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UNESE Argon-39 Measurement Techniques

Developing an above-ground Argon-39 Measurement Capability

January 2021

Thomas Alexander
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U.S. DEPARTMENT OF ENERGY

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Abstract

The Underground Nuclear Explosion Signatures Experiment (UNESE) sought to use ^{37}Ar as a tracer for measuring noble-gas migration in the soil surrounding historic Underground Nuclear Explosions (UNE). One unexpected observation was the presence of the much longer-lived isotope ^{39}Ar from historic UNEs. Quantifying the activity of ^{39}Ar proved difficult due to the lack of capability to measure significantly-above-background levels of ^{39}Ar and a general discomfort to repeatedly expose Ultra-Low-Background Proportional Counters (ULBPCs) to significant radioactivity. Because the whole-air samples collected for the ^{37}Ar tracer measurement were already being measured on the above-ground argon capability, it was decided to expand that capability to include ^{39}Ar. This document describes the efforts required to achieve quantitative reporting of the ^{39}Ar backgrounds measured during experiments at the sites of the historic Barnwell and Disko Elm UNEs.

Summary

The Underground Nuclear Explosion Signatures Experiment (UNESE) sought to use ^{37}Ar as a tracer for measuring noble-gas migration in the soil surrounding historic Underground Nuclear Explosions (UNEs). One unexpected observation was the presence of the much longer-lived isotope ^{39}Ar from historic UNEs. Quantifying the activity of ^{39}Ar proved difficult due to the lack of capability to measure significantly-above-background levels of ^{39}Ar and a general discomfort to repeatedly expose Ultra-Low-Background Proportional Counters (ULBPCs) to significant radioactivity. This document details the steps taken to improve the quantification of previously collected samples and to develop an above-ground capability for quantification of high-activity ^{39}Ar samples.

Samples collected as part of UNESE Phase 1 were counted in one of two energy intervals: a 3–400 keV window for ^{39}Ar and or a 5–15 keV high-gain window used to count ^{37}Ar samples. Due to the high activity of the samples, a broader energy window of 15–650 keV was chosen to observe both the ^{39}Ar beta endpoint energy and a background region. This method was utilized for analysis of all ^{39}Ar samples collected as part of UNESE Phase 2. Because of the unexpectedly high activity of some samples, a method was also developed to analyze samples using a reduced volume of the starting sample in order to lower the detector count rate.

In order to improve the quantification of ^{39}Ar in samples collected for both UNESE phases, a new ^{39}Ar gas standard was created with 10× the activity of the previous standard (Williams et al. 2017). This new standard allowed for better quantification of high-activity samples, because it was no longer necessary to scale up a low-activity reference sample which over-emphasized detector background and noise. The new ^{39}Ar standard was also used to recover additional data from Phase 1 samples that had been counted at nonstandard pressures, by counting at a series of pressures to develop a curve which could be fitted to calculate the ^{39}Ar activity from the early Phase 1 samples.

The results of this work have led to a reanalyzed set of ^{39}Ar measurements from the UNESE Phase 1 and Phase 2 gas migration experiments. These results have improved uncertainties, particularly in the case of the Phase 1 measurements. This analysis has led to increased confidence in the UNESE ^{39}Ar results and has improved the capability to measure high-activity ^{39}Ar samples in the future.

Acknowledgments

The authors wish to acknowledge the National Nuclear Security Administration, Defense Nuclear Nonproliferation Research and Development, and the Underground Nuclear Explosion Signatures Experiment, a multi-year research and development project sponsored by NNSA DNN R&D and collaboratively executed by Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Mission Support and Test Services, Pacific Northwest National Laboratory, and Sandia National Laboratories.

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Acronyms and Abbreviations

ADC	Analog-to-Digital Converter
AGC	Absolute Gas Counting
NNSS	Nevada National Security Site
PNNL	Pacific Northwest National Laboratory
ROI	Region Of Interest
SUL	Shallow Underground Laboratory
ULBPC	Ultra-Low-Background Proportional Counters
UNE	Underground Nuclear Explosion
UNESE	Underground Nuclear Explosion Signatures Experiment

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1.0 Introduction

The Underground Nuclear Explosion Signatures Experiment (UNESE) sought to use ^{37}Ar as one of several tracers for measuring noble-gas migration in the soil surrounding historic underground nuclear explosions (UNEs). Samples were collected from two sites within the Nevada National Security Site (NNSS) as part of the UNESE Phase 1 and Phase 2 experiments. The UNESE Phase 1 gas migration experiment was conducted at the site of the Barnwell UNE, U-20az, while UNESE Phase 2 was conducted in and around the U-12p tunnel (P-tunnel) complex with a focus on the site of the Disko Elm UNE (C. Johnson et al. 2019; Christine Johnson et al. 2020).

One unexpected observation was the strong presence of the much longer-lived isotope ^{39}Ar from the historic UNEs. Anecdotally, the first observation of ^{39}Ar in a UNESE sample was initially written off as a failing proportional counter that had begun to pulse uncontrollably; the rate was far beyond expectation for a ^{37}Ar sample. Closer inspection with an oscilloscope showed healthy gas-gain pulses at kHz rates. A small fraction of the sample was measured in the shallow underground lab to validate the signature was ^{39}Ar. (McIntyre et al. 2017).

Quantifying the excess ^{39}Ar proved difficult. The calibration measurements necessary to quantify these samples on the new above ground system had yet to be made. Further, it was unknown if the lifetime of the proportional counter would be severely reduced due to carbon buildup on the anode wire from so many radioactive decays. Because of this, there was a discomfort to exposing sensitive Ultra-Low-Background Proportional Counters (ULBPCs) to these samples to create the necessary reference measurements.

