

PIERCING DEVICE FOR GAS EXTRACTION FROM APOLLO 17 SAMPLE CONTAINER: FINAL DESIGN & KEY LEARNINGS. T. Schild^{1,2}, F. E. McDonald², P. de Medeiros³, M. Apolloni², N. Bamsey², R. Biella², Y. Butenko², A. Dowson², A. Cowley³, R. Lindner², A. Makaya², F. Schärnholz³, S. Eckley⁴, J. Gross⁴, B. Jolliff⁵, F.M. McCubbin⁴, A. Meshik⁵, R. Parai⁵, O. Pravdivtseva⁵, Z. Sharp⁶, C. Shearer⁶, R. A. Zeigler⁴, and the ANGSA Science Team⁷. ¹European Space Resources Innovation Centre (ESRIC), Belvaux, Luxembourg (timon.schild@esric.lu); ²ESA ESTEC, Noordwijk, Netherlands; ³ESA SSEAC, Cologne, Germany; ⁴NASA JSC, Houston, USA; ⁵Dept. of Earth & Planetary Sciences and Dept. of Physics, Washington University in St. Louis, USA; ⁶Institute of Meteoritics, University of New Mexico, USA; ⁷<https://www.lpi.usra.edu/ANGSA/teams/>

Introduction: In February 2022, the pristine lunar regolith core sample 73001 was successfully opened for analysis, 50 years after its collection during the Apollo 17 mission [1]. It is the lower part of a double drive-tube core (73001/73002) [2], taken at station 3 in the Taurus Littrow Valley [3]. It was sealed in a Core Sample Vacuum Container (CSVC) directly after its collection [4], and has since been stored in an Outer Vacuum Container (OVC) evacuated to $\sim 6 \times 10^{-2}$ mbar [5].

Its collection depth (up to 70 cm), its low estimated temperature at collection (~ 250 K [6]), and its storage under vacuum, make the 73001 core sample a prime candidate to still contain gaseous volatiles. A main objective for the analysis of this sample is therefore to investigate the presence and nature of those trapped gases. This work has been undertaken by the Consortium for the Advanced Analysis of Apollo Samples (CAAAS), as part of the ANGSA initiative.

The extraction of gases from CSVC 73001 is a novel operation. It required the development of custom hardware, in the form of a piercing tool for opening the CSVC, and of a gas extraction manifold [7] for the collection of the released gases. Herein, we propose to review the final implementation of the piercing tool successfully used to puncture the 73001 CSVC.



Figure 1: Piercing tool connected to gas extraction manifold during gas extraction campaign.

The points discussed include the final construction of the piercing tool, the steps taken to qualify it for use, and an assessment of its performance. Lessons learned from this work can help to improve the design and use of future sampling, storage and extraction tools.

Piercing tool design: The CSVC piercing tool (Figure 1) is an Ultra High Vacuum (UHV) compliant vacuum chamber, with a stainless steel piercing tip mounted to a bellows based linear feedthrough. A custom holder positions the CSVC within the vacuum chamber. An actuation mechanism around the chamber allows the piercing motion to be controlled manually.

Prior to operations, the CSVC is first assembled with the holder, which is then introduced into the vacuum chamber. This is done in a glovebox under inert atmosphere. Once the vacuum chamber is sealed, it is removed from the glovebox and assembled with the actuation mechanism and the gas extraction manifold. The chamber is evacuated to the desired pressure ($\sim 10^{-8}$ mbar), and piercing is conducted by driving the stainless steel tip into the bottom face of the CSVC. This opens a hole to release the trapped gases into the manifold.

Testing & Qualification: To minimize the risk of sample contamination, the 73001 CSVC had to remain safely stored in its OVC until the gas extraction campaign. Therefore, the hardware had to be built and validated without access to the CSVC for inspection, measurement or testing. This left a number of unknowns that had to be factored into the design process, such as:

The exact dimensions of the CSVC: Dimensions were derived from engineering drawings [8] and from archived photographs. Notably the length of the CSVC (~ 385 mm), its diameter (~ 50.2 mm), and its wall thickness (0.38-0.64 mm) could only be estimated.

The position of the core sample within the CSVC: Analysis of engineering drawings indicated that the bottom of the core sample tube (covered by a PTFE cap) could be in direct contact with the wall to be pierced, or a gap of up to 3.3 mm could exist.

