

## SUPPLEMENTARY MATERIAL FILE

### **A High-Resolution Continuous Melter System for Sea Ice and Sediment-Laden Ice Applications**

\*Rafael dos Reis<sup>1†</sup>, Denise Mondragon<sup>1†</sup>, Nolan Magner<sup>1</sup>, Bruce Vaughn<sup>2</sup>, Valerie Morris<sup>2</sup>, Kevin Hand<sup>3</sup>, Catherine Walker<sup>4</sup>, Christopher R. German<sup>5</sup>, Joseph McConnell<sup>6</sup>, Helle Astrid Kjær<sup>7</sup>, Melisa Diaz<sup>1</sup>

<sup>1</sup>School of Earth Sciences, The Ohio State University, 43210, Columbus-OH, USA.

<sup>2</sup>Institute of Arctic and Alpine Research, University of Colorado, 80309, Boulder-CO, USA

<sup>3</sup>Jet Propulsion Laboratory, California Institute of Technology, 91109, Pasadena-CA, USA

<sup>4</sup>Department of Applied Ocean Physics and Engineering, Woods Hole Oceanographic Institution, 02543, Woods Hole-MA, USA

<sup>5</sup>Department of Geology & Geophysics, Woods Hole Oceanographic Institution, 02543, Woods Hole-MA, USA

<sup>6</sup>Division of Hydrologic Sciences, Desert Research Institute, 89512, Reno, NV, USA

<sup>7</sup>Physics of Ice, Climate and Earth (PICE), Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

†co-first authors

\*Author correspondence: dosreis.3@osu.edu

This document provides the experimental setup and validation stages used to characterize the continuous melter system for sea-ice applications and describes the associated electronic control settings. Also, here we present the additional carryover tests performed for trace elements not included in the main manuscript (Ag, Cd, Ce, La, Nd, Pb, Pr, Rb, and Sr). It presents the concentration profiles for these elements across the samples (S1–S23), highlighting the four standard pulses (S4, S10, S15, and S20) and the corresponding post-peak responses. The figures and tables provided here allow direct comparison with the core set of elements shown in the main text and confirm that these additional species exhibit similarly low carryover and rapid return to baseline under the same experimental conditions.

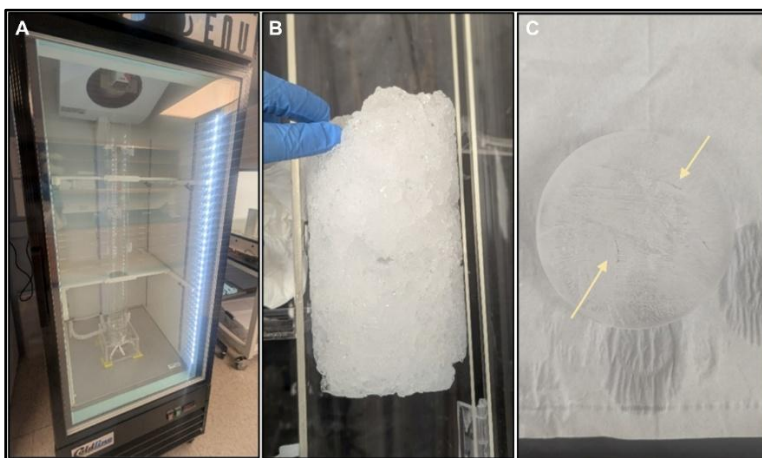
In the supplementary datafile spreadsheet, the carryover tests show (Table S3) that the enriched pulses for silver, cadmium, cerium, lanthanum, neodymium, lead, praseodymium, rubidium, and strontium behave very similarly to the core set of analytes. LOD and LOQ are described in Table S4. Residual concentrations in the first post-peak fraction typically fall in the range of roughly 1–5% of the preceding peak, with only a few cases approaching that upper bound, and subsequent fractions rapidly collapse back toward baseline with residuals generally below 1%. Negative or near-zero residuals are common beyond the first one or two fractions, indicating that apparent fluctuations are

dominated by noise around the blank rather than by persistent contamination. When integrated over the full post-peak interval, the cumulative carryover for each element remains modest and does not indicate any systematic build-up of signal between pulses. Together these patterns confirm that the melter system clears these additional trace elements efficiently between injections and that their inclusion does not introduce appreciable memory effects into the analytical sequence.