The samples collected for the ^{37}Ar tracer experiment were already being measured on the above-ground argon capability, so the obvious solution was to expand that capability to include ^{39}Ar as a measurable isotope. Samples were measured for ^{39}Ar in the same way the system measured ^{37}Ar: both were counted at the final pressure yielded from the whole-air separation process (not a whole number – e.g. 7 atm). Much of the data were taken before characterizing the efficiency of the system, with that task set to be a follow-up measurement to turn qualitative data into quantitative reporting. Later samples, primarily those for UNESE Phase 2, were all backfilled with P10 to bring the total gas pressure up to a uniform 10 atm before being measured for ^{39}Ar, which greatly simplified quantification.

This report covers the efforts to provide a quantitative analysis of ^{39}Ar in each sample measured under the UNESE project during the sampling campaigns for both UNESE Phase 1 and Phase 2. The results are a best effort at correcting data collected between 2016 and 2018.

2.0 Sample Analysis Strategy

Both long-lived radioisotopes of argon (^{37}Ar and ^{39}Ar) were measured using proportional counters at Pacific Northwest National Laboratory (PNNL). Several of the samples were sent to be counted in the Shallow Underground Laboratory (SUL) at PNNL (hereafter referred to as "underground"), but the vast majority were high enough in activity to be counted in an above-ground laboratory.

2.1 Measurement of ^{39}Ar

The isotope ^{39}Ar beta decays with a 565 keV endpoint energy and has a half-life of 269 years. The proportional counter is filled with argon purified from various sources—typically whole air or degassed water—and mixed with methane to produce P10 count gas. The detector is calibrated to a known gain by placing a ^{241}Am sealed source near the proportional counter body and then adjusting the high voltage to reach the desired dynamic energy range.

The isotope is measured by comparing the sample spectrum against a detector-specific background spectrum and an "efficiency" or reference spectrum from a known-activity ^{39}Ar P10 sample. These measurements must be performed at the same pressure as the sample pressure, because the stopping power of the gas leads to variations in the spectral shape for different pressures. By observing the expected detector response to a sample with known activity (reference standard), unknown samples can be quantified relative to the known sample.

2.2 Phase 1 Sample Analysis Strategy

The first measurements of ^{39}Ar in the above-ground proportional counting capability were performed on the Laboratory Prototype of the Argon Field System project. During the Phase 1 sampling campaign, ^{39}Ar measurements were made using an energy region of interest (ROI) from 3–400 keV. This method was used previously to measure ^{39}Ar from ground-water age dating samples in the underground (Mace et al. 2017). Though the energy window does not extend to the endpoint of the ^{39}Ar beta-decay spectrum, it was typically sufficient to encompass the measured spectrum for the counts (<100 per day) observed in the groundwater samples. For the UNESE sample set, however, the count rate was often high enough that the high-energy tail of the spectrum could not be observed with the 3–400 keV ROI; consequently, the spectrum was cut off at approximately 375 keV (not quite reaching 400 keV due to digitizer saturation). Figure 1 shows a spectrum from one of these early samples.

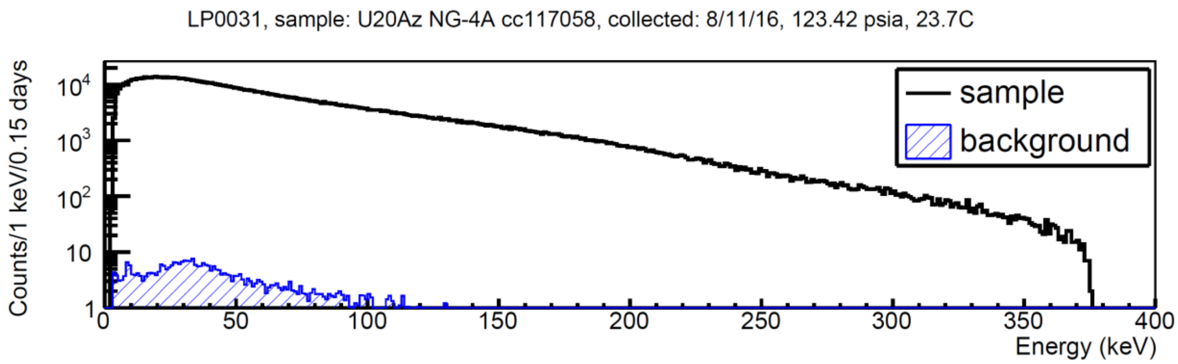

Figure 1. Example of an ^{39}Ar measurement from the Phase 1 sample set. Rounded off edges at the low energy threshold are a result of significant pile-up in the data. The sharp cut-off near 375 keV is a result of saturating the ADC at the supplied gain. The gain was chosen to mirror the underground measuring systems, which typically saw samples more similar the blue spectrum (background.)

As the rate of samples returning from the NNSS increased, a faster routine was necessary to maintain sample throughput. The 5–15 keV ROI of the ^{37}Ar measurement spectrum was utilized. This region falls above the expected ^{37}Ar signature and is comprised of only background counts from ^{39}Ar and other sample-independent sources, such as cosmic rays, backgrounds from the nearby shielding, and activation products in the detector itself. While only a small portion of the ^{39}Ar beta spectrum is observed in the 5–15 keV ROI, high count rates were believed to still allow for reasonable quantification. This method was expected to be viable due to initial studies performed in the underground, where backgrounds are consistently low.

2.3 Phase 2 Sample Analysis Strategy

For the Phase 2 sampling campaign, a measurement strategy more aligned with the needs of the UNESE experiment was chosen; for ^{39}Ar measurements the proportional counter gain was set such that the dynamic energy range was between 15 and 650 keV. This allowed for observation of the beta-decay endpoint and a region above the expected ^{39}Ar signature to observe any remaining backgrounds.

