COMPREHENSIVE VENUS SURFACE ENVIRONMENT SIMULATION WITH THE GLENN EXTREME ENVIRONMENT RIG.
J. A. Balcerski[1], T. Kremic[2], L. M. Nakley[2], G. W. Hunter[2], S. T. Port[2]. [1]Ohio Aerospace Institute, 22800 Cedar Point Rd, Cleveland, OH 44142 (jeffreybalcerski@oai.org), [2]NASA Glenn Research Center, Cleveland, OH 44135

Introduction: NASA's Glenn Research Center (Cleveland, OH) maintains and operates the Glenn Extreme Environment Rig (GEER), a 800 L heated pressure vessel capable of simulating the atmospheric conditions at the surface of Venus, amongst others. GEER successfully completed its inaugural long-duration experiments in 2013, in which it demonstrated continuous thermochemical simulation of Venus' reference surface environment for more than 30 days (1). Shortly thereafter, GEER demonstrated continuous operation for 80 days at the target conditions. GEER has the ability to precisely control 8 independent minor gas streams in addition to the CO_2 carrier gas (for Venus applications, N_2, SO_2, H_2O, CO, COS, H_2S, HCl, and HF) to the sub-ppm level, thereby simulating the chemical environment of Venus' surface atmosphere with as high fidelity as the thermal and pressure conditions. Inclusion of minor gas species has been demonstrated to be absolutely necessary for accurately reproducing geochemical interactions of Venus' atmosphere with its surface and with technology intended to operate in that environment. The combination of large volume, precision-controlled supply gas mixing, constant analytical monitoring of physical and chemical test conditions, and long-duration operation make GEER unequaled among current Venus environment test facilities. This facility is made available for use by public, private, and non-profit researchers for scientific experiments and technological advancement.

Pressure Vessel Description: GEER is a 36" interior diameter pressure vessel (Figure 1), constructed of 304 stainless steel (selected due to having a combination of corrosion resistance and strength characteristics surpassing that of either of 316 stainless or Inconel™) and is capable of operating at a maximum of 475 °C and 94 bar. Full access to the 36" diameter interior vessel (e.g., for large test articles) is provided through a 56" diameter roll-away head flange (Figure 2), with access also provided through multiple 3" and 4" "user ports" on both ends for smaller test articles. These ports can each support multiple ¼" ,½" , and ¾" feedthroughs, to accommodate active experiments that require power and/or data connections.

Facility Analytical Support: In addition to the nine internal thermocouples and dual pressure transducers monitoring the chamber, the facility-operates a mass spectrometer and a multi-column gas chromatograph that provide quantitative tracking of targeted gas species during operation, via a combination of manual and automated sampling. True in-situ analytic capabilities, to allow for zero-loss, continuous monitoring of gas concentrations, are currently being added and expected to be operational by early 2022. Results from these analytic instruments are compared to upstream, high-precision gas flow meters to verify the composition and monitor changes over time.

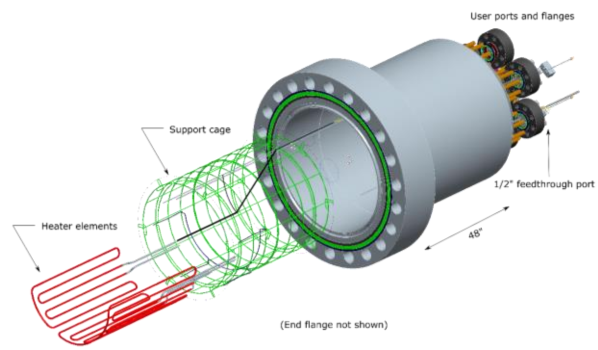

Figure 1. GEER access and heater placement. (Head flange not shown.)