Additionally, we present the melt head FEP surface-coated results in a Figure S6 that indicated better results for Al and Ni carryover addressing the contamination observed in gold-coated melt head. A consideration for usage is also described for future applications in this system.

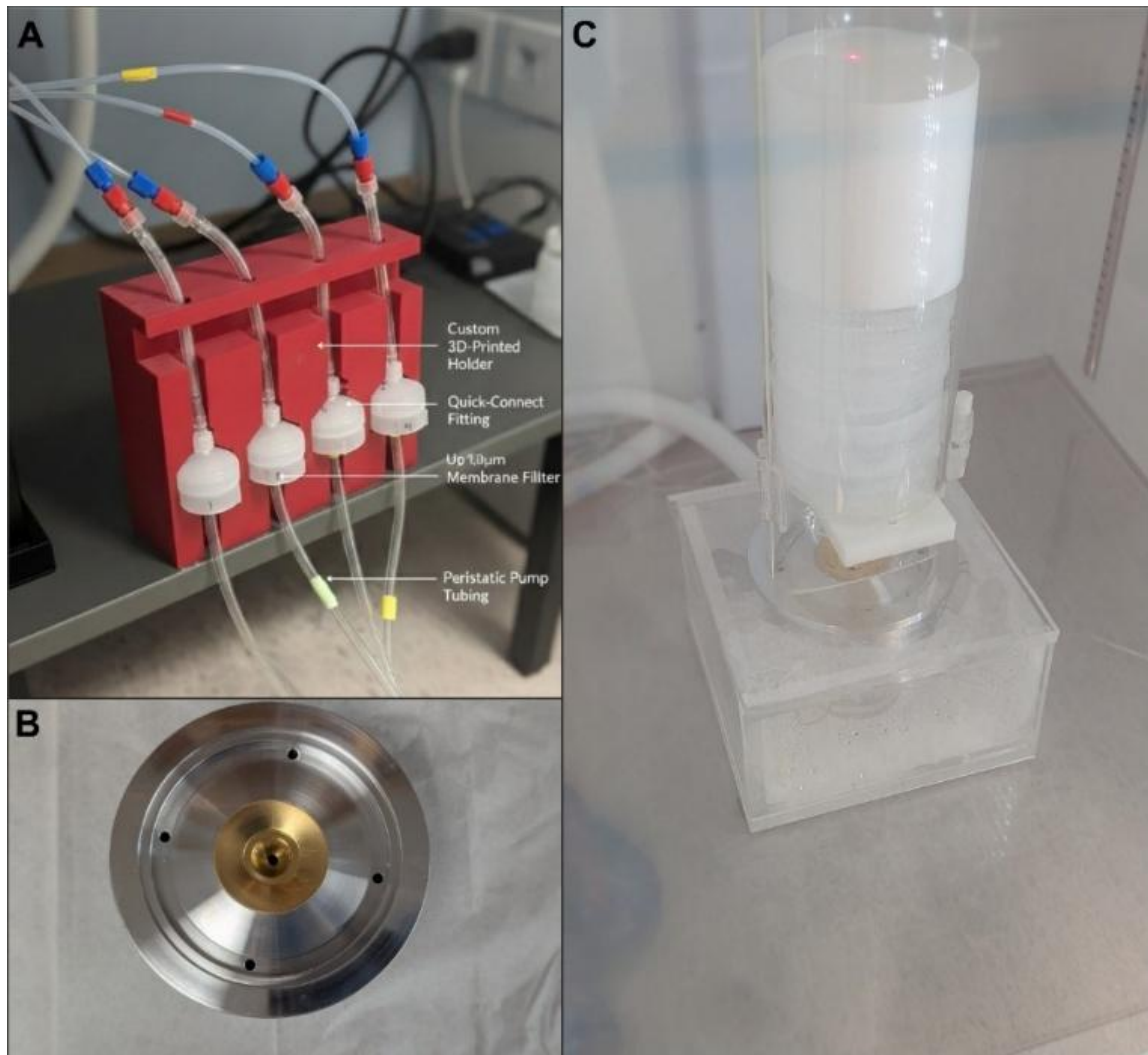
### System Setup and validation test

In the melter system setup, Stage 1 is illustrated by a photograph of the upright freezer housing the circular core holder, with a laser distance sensor mounted above the freezer to track core length and trigger vial changes. The circular holder keeps the core centered beneath the melt head while maintaining stable thermal contact, ensuring that melting proceeds uniformly from the bottom upward. Figure S1B shows a low-density ice core prepared after mechanical post-processing and refreezing inside a circular mold to preserve the core geometry. Figure S1C displays an artificial ice disc prepared with a controlled sediment load, used to test the system's ability to recover particulate material.



**Figure S1.** Stage 1 freezer setup and validation test samples. (A) Upright laboratory freezer used in Stage 1 to house the vertical core holder and melter assembly under controlled subzero conditions. (B) Artificial low-density ice core after post-processing and refreezing, prepared to mimic porous sea-ice sections for method validation. (C) Sediment test disc used to evaluate particulate recovery; yellow arrows highlight localized dust accumulation embedded within the ice matrix.

Subsequent panels (Figure S2A–C) present the filtration rack, the melt head, and images from the salinity validation experiments. In Figure S2C, the interlayered salinity test is shown, in which alternating “salty” and deionized water discs were melted to assess how effectively the system preserves sharp vertical gradients in conductivity. Together, these figures provide visual context for the mechanical design and demonstrate how the melter, filtration assembly, and validation tests operate to support high-resolution sea-ice capability in this new system.