Samples from the Phase 2 borehole had higher ^{39}Ar activities than most of the Phase 1 campaign samples. In order to bring the count rates down, a method for down-blending the samples after chemical separation was developed. Samples from the Phase 2 borehole would initially process in the standard way; the argon gas would be separated from the whole air and then mixed with methane to produce P10 count gas. While ramping the detector voltage, the recorded count rate would be monitored. Samples that exhibited greater than 60 Hz in the detector would have most of the sample removed. The target pressure decrease on an activity reduction was typically from 5000–7000 torr down to 200 ± 50 torr. The sample would then be quantified in terms of the amount of gas left in the detector, rather than on how much was originally delivered to the proportional counter by the purification process. The sample would then be backfilled up to 10 atmospheres using Ultra P10 for measurement. Because ^{39}Ar measurements are made relative to the activity of Ultra P10, this did not introduce additional uncertainty. It is helpful to count ^{39}Ar samples at the highest available pressure; the increased gas density improves counting efficiency by increasing the stopping power of the count gas, thus allowing higher-energy betas to deposit more energy into the count gas and moving counts away from the triggering threshold of the detector.

Phase 2 samples had both a pressure-matched background and efficiency, reconstruction of these data was not necessary.

3.0 Data Recovery

Two tasks were accomplished to improve the quantification of ^{39}Ar in samples collected in UNESE Phase 1 and Phase 2. The first was the development of a high-activity ^{39}Ar P10 gas standard. This was used to characterize the above-ground proportional counters for ^{39}Ar. The second task involved measurement of the new ^{39}Ar standard at a series of detector pressures. Early samples collected as part of UNESE Phase 1 were counted at various pressures before the effects of pressure variations on the quantification were well-understood. By measuring a known standard at a series of pressures it was possible to improve the quantification of ^{39}Ar in those early samples.

3.1 The High-Activity ^{39}Ar Standard Gas

Accurate quantification of the high-activity UNESE samples required developing a high-activity P10 standard. An existing standard at about 50× atmospheric levels was available to the above-ground capability between the Phase 1 and Phase 2 sampling campaigns. However, the volume of gas available meant only 1 detector was able to be filled on the Lab Prototype system. The resulting measurement was bootstrapped successfully to quantify samples on the Argon Field System as well.

A high-activity P10 count gas (given the name AP-10) was created specifically to allow for the characterization of each above-ground proportional counter for ^{39}Ar. A single “Zone 1” sample from the borehole above P-tunnel was expanded from a proportional counter into a 15.6 L high-pressure gas cylinder and 1500 psi of Ultra P10 was mixed on top of the sample.

The AP-10 count gas was measured at 4 pressures in 3 ULBPC detectors of different lengths, by a technique known as absolute gas counting (AGC). Figure 2 shows the variation in spectral response observed from the AGC detectors and highlights the importance of having pressure-specific efficiency spectra. This technique has been demonstrated previously for ^{39}Ar (Williams et al. 2017).

The technique uses a larger amount of sample and time to analyze but allows for an absolute measurement of the specific activity, without the need to compare against an efficiency reference sample. Geometric effects are simulated to correct for detector wall and threshold effects. The corrected measurements performed at the lowest three pressures (3.0, 4.4, and 6.9 atm of P10) were consistent and were thus combined to obtain a best estimate of the AP-10 standard’s ^{39}Ar activity. The highest-pressure measurement (8.2 atm) was anomalously low (by ~2σ), a behavior also observed in previous measurements of radio-Xe samples. This anomalous behavior is attributed specifically to the three aging unequal length counters used for the AGC measurement and is not expected to affect measurements performed with the other proportional counters used in this work.

The AP-10 was measured to less than a percent of statistical error, with a mean value of 749.0±3.3 µBq/cc P10 @ NTP (293.15 K, 760 Torr.) This gas standard is then about 500× atmospheric levels. Often, the specific activity of a standard P10 is given as the activity of the analyte of interest. In this case, the AP10 is 896.5±3.9 µBq/cc Argon @ STP (273.15K, 750 Torr.)

