitored. However, the exact landing spot will not be known due to deviation between forecast and real wind. We expect the real landing spot to be within some kilometers of the predicted landing spot.

**Question 6. Does the gondola crash land? Is there a risk that if it does, batteries or other equipment will ignite?**

**Response:** The gondola descends to the ground via a parachute and will have a velocity of 4-6 m/s. Crush pads mounted under the legs of the payload are designed to decrease the shock of the landing impact. The structure has been designed to withstand a 10 g load of the full payload mass (600 kg) even under conditions were only one leg makes initial contact with the ground.

The batteries are mounted at the center of the lower deck away from edges of the platform such that they will not experience a direct impact with the ground. We anticipate the batteries will have expended ~ 75% of their stored energy prior to initiating descent. We further anticipate that the containment method used to house the batteries will safely isolate them from the landing shock even in the event of a crash landing. The batteries will be housed in an array of boxes and strapped down with a cargo net. Each insolated metal battery box will provide additional isolation from landing shock and the other batteries.

The cell chemistry is Lithium Nickel Manganese Cobalt (LiNiMnCo). This chemistry was selected after evaluating energy, power, and safety consideration of various battery chemistries. An overview and more information on various Lithium-ion battery technologies can be found in

Miao et al, Energies 2019, 12(6), in particular, Figure 4 present a comparison of several different chemistries.

The cells are from AA Portable Power Corp INR-26650-5000 and we are using package model numbers PR-CU-R635-14S3P and PR-CU-R635-8S3P housed inside aluminum cans with an electronic monitoring system. The engineering flight will carry enough power, with some additional overhead, to complete the mission. It will not carry the full energy capacity required for a science flight. Thermal profiling of the battery system under full load discharge rates over a time period consistent with the engineering flight plan indicates the batteries will remain well within their temperature ratings throughout the flight. During ascent and descent, the batteries will be electrically isolated from their loads (with the exception of the flight computer and ground communication radio).

Besides the batteries there are no additional energy sources on the payload.

**Question 7. Has Swedish Space Corporation experienced any incidents where its balloons or gondolas have caused damage or injury on the ground?**

**Response:** No, during the more than 200 launches that SSC has performed, there has been no damage or injury either during launch, flight, or landing.

**Question 8. Please expand on other potential fire hazards posed by the battery powering the balloon.**

**Response:** Thermal runaway is the main fire hazard. Other potential fire hazards could be overheating of payload components and should be mitigated by the monitoring system. A 2017 FAA report discusses the fire hazard of lithium batteries. Figure 13 shows the onset of thermal runaway from LiNiMnCo (C-long-sized) cells to be 200 °C. Our preliminary laboratory tests indicate during max loading the max temperature of the battery pack is 82 °C. The report found that LiNiMnCo is a moderate battery choice. The LiNiMnCo batteries were more likely to have the cell eject its contents which prevents heat propagation between cells, but this result is dependent on how the cells are packaged together. Our packaging and mounting configuration will aid in compartmentalizing battery cells and reduce damage propagation in the event of damage.

**Question 9. Can you outline the specific potential risks/safety issues associated with each phase of the operation, i.e., during launch/ascent, descent and retrieval?**

**Response:**

*At launch:* Unexpected wind direction or speed change; faulty balloon; pressurized gases and system; ESD; on-base radio interference

*During ascent:* Faulty balloon (hole in envelope); too much or little lifting gas

*At float:* Wind prognosis not accurate (trajectory difference)

*Cut-down and landing:* Planned landing spot in an area with safety concerns; cut-down does not execute as expected; wind drift under parachute higher than anticipated; gondola structure not strong enough for forces during cut-down

**Question 10. Are there factors in the April 2010 balloon launch accident in Alice Springs, Australia that we should be concerned about for the upcoming planned launch? Specifically, are there lessons worth noting that may be relevant to SCoPEx? For example, NASA's own accident report noted the following, *inter alia*:**

i. **Weather conditions were acceptable for launch and there were no technical problems BUT**
ii. **"...in the course of our investigation, we found surprisingly few documented procedures for balloon launches".**
iii. **"No one considered the launch phase to be a potential hazard."**
iv. **There were some 25 causes identified as potential reasons for the accident, including "…insufficient risk analysis, government oversight and public safety issues".**

**Response:** As it happens, Keutsch, Keith, and Dykema of the SCoPEx team heard details of this accident at one of the very first meetings we had with a NASA balloon expert, long before we started talking to commercial balloon operators. Our impression is that the Alice Springs accident has encouraged balloon operators to rethink launch risks and improve procedures.

We are satisfied that SSC has had full access to the NASA investigation regarding the 2010 Alice Springs accident, and it has been discussed internally at SSC and together with NASA safety to reduce the chance of similar accidents at Esrange. For example, the mechanical safety system at SSC has been changed due to the incident. In addition, SSC has its certified procedures for balloon launches (ISO 9001:2000).