**Figure S2.** Components of the continuous melter filtration and validation test. (A) Custom 3D-printed rack holding inline membrane filters (1  $\mu\text{m}$ ) connected via quick-connect fittings to peristaltic pump tubing for simultaneous filtration of multiple melt fractions. (B) Detail of the machined melt head device, showing the central gold coating in an aluminum device. (C) Melt head installed beneath the vertical core holder inside the freezer, with the sea-ice (artificial ice) core interlayered by salty and DI water discs positioned directly above the heated plate to enable controlled, bottom-up continuous melting under enclosed, temperature-stable conditions.

## **Electronic Settings**

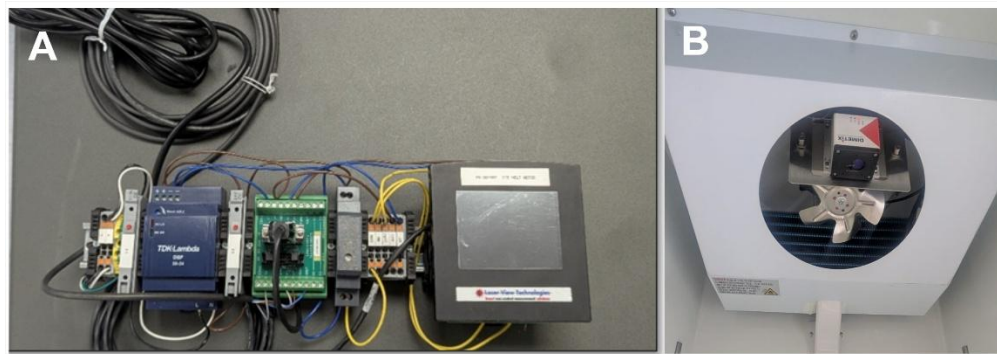
### **PLC Integration and Relay Function**

The control architecture consists of a programmable logic controller (PLC) and an auxiliary relay module (Figure S3A) connected to a precision laser mounted inside the freezer (Figure S3B). The laser measures the distance between the top of the freezer and the top of the ice core continuously as it melts from the bottom. As the ice core melts, the distance between the laser and the top of the core increases. The PLC (Figure S4) receives these discrete measurement inputs from the laser and determines when a pre-set amount of ice has melted by comparing the most recent measurement to a baseline recorded at the start of the run. The pre-set amount of ice is input into the PLC before each run and can be changed to accommodate different types of analysis and varying ice densities. Once the requisite amount of ice has melted, the PLC closes the auxiliary relay, sending a 5V signal to a timing mechanism.

