Abstract: We have developed an Atom Trap Trace Analysis setup for $^{39}$Ar as well as an extraction and separation system for water and ice samples. Our results reveal the potential of this tabletop experiment based on laser cooling techniques to routinely measure small samples down to 0.1 mL STP of argon within less than a day. For the first applications to date groundwater we achieved a stable atmospheric count rate of $3.58 \pm 0.10$ atoms/h.

1. INTRODUCTION

Atom Trap Trace Analysis (ATTA) is an ultra-sensitive counting method for rare isotopes [1]. It is based on the high selectivity of resonant photon scattering during laser cooling and trapping distinguishing the rare isotope from the abundant ones. The special strength of this method is that for dating with long-lived isotopes only small sample sizes are required for practical measurement time.

2. METHOD

Our ATTA-apparatus follows the concept as the ones described by Jiang et al. [2, 3]. It consists of a liquid nitrogen-cooled metastable argon source driven by a RF-field. In different stages the divergent atom beam is collimated, focused and slowed down longitudinally below the capture velocity of the magneto-optical trap. With that a single atom can be detected observing its fluorescence light with an avalanche photo diode. The $^{39}$Ar concentration is inferred by the observed atom counts per time normalized by the carefully determined count rate of an atmospheric sample (commercial bottled argon). This approach requires a stable and reproducible performance of all components of the apparatus leading to robust $^{39}$Ar detection efficiency. Therefore, before and after each measurement different control measurements of the stable isotopes such as the $^{38}$Ar loading rate of the magneto-optical trap and the $^{40}$Ar atom beam profile are performed. Furthermore, we measure and stabilize all laser powers and frequencies actively and monitor the metastable atom flux, the laser powers and frequencies and locking signals during $^{39}$Ar measurements.

There are two different modes in which our apparatus can operate. In throughput configuration, where the sample is pumped out of the vacuum chamber, 0.5 to 1 L STP of argon is necessary for a 15- to 30-hour measurement. In recycling mode the gas circulates in a closed vacuum system. Thereby, less than 0.1 mL STP of argon is needed to run the system. Since the abundance of $^{39}$Ar ($^{39}$Ar/Ar = $8.23 \times 10^{-16}$) is about 600 times lower than that of $^{81}$Kr and about 25,000 times lower than $^{85}$Kr, enriched samples have been used to get a sufficient count rate for optimization and characterization of our setup. This however has induced a detectable contamination embedded in the vacuum system, which accumulates while operating in recycling mode. We can deduce from the accumulated background in recycling mode that its contribution is less than 2% in throughput configuration.
3. RESULTS

By systematic optimization with enriched samples we achieved an atmospheric count rate of 3.58 ± 0.10 atoms/h. A total number of 1162 $^{39}$Ar atoms were counted within 324 hours distributed over 28 single measurements each with a length of 3h to 21h. The statistics indicates the behavior of the expected Poissonian distribution. A small long-term drift could be correlated to the deterioration of the source monitored with our beam diagnostics tools. This count rate and stability are sufficient for dating of groundwater samples with $^{39}$Ar-ATTA [4]. An agreement on the 1σ-confidence level with the concentrations measured by Low-Level Counting in the underground laboratory in Bern was achieved. In addition, synthetic samples with known concentration covering the whole dating range also show excellent agreement.

4. CONCLUSIONS

Current developments such as more efficient cooling techniques and a source with a higher flux of metastable argon atoms aim to enhance the count rate. Shorter measurement times together with a reduction of statistical uncertainties thus are possible. Due to the contamination in the apparatus, we chose the throughput mode of operation and analyzed argon gas of several tons of water. It should be possible to reduce the contamination for recycling sufficiently by replacing the affected vacuum parts. In this case we expect a reduction in the needed argon to 0.1 mL STP, corresponding to about 0.25 L of water or 0.1 kg of ice.

REFERENCES