Contributions to Venus Science and Exploration Technology: To date, GEER has been utilized for several competitively awarded science research efforts, including experiments on surface-atmosphere interaction, rock weathering, and atmospheric dynamics (1–4). These investigations conclusively demonstrated that the presence of minor gas species has a substantial impact upon experimental outcomes and that the presence of CO_2 alone is insufficient to accurately reproduce the effects of the Venusian atmosphere. Sulfur species (i.e., SO_2, COS, and H_2S) are especially relevant, with sulfidizing reactions taking place concurrently with oxidizing reactions to form sulfides, oxides, and sulfates, all of which are predicted from thermodynamics and observed in long-duration exposure tests (1-4). The facility has also been successfully used for testing the suitability of a wide range of engineering materials for use at Venus' surface and for maturing exploration instruments and technology. For example, it has been demonstrated that transition metals, especially copper, iron, and nickel, react rapidly with the Venus reference environment, even when using traditional protective cladding. (6-7). This remains the case (though to a lesser degree) even when these metals are alloyed as stainless steels or other materials commonly used in aerospace applications for extreme environments (6-8).

Versatility of Test Environments: Although GEER has historically supported Venus-related work, and is especially suited for long-exposure tests at Venus surface conditions, its current configuration also allows for indefinite exposure to the ambient conditions of the lower clouds. Moreover, the facility was designed to flexibly accommodate different chemical environments (within the temperature and pressure tolerances of the vessel). The programmable gas mixing and delivery system will allow for practical simulation of other planetary and exoplanetary atmospheres. Future use of GEER for these environments continues to be evaluated by the GRC facilities and research teams and may be offered for use in response to specific requests.

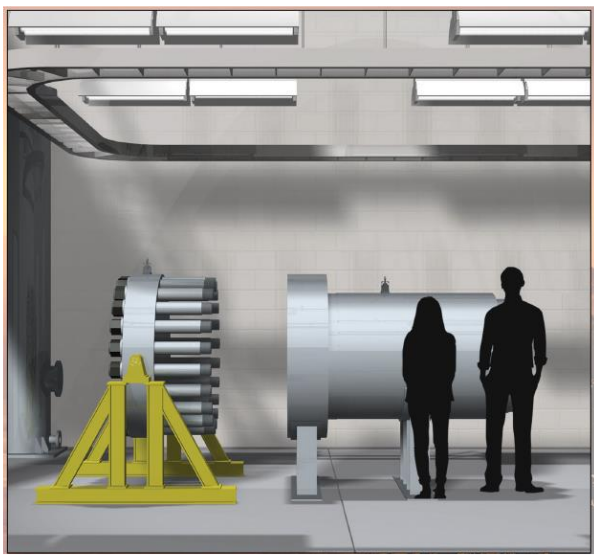

Figure 2. Scale rendering of GEER facility, shown with head flange removed for interior access

Collaborative Research and Development:

The GEER facility is available for researchers proposing to a variety of opportunities including NASA ROSES solicitations. To date, the facility has been utilized for experimental work conducted under awards from the Solar System Workings, Hot Operating Temperature Technology, Small Business Innovative Research programs, along with a range of directly-funded and private contract arrangements. GRC is able to provide test condition data (including temperature and pressure tracking and selected gas quantities), sample preparation and handling, custom support and interface hardware, electrical feedthroughs, and custom temperature, pressure, and composition profiles, as well as expertise to help plan and conduct desired experiments or tests.

References: [1] Harvey, R. et al. (2014). 2014 GSA Annu. Meet. Vanc. Br. Columbia. [2] Radoman-Shaw, B. et al. (2016). [3] Radoman-Shaw, B.G. (2019). [4] Santos, Alison et al. (2019). [5] Neudeck, P.G. et al. (2016). AIP Adv., 6, 125119. [6] Lukco, D. et al. (2018). Earth Space Sci., 5, 270–284. [7] Lukco, D. et al. (2020). J. Spacecr. Rockets, 57, 1118–1128. [8] Costa, G.C. et al. (2018). Corros. Sci., 132, 260–271