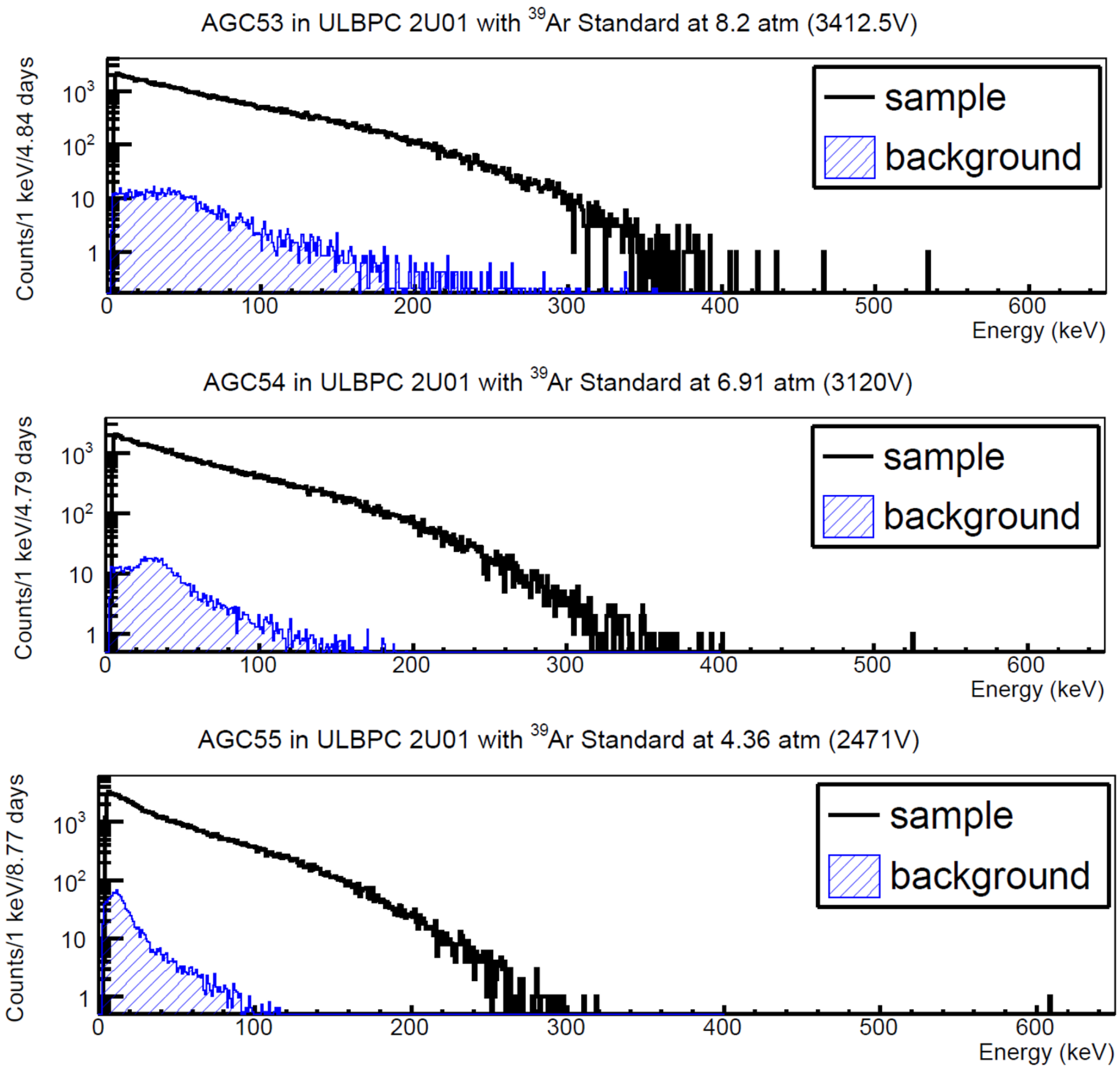

Figure 2. A comparison of the AP-10 measured at 3 different pressures in the same ULBPC for the AGC measurement, with corresponding backgrounds. The change in spectral response with pressure shown here helps illustrate the importance of having comparison spectra at each pressure that samples were measured.

While the nominally 50× standard was enough for underground measurements, it did not sufficiently dominate backgrounds in the above-ground system. By comparison, the nominal 500× standard sufficiently suppresses the backgrounds in an efficiency spectrum and builds confidence in the reporting using the full spectrum.

3.2 Collecting New Data for Old Samples

Once a large-volume high-activity efficiency gas was produced (AP-10), data could be acquired at all the necessary pressures in the argon Laboratory Prototype system. Along with varying pressures, the ADC triggering threshold was increased midway through the Phase 1 sampling campaign as pile-up in the samples became more well-understood. While this lowered pile-up %, it increased the number of variables that had to be accounted for in this re-analysis effort.

Because the efficiency measurement accounts for the expected pile-up for a given data acquisition configuration, data can be quantified assuming the efficiency measurement was made in the same configuration. Measurements of the AP-10 gas were taken from 7 to 10 atmosphere P10 in both the ^{37}Ar (0–15 keV) and ^{39}Ar (0–400 keV) gain settings at both trigger settings in increments of 0.2 atmospheres to capture the variations in spectral response that occurred during the actual sampling campaigns.

The sample was measured at 10 atmospheres of P10 at laboratory temperature, approximately 2 L of argon STP, in 5 different detectors. This measurement controls for differences in quantification, because the 5 detectors were open to each other during loading, thus removing temperature and pressure errors from intra-comparison. The deviation of count rates from these measurements is 0.91%, in good agreement with the previously quantified 1% uncertainty for the volumes of the proportional counters. The counters then are believed to be responding equally and the efficiency spectrum from one detector is considered acceptable for use in another detector. After each of the detectors completed the measurement at 10 atm, gas was successively removed in small quantities, the sample volume was re-quantified, and a measurement was taken for the multiple scenarios necessary to re-analyze the old data at varying pressures.

To further probe the uncertainty caused by considering the detectors to be interchangeable, all of the samples are plotted together with their sample volume plotted against the number of counts that passed all pulse-shape and coincidence cut logic. This is shown in Figure 3. The error caused by quantifying the argon—pressure, volume, temperature measurement errors—was found to be 1.36%, using the GUM method (Joint Committee For Guides In Metrology 2008). This is used as the error on the *x* axis, while the error on the *y* axis is purely statistical. The error reported on the slope of the linear fit, 2.2%, is taken as the total uncertainty on quantifying a sample with the added effect of detector generalization. Each sample in this study uses this value.

