Supplementary file for:

**Percent-level production of $^{40}$Ar by an overlooked mode of $^{40}$K decay**

Jack Carter$^1$, Ryan B. Ickert$^{1,2}$, Darren F. Mark$^{1,3}$, Marrisa M. Tremblay$^2$, Alan J. Cresswell$^1$, David C.W. Sanderson$^1$

$^1$SUERC, Rankine Avenue, Scottish Enterprise Technology Park, East Kilbride, G75 0QF  
$^2$Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN 47901  
$^3$University of St Andrews, College Gate, St Andrews, KY16 9AJ, Fife, Scotland, UK

**Correspondence to:** J. Carter (j.carter.1@research.gla.ac.uk)

**X-ray counting experiment**

We attempted a pilot study to test whether the characteristic ~ 3.2 keV x-ray emitted during both ground state and excited state electron capture of $^{40}$K could be detected. In our experimental set-up, we used a 50 mm by 5 mm KCl disc as a $^{40}$K source and a thin Be-window Ge detector (Ortec LoAx). The source and detector were housed in Pb brick containment to limit x-rays from the surrounding environment. Counts were taken over ~ 250000 s (approximately 2.9 days) to test the possibility of detection. We show example spectra of the background, KCl, and KCl with background subtracted below (Figure S1, A - C).

![Figure S1](image-url)  
Figure S1. (A) Spectrum measured for the laboratory background, (B) KCl spectrum, and (C) KCl spectrum with background subtracted (C). The detector resolution in the ~3 keV region is approximately 50 eV at full-width half-maximum.

The lower limit of x-ray energy detection is approximately 3 keV, resulting in an exponential noise pile across the energy region we are attempting to observe (Figure S1 A). Unfortunately, this noise pile-up dominates the region of interest during measurement (Figure S1 B). The Ar-K x-ray is detected (Figure S1 C), but is difficult to resolve from the noise pile up. Note that the characteristic x-ray does not appear at exactly 3.209 keV due to what we believe to be a non-linearity in the relationship between energy and channel number in the detector. This demonstrates that the $^{40}$K characteristic x-rays can be detected in our simple experimental configuration.

**Conclusions and Recommendations**
The pilot study here shows the potential of determining the existence of the electron capture to ground state decay through the detection of characteristic ~3 keV x-rays associated with the relaxation of the daughter $^{40}$Ar nucleus after decay. However, the absolute verification requires the detection of excess x-rays that are not coincident with the $\gamma$-ray from the de-excitation of $^{40}$Ar$^{2+}$ to $^{40}$Ar$^{0+}$. In our experiment, a simple KCl source is used pressed to a thin disc to aid in the minimisation of self-absorption. However, this still results in a low count rate at the x-ray energy. Therefore, we recommend the use of a source enriched in $^{40}$K, and a thinner sample to limit x-ray self-absorption. We also recommend the use of a NaI detector which offers both greater resolution at low energies and a much lower detection limit. Furthermore, counting over a very long period, on the order of months, is required to accumulate enough measurements to yield a precise result. The low activity of the potassium may also require long counting experiments in extremely low background environments, such as the Boulby Dark Matter Laboratory.