The pressure within the CSVC: Since the performance of the CSVC seal is unknown, its internal pressure could vary from $\sim 10^3$ mbar (i.e. atmospheric pressure) and $\sim 10^{-12}$ mbar (i.e. lunar vacuum).

The interaction of the piercing tip with the CSVC: Although the build material of the CSVC is known (304L stainless steel), its properties may have been altered by ageing and/or exposure to the lunar environment.

To qualify the piercing device for use, extensive testing was conducted using custom built mock-ups of the CSVC and the drive tube. The tests assessed the piercing performance over a range of scenarios, including variations in CSVC base wall thickness, simulated CSVC residual pressure, piercing tip shape and length, and drive tube position within the CSVC. By using a 45° slanted piercing tip with a penetration depth of 4.9 mm, it was demonstrated that the CSVC mock-ups could be pierced reliably across the varied scenarios considered, without penetrating the PTFE cap of the drive tube, shedding material, or inducing leaks into the system under UHV.

Outcome and key learnings: The piercing tool was successfully used in conjunction with the gas extraction manifold to process CSVC 73001 in February 2022 [1]. As intended, the tool produced an opening in the bottom wall of the CSVC, without puncturing the PTFE cap protecting the underlying sample (Figures 2 & 3). A total of 9 gas samples were collected for further analysis at different stages of the extraction process, from the gas contained in the OVC to the gas evacuated from the pierced CSVC over several days. The observations made during the gas extraction campaign could indicate that the CSVC had leaked and equilibrated with the OVC, while the OVC remained leak-free. It is thus believed that the sampled gases could contain a mixture of lunar gases and residual N₂ from the OVC. The upcoming detailed analysis of the gases will allow to confirm this hypothesis.

The piercing tool met the main science and curation requirements, with several lessons learned and suggested points of improvement noted (e.g., ease of handling, evacuation speed). Some limitations of the tool can be traced to the CSVC design and/or unknowns in not being able to inspect it in advance. For example, a large volume for the piercing tool main chamber was required to make the system resilient to potential discrepancies between the written records and the actual CSVC dimensions. This in turn lowered evacuation performances.

To improve the design and interoperability of future sampling tools, sample containers and sample processing systems, recommendations can be derived from this work:

Downwards compatibility of future tools: should be enhanced by design, by assessing and anticipating non-nominal uses of the hardware early in the development

process. Possible improvements include a high level of standardization and redundancy around system interfaces (i.e., mechanical, pneumatic, electronic)

Advanced information on individual parts (dimensions, material properties, etc.): should be collected, curated and regularly updated, to enable more efficient design and better integration of new tools with legacy hardware. By leveraging modern technologies, digital twins of all manufactured flight hardware could for instance be produced.

Physical replicas of critical hardware: should be manufactured and curated, to further enhance future integration capabilities, especially by allowing hardware in the loop testing for qualification.



Figure 2: Bottom wall of CSVC 73001 after piercing.

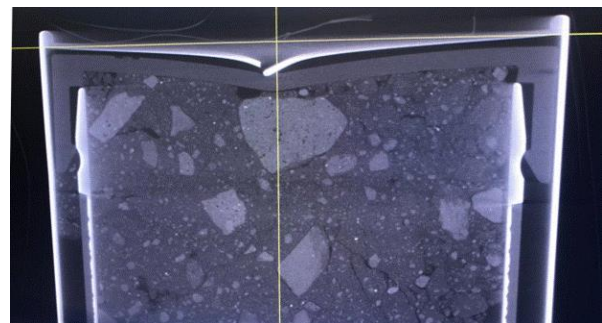


Figure 3: XCT scan of CSVC 73001 after piercing.

Credit: S. Eckley and R.A. Zeigler.

References: [1] McDonald F.E. et al. (2022), 10th European Lunar Symposium. [2] Meyer C. (2011) Lunar Sample Compendium. [3] Schmitt et al. (2017) Icarus, 298, 2-33. [4] Butler P. (1973) Lunar Sample Info. Catalog, NASA JSC. [5] Allton J.A. (1989) JSC23454, NASA. [6] Keimh S.J. and Langseth M.G. (1973) Proc. 4th Lunar Sci. Conf. 2503-2513. [7] Parai. R et al. (2021) LPSC LII, Abs #2665. [8] NASA JSC (1971) CSVC Technical Drawing, M-11306.