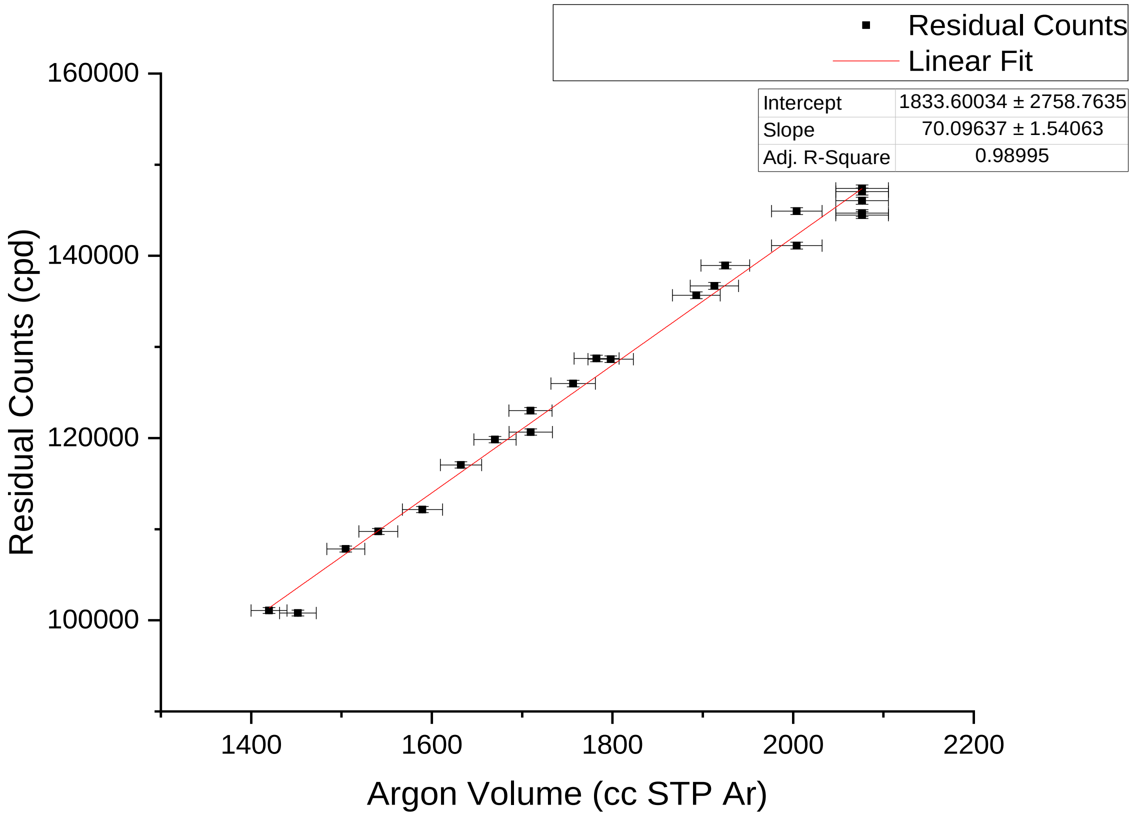

Figure 3. A subset of the data used to probe the total uncertainty of quantification for the method used to reconstruct the UNESE data. Due to the number of unique samples taken during UNESE, it was not feasible to get a detector-specific efficiency for each sample. The total uncertainty from quantification is taken as the uncertainty on the slope of the fit of this data. Though small, the offset is not constrained to zero to account for other backgrounds in the detectors.

4.0 Results from Re-Analysis of Phase 1 Samples

For a complete listing of results, see Appendix A.

The two kinds of samples that were re-analyzed were ^{39}Ar-specific 0–400 keV samples and 5–15 keV samples from the ^{37}Ar measurement. Accounting for the correct pressure and threshold when selecting the efficiency file for each sample allowed the ^{39}Ar activity between 6 and 10 atmospheres to be quantified satisfactorily. In total, the activity for 88 samples from the Phase 1 sampling campaign were quantified. The samples are analyzed using a Poisson model for the signal, a binomial model for the background, and a Gaussian model for the efficiencies. This is implemented using ROOT (Aalseth et al. 2013; Brun and Rademakers 1997). All of the values reported from this re-analysis effort are set at a confidence interval of 68%.

4.1 Discussion of Re-Analysis from 0–400 keV Samples

The AP-10 measurements between 7 and 10 atmospheres in the 0–400 keV gain setting were very successful in reproducing the data created from Phase 1 samples. In total, 41 samples were re-analyzed in this method.

While efficiency measurements at each 0.2 atmosphere step were created, backgrounds were only available at 8.5, 8.9, and 10 atmospheres. Most samples reported here had between 10^5 and 10^6 counts per day in the analyzed 0–400 keV ROI and were analyzed using the 8.5 atmosphere backgrounds. Accounting for differences in ADC threshold, the variation from the 8.5 atmosphere background from a 6 or 10 atmosphere measurement was found to be 1300 counts. This variation was scaled for the actual pressure of each sample and typically found to be insignificant compared to the ^{39}Ar activity of the sample. Additional caution was taken with samples where this was not true—if the background variations could impact the sample's reported activity, then a background at the correct pressure (±0.1 atm) was required to be collected or it was not included in this analysis.

It is worth comparing the best values reported from these analyses against an effort done in 2017 to bootstrap data (Figure 4) from the underground detectors, comparing the 5–15 keV region to the 3–400 keV region. There is a very strong correlation between the measured activity and the estimated activity, although the slope of the line points to a factor of 0.3553 relating the two. It is believed that this factor is a combination of the differences in the pre-amplifier hardware between the above- and under-ground systems, as well as the fact that most of these samples, when originally measured in the above-ground system, exhibited significant pile-up that would later be remedied by increasing the ADC threshold for triggering.