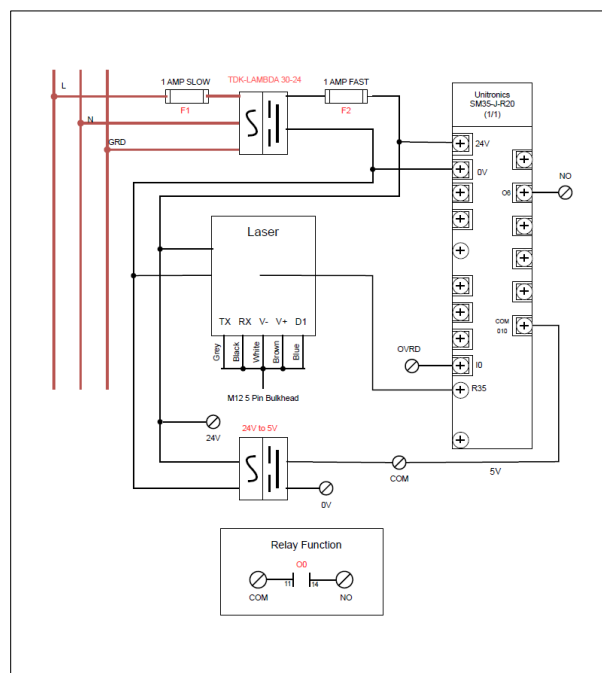
### **Signal Output and Fraction collector commands**

Once the PLC has sent the 5 V signal to the timing mechanism, the signal passes through a 5VDC voltage regulator to protect the timing mechanism by clamping the input to a controlled 5VDC level and suppressing transient overvoltage excursions. The timing mechanism utilizes an ELEGOO MEGA 2560 with an ELEGOO UNO TFT touch screen to send the 5VDC input pulse from the PLC to the next stage in the process after a specified delay. The delay time is determined through a series of tests and is based on the time it takes meltwater to travel from the melt head to the fraction collectors. The final delay time for our system was  $\pm 1.30$  min (density  $\pm 0.91$ ) but will likely vary based on ice density and melt head temperature. After the specified delay, the 5V signal is sent from the timing mechanism to the built-in multi-purpose Input/Output ports (I/O ports) of a Gilson FC204 fraction collector (FC1). This input triggers FC1's built-in "Remote Start/Advance" function, beginning sample collection in a new test tube. The "Remote Start/Advance" function automatically sends an output pulse from a second set of FC1's I/O ports which are connected to I/O ports on a second Gilson FC204 fraction collector (FC2). Upon receiving the signal from FC1, FC2's "Remote Start/Advance" function is

also triggered. This allows both fraction collectors to advance simultaneously, ensuring samples from the same regions of a given core are collected in both fraction collectors at the same time.