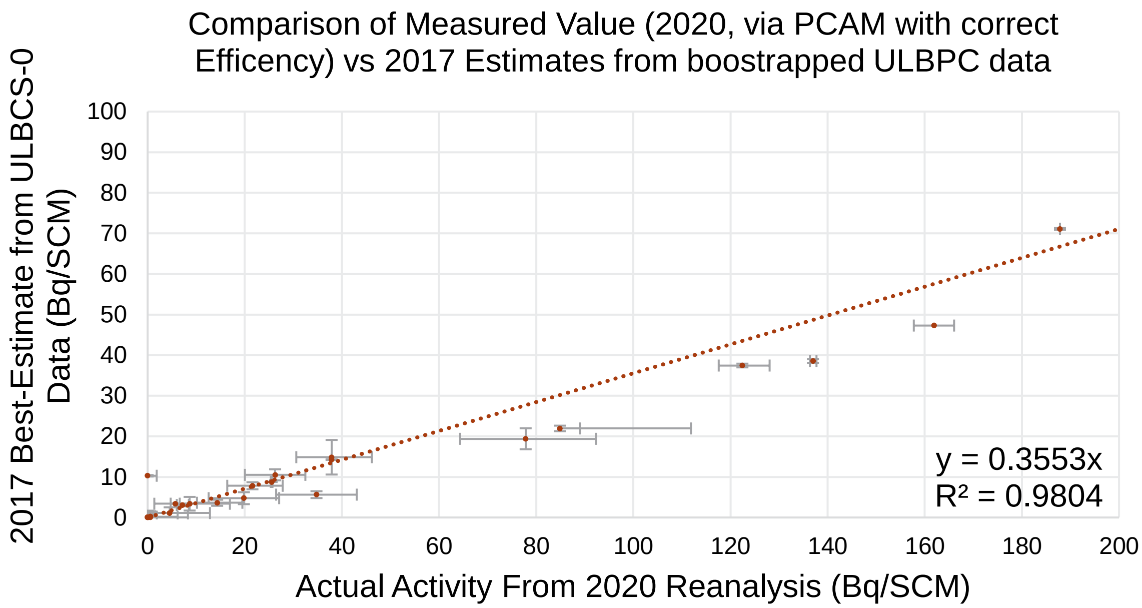

Figure 4. Relationship showing the current analysis vs a previous effort to estimate the activity of the Phase 1 samples. The current analysis considers more sources of error, such as quantification and rate, that were not yet fully understood in 2017.

4.2 Discussion of Re-Analysis from the 5–15 keV Samples

Analysis of the ^{37}Ar ROI samples for ^{39}Ar was accomplished by the same methodology as the 0–400 keV samples, except a significantly smaller percentage of the beta-spectrum was observed. For samples where the ADC threshold was set lower, only about 4.5% of the full spectrum is observed in the 5–15 keV region (Figure 5), as compared to 63% in samples measured in the 0–400 keV region. In lower-activity samples, the region was reduced to 10–15 keV if a mismatch in the 8 keV peak caused by the excitation of copper from cosmic rays created uncertainty; this occurred for very few samples. At the higher ADC threshold, which features significantly fewer events rejected due to pileup, the efficency improves to 9% of the full-spectrum counts. When coupled with additional uncertainties, such as with stable gas quantification, the error bars for the 68% confidence interval blow up quickly, with most samples having errors approximately in the range of -20% to +80% of the best value. While it was hoped that quantifying these samples would prove to be useful additional datapoints, the large uncertainties relegate this data to being verification of measurements of the backgrounds observed in earlier samples.

A subset of this type of sample was also initially analyzed improperly due to a bug in the data collection software developed for the laboratory prototype system. The time in which the pulse began recording to disk relative to the start of recording varied when the ADC triggering threshold was adjusted from 15 to 30 on some channels. This in turn affected the pulse processing algorithms, which expected the start of the pulse to be in a different location, causing the pulse-shape analysis routine to mischaracterize a significant number of pulses. For this re-analysis effort, the pulse-shape analysis routine was adjusted to properly find the start of these late pulses on a sample-by-sample basis, reinstating pulse-shape discrimination identical to unaffected samples.

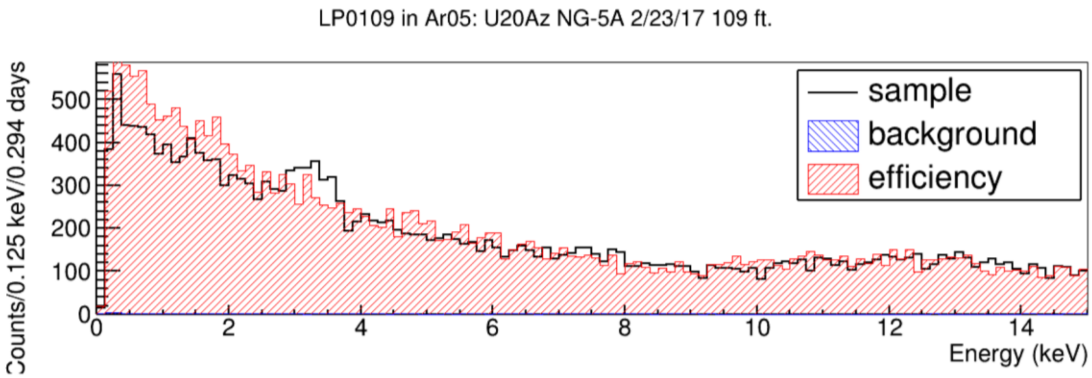

Figure 5. Example of a measurement made using the 5–15 keV region for ^{39}Ar. Below 5 keV, the low-energy response can become poorly behaved as activity increases. ^{37}Ar activity in a sample can also cause quantification issues. Above 5 keV, the sample and efficiency are often in very good agreement. Notice that background is not visible on a linear scale; because the background is scaled for sample time, it is not visible concurrently with the ^{39}Ar signal.

A similar comparison can be made to the 2017 analysis (Figure 6) of these samples from the 5–15 keV portion of the ^{37}Ar measurement. A similar slope is observed, and a similar R^2. While the error bars are much larger after the present effort, the increased statistical rigor from collecting efficiency data at each pressure and having comparison spectra lends significant trust to the measurements.

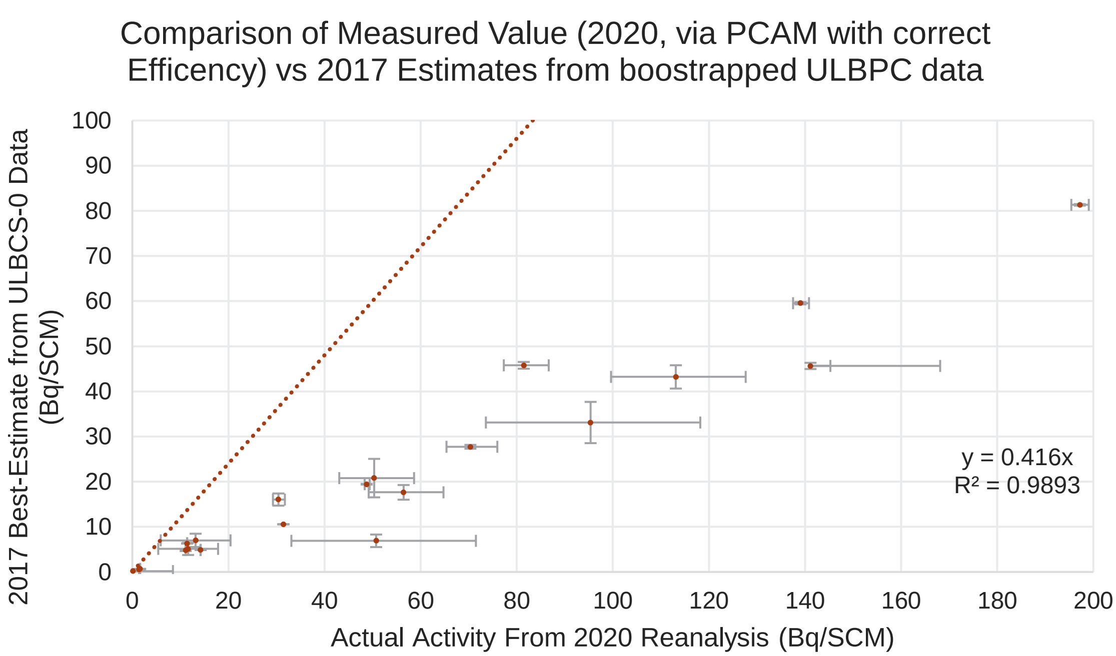

Figure 6. Relationship showing the current analysis vs a previous effort to estimate the activity of the Phase 1 samples. The current analysis considers more sources of error, such as quantification and rate, that were not yet fully understood in 2017. Not all of the 43 samples measured from the ^{37}Ar ROI were originally included in the 2017 estimates.

5.0 Conclusion

Dual-isotope measurement by using separate regions of the 0–15 keV spectrum has proven feasible, but the limited portion of the ^{39}Ar beta spectrum available for analysis in this ROI greatly expands uncertainty.

In this effort, a significant number of measurements from the UNESE Phase 1 dataset were re-evaluated using best practices for ^{39}Ar analysis. To accomplish this, a high-activity ^{39}Ar P10 standard was produced and characterized to allow for comparison of measured spectra in 0.2 atm increments from 7 to 10 atmospheres of P10. Additional uncertainty was evaluated for using one detector's efficiency spectra to analyze data collected in another detector. In total, 89 samples were re-evaluated, of which 86 samples were deemed reportable and 3 were deemed unreportable due to low sample pressure.

Comparisons were made to previous attempts to recover these data. The previous results were typically consistent with the "Factor-of-Two" caveat that came with their reporting. The separation can be assumed to be related to different pre-amplifiers being used in the underground and above-ground facilities.

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Appendix A – UNESE Phase 1 Results

Sample ID	Sample Identifier	Low Bound	Best Value	Upper Bound
		Bq/SCM	Bq/SCM	Bq/SCM
LP0026	U19c-PS1D #2	---	---	7.39E-03
LP0027	U20Az NG-1A (08/11/16)	198.22	205.48	212.74
LP0028	U20Az NG-3A (09/01/16)	0.16	0.17	0.18
LP0029	U20Az NG-2A (08/25/16)	36.74	37.88	39.23
LP0030	U20Az NG-2A (09/01/16)	19.20	19.82	20.55
LP0031	U20Az NG-4A (08/11/16)	611.25	648.61	692.20
LP0033	U19c-PS1D #1	0.52	0.54	0.56
LP0034	U20Az NG-2A (08/11/16)	132.84	136.99	142.18
LP0035	U20Az NG-2A (08/22/16)	116.23	120.38	124.53
LP0036	U20Az NG-5A (09/08/16)	216.90	225.20	233.50
LP0037	U20Az NG-3A (08/11/16)	13.91	14.32	14.94
LP0038	U20Az NG-2A (09/15/16)	156.70	161.89	168.12
LP0039	U20Az NG-1A (09/15/16)	4.37	4.54	4.71
LP0040	U20Az NG-4A (08/25/16)	408.88	422.38	436.90
LP0041	U20Az NG-3A (09/15/16)	20.86	21.59	22.31
LP0042	U20Az NG-4A (09/08/16)	23.77	25.53	27.40
LP0043	U20Az NG-5A (08/11/16)	72.96	77.83	83.44
LP0044	U20Az NG-1A (09/01/16)	235.58	253.22	273.97
LP0047	U20-Az NG-3A, 9/28/16	---	---	---
LP0048	U20-Az NG-5A, 9/15/16	149.44	122.46	126.61
LP0049	U20-Az NG-5A, 9/28/16	226.24	233.50	241.80
LP0050	U20-Az NG-5A, 9/29/16	181.61	187.84	194.06
LP0051	U20-Az NG-5A,10/20/16	79.91	84.89	90.49
LP0052	U20Az NG-4A,10/31/16	---	---	---
LP0053	U20Az NG-3A, 10/19/16	24.70	26.26	28.02
LP0058	U19c Post-shot pipe background	0.55	0.57	0.59
LP0060	U20Az NG-1A 11/3/16 - CC050050	0.52	0.54	0.57
LP0061	U20Az-NG-2A 11/3/16 - CC053318	406.81	617.48	1276.47
LP0062	U20Az-NG-5A 12/13/16-CC050068	236.61	244.92	253.22
LP0063	U20Az-NG-2A 12/13/16-CC053124	585.31	607.10	629.93