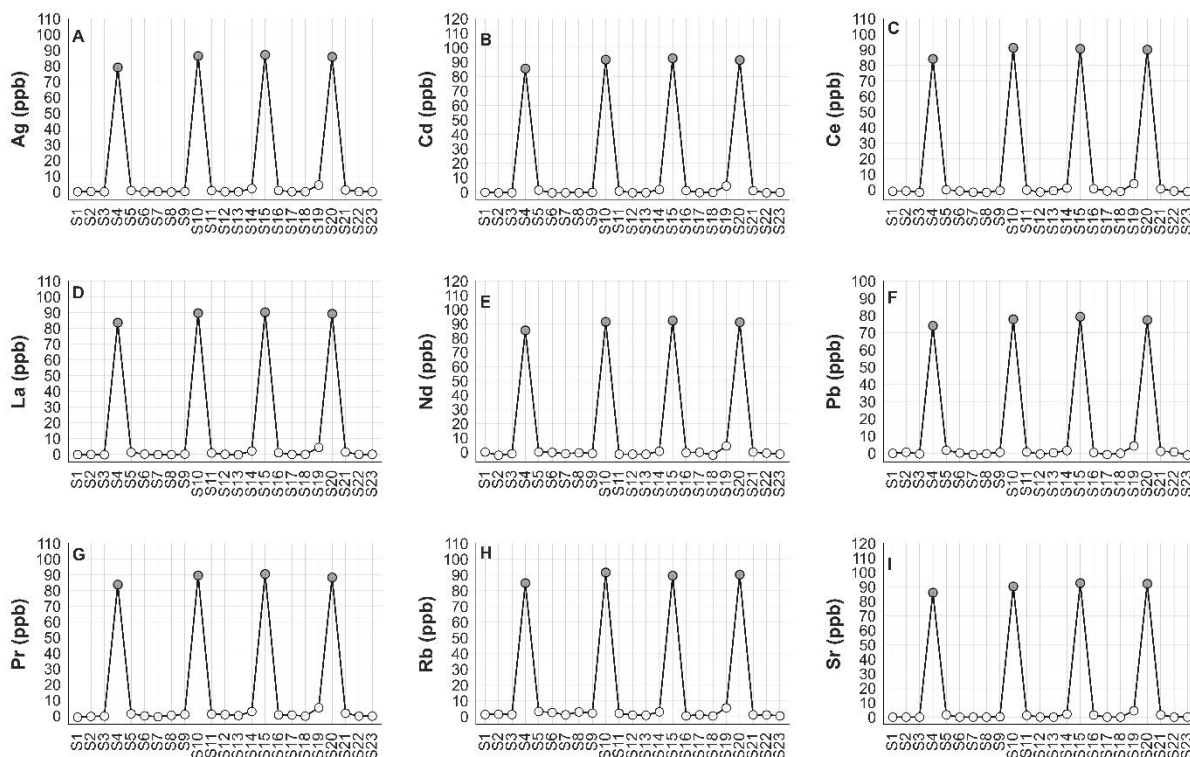


**Figure S3.** Electronic setup related to the laser and signal to pulse fraction collectors. **A)** Electronic connections, PLC interface, and relay system mounted on a DIN rail. **B)** Dimetix laser setup centralized inside the freezer.



**Figure S4.** Electrical wiring diagram for the laser distance sensor and PLC control unit. The schematic shows AC mains power distribution through fused protection to a 24 VDC power supply (TDK-Lambda 30–24), regulated 5 VDC supply, and the Unitronics SM35-J-R20 PLC. The laser head is connected via an M12 5-pin bulkhead connector, with dedicated lines for power, communication (TX/RX), and the digital output (D1) used to trigger the PLC input (I0). Relay output O0 (COM–I4–NO) provides the control signal for downstream devices (e.g., fraction collector trigger), while common returns (0 V) and grounding are explicitly indicated to ensure safe and stable operation.

Here, we document the performance of nine more elements related to T3 showing their peaks (Figure S5) and carryover (%) in Table S3. The LOD and LOQ can be accessed in Table S4.



**Figure S5.** Concentration profiles for additional trace elements (Ag, Cd, Ce, La, Nd, Pb, Pr, Rb, and Sr) measured in the A-series carryover experiment (S1–S23), showing four enrichment pulses (S4, S10, S15, and S20) followed by rapid return to near-baseline levels in subsequent fractions.