LP0065	U20Az-NG-5A 11/3/16 -CC053140	108.97	116.23	124.53
LP0066	U20-Az NG-3A 11/3/16	33.42	34.77	36.32
LP0067	U20Az-NG-1A, cc053447	239.73	246.99	255.29
LP0068	U20-Az NG-5A 12/14/16 cc121814	236.61	243.88	252.18
LP0069	LP0059 (U19c-PS1D #1) Split (1atm @ 10 atm P10)	1795.36	1868.00	1951.02
LP0071	U2ez Ar2-Shallow - CC053687.	8.37	8.64	8.94
LP0073	U2ez-Ar1-Deep. CC16378.	36.74	37.88	39.23
LP0075	U2ez-Ar2 - CC026045	27.92	28.85	29.78
LP0076	U2ez Ar1-Middle - CC053428	22.42	23.04	23.77
LP0077	U2ez Ar2-Middle. CC053694. 8.1 atm P10	5.22	7.14	11.31
LP0078	U2ez Ar1-Shallow - CC049998	5.52	5.68	5.85
LP0079	20Az NG-4A. 4/11/17. cc 122258.	421.34	449.36	480.49
LP0080	U20-Az NG-4A 4/10/17 cc 121666	59.26	60.09	60.92
LP0082	U20Az NG-4A April 10, 2017. 184 Ft	22.62	31.44	51.27
LP0083	U20Az NG-2A April 11, 2017 Overnight	544.83	745.12	1172.69
LP0089	U20-Az NG-3A # cc056085	10.48	13.18	17.85
LP0090	U20Az NG7 4/25/17 cc05060704	0.97	1.43	2.70
LP0091	U20Az NG-3A 90 ft. 2/22/17. cc056052	24.08	30.41	41.20
LP0092	U20Az NG-5A 2/23/17. cc121805	99.73	135.95	214.82
LP0093	U20Az NG-6A-Middle. CC049979	58.43	80.12	126.61
LP0094	U20Az NG-1A-10 4/11/17 P256699	9.07	11.42	15.46
LP0095	U20Az NG-3A 2/13/17 cc122255. 184 ft.	64.65	81.47	110.00
LP0096	U20Az NG-3A 90 ft. 4/11/17. cc049970.	17.95	22.62	30.72
LP0097	U20Az NG-1A 2/23/17. cc117058	191.99	256.33	386.05
LP0098	U20Az NG7-Deep 4/25/17. cc053128	35.08	48.78	79.81
LP0100	U20Az NG-2A 12/14/16	441.06	556.25	753.43
LP0101	U20Az-Tedlar. Cc053140	182.65	341.43	381.90
LP0102	U20Az NG6-Deep	79.18	113.12	195.10
LP0103	U20Az NG-2A 4/12/17.	414.07	573.89	1026.36
LP0104	U20Az NG-1A-3. 4/12/17	145.29	197.18	306.14
LP0105	U20Az NG-5A-Deep	193.03	257.37	386.05
LP0106	U20Az NG-5A-Top	36.43	50.75	82.81
LP0107	U20Az - Soil PT 4/12/17. P264019.	7.72	11.10	19.51
LP0108	U20Az NG-5A. 131 ft. P264021. 4/11/17.	95.89	141.14	265.67

LP0109	U20Az NG-5A 2/23/17 109 ft.	38.40	56.46	106.89
LP0110	U20Az-GZ, 6 ft. P 256770.	8.50	11.62	18.47
LP0111	U20 Az NG-6 Shallow. 4/27/17. P264022.	50.64	70.36	115.19
LP0112	U20Az NG7-Shallow	1.23	1.63	2.39
LP0114	U20Az-NG1A cc053149	105.85	139.06	202.37
LP0115	U20Az - NG1A-1 6/8/17	---	---	---
LP0131	U20Az NG-5A Deep 480 6/7/17 cc 121779	9.67	14.22	26.88
LP0132	U20Az NG-4A-2 06/08/17 cc050050	709.84	999.38	1691.58
LP0134	U20Az NG-5A-Shallow 06/08/17 cc053124	240.76	316.52	461.81
LP0139	U20Az NG-5A Shallow 6-6-17. P256889	63.82	95.37	188.88
LP0141	U20Az Air Sample	0.13	0.16	0.20
LP0142	U20Az NG-1A-2 6/7/17 P210598	19.41	20.55	21.69
LP0149	U20-Az NG-1A-1 6/8/17 cc053318	110.00	129.72	157.74
LP0150	U20Az NG-3A-1 @ 90 ft. 6/8/17 cc053447	35.91	50.33	84.06
LP0171	U20Az Tarp 1 no Blower	0.01	0.03	0.04
LP0173	U20Az Pit Bottom AS0629810	1.42	2.21	5.01
LP0176	Soil PT S Tarp no blower 8/10/17 CC050044	0.67	0.81	1.02
LP0177	U20Az Tarp 2 no Blower	0.06	0.09	0.16
LP0180	U20Az PS Cavity 8/10/17 P264013	802.20	1035.70	1463.27
LP0182	U20Az Soil PT Ridge S P256770	0.47	0.68	1.20
LP0186	U20Az PS Cassing [sic] 8/10/17 P256699	49.40	59.88	75.97
LP0187	U20Az NG-5A-Mid 8/9/17 P256804	42.13	48.57	57.49
LP0189	U20Az Canyon 8/9/17 P264021	0.20	0.27	0.41
LP0193	U20Az Surface GZ PT P256778	2.17	3.20	6.10

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