### Melt head FEP surface-coated performance

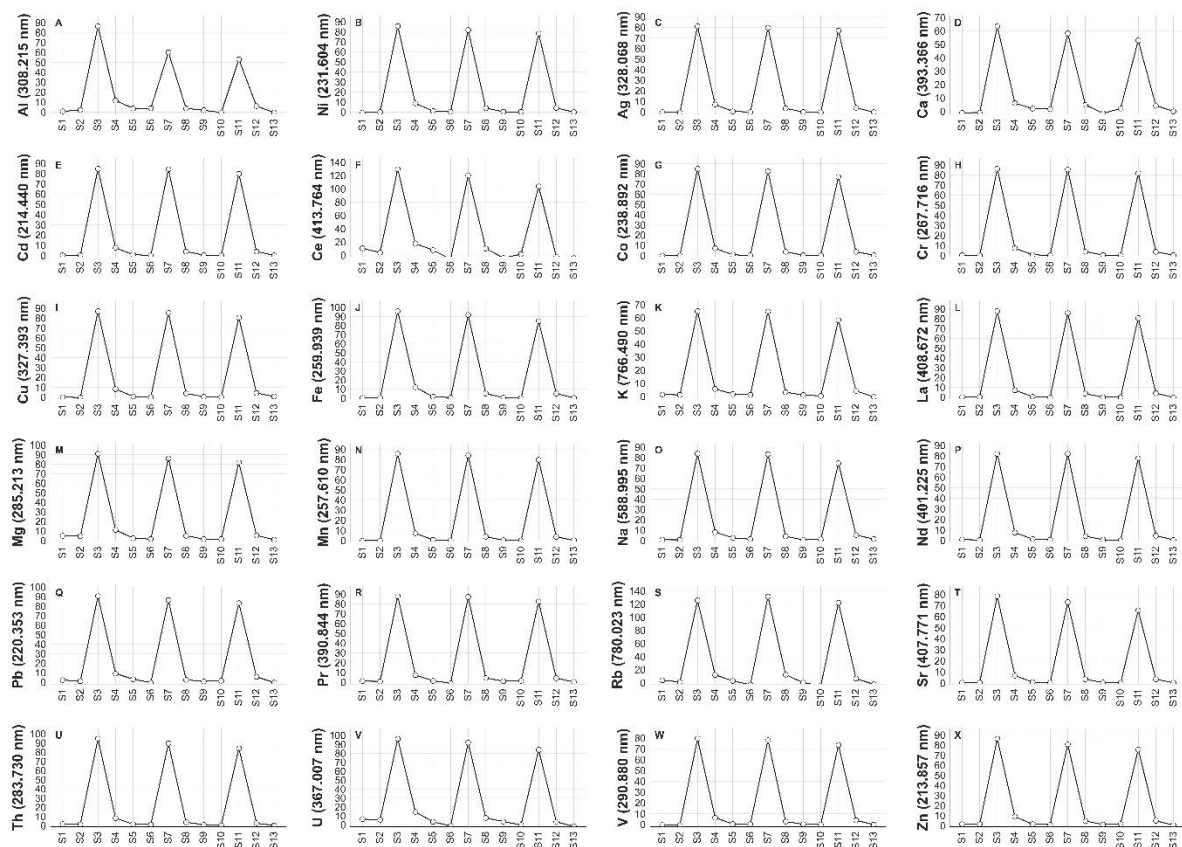
The FEP-coated melt head showed stable carryover behavior across all 24 elements evaluated (Figure S6). For the three pulse tests, immediate post-peak fractions for Al and Ni remained on the order of ~5–14% of the corresponding peak concentrations, comparable to the patterns observed for transition metals such as Cu, Fe, Mn, Co, and Zn, as well as for the major cations Ca, Mg, Na, and K. Post-peak responses for rare earth elements (La, Ce, Nd), Sr, Pb, Th, U, and V also fell within this low-to-moderate range, with rapid attenuation toward near-baseline levels by the second and third fractions. These results indicate that the FEP surface effectively suppresses adsorption-driven memory, yielding reproducible pulses with minimal residual contamination and no evidence of cumulative carryover along the sequence.

## **Consideration for usage**

Considering applications for other ice core archives, ice sections with high particulate loads (for example volcanic ash layers) need particular care during stages 2 and 3 of the melting procedure. In these cases, close attention to the flow sensors is needed to keep flow rates stable, maintain the target depth resolution, and limit excessive mixing. Although test T2 showed good performance for both high and low-salinity layers, cores with very different salinity regimes (such as brine-rich sea ice, polar ice-core records and tropical glacier ice) are best processed in separate runs, with dedicated cleaning steps between runs to minimize cross-contamination. Cleaning of the melt head and replacement of tubing and filter holders are labor and time-intensive, so these operations should be scheduled deliberately to minimize memory effects and cross-contamination for sensitive analytes.

Natural sea ice presents a complex analytical challenge due to physical and biogeochemical heterogeneity (Miller et al., 2015). These features are unpredictable, therefore, these validation and performance experiments represent a baseline for major variability expected in sea ice core records. Applying this system to natural sea ice cores will require careful optimization and may benefit from adaptive sampling strategies to manage these heterogeneities.

Concentration (ppb)



**Figure S6.** FEP-coated melt head test for 24 elements, showing three consecutive injections (S3, S7, S11) followed by low post-peak signals. For all elements, carryover is largely confined to the first fraction after each pulse and rapidly returns toward baseline, indicating limited memory effects and stable performance of the FEP surface across major, trace, and rare-earth elements.