

Performance Review of the High Efficiency Neutron Counter

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ABSTRACT

A performance review of several High Efficiency Neutron Counters (HENCs) has been conducted for the purposes of quantifying the ranges of the inherent operating parameters, and for the qualitative assessment of the application of these parameters for the measurement of various waste types. The HENC is a passive neutron counter intended for use with multiplicity counting techniques for the assay of 200 liter (55 gallon) drums containing plutonium contaminated waste. The counter utilizes 113 ^3He proportional tubes which are organized into multiple counting channels and are arranged in a 4π geometry about the assay cavity. An Add-A-Source (AAS) Matrix Correction assembly is incorporated into the counter as the basis for compensating the assay values for the perturbation of the drum contents. Prior to use in the field, several fundamental operating parameters for the HENC must be determined during characterization of the counter. These parameters are determined by the neutron response characteristics of the assay cavity and signal processing electronics, and are differentiated from more typical calibration parameters as they are determined without the need for actual or representative plutonium or mixed-oxide samples. Examples of operating parameters include HV plateau, die-away profile, pre-delay setting, dead time parameters, central empty drum efficiency, gate utilization factors and spatial response profiles.

The performance review is based on five HENCs manufactured in the span of approximately ten years, all of which are currently operating in the field at various nuclear facilities. The review serves to identify the range of values used for each of the operating parameters, and the impact on performance, if any, as a function of that range. The resulting database can then serve both as a standard by which future systems can be type tested, and as a source of initial settings for the operating parameters with the evident benefit of time-savings in the characterization process. By demonstrating that the HENC can be manufactured reproducibly and that basic tests can confirm that a new instrument conforms to the standard, behaviors of the class can be adopted. For instance the arduous procedure of establishing the AAS calibration and Total Measurement Uncertainty budget need not be repeated. Certain other ratio dependences, such as high-Z parameters and cosmic-ray rejection thresholds can be established quickly for guidance and changed as needed for a particular installation or application.

INTRODUCTION

The High Efficiency Neutron Counter (HENC) was originally designed and developed in a collaborative effort between Canberra Industries and the Department of Energy (through the LANL NIS-5 group) under a Cooperative Research and Development Agreement [1]. The counter was intended to accurately measure the plutonium content in 200 liter drums ranging

from fractions of a gram to several hundreds of grams for a wide range of matrix materials, and is capable of a relatively low minimum detectable activity (MDA) in a short count time. HENCs have been used (and continue to be used) at several waste disposal sites for measuring a variety of fissile and other radioactive materials, and for discriminating between low-level waste and intermediate-level waste for the quantification and sentencing of drums.

The nominal HENC assay cavity is a 81 cm (32") wide, 86 cm (34") long, and 102 cm (40") tall and can measure containers up to a size of 200 liter drums (57 cm diameter and 87 cm height). The counter utilizes 113 ³He-filled proportional counting tubes arranged in a 4π geometry about the assay cavity and is divided into 16 counting channels. Table I gives the distribution of tubes and counting channels around the assay cavity, as well as the active lengths. Each tube has a 2.54 cm outer diameter, a stainless steel wall, and is filled to 7.5 atmospheres partial pressure. For each detector bank the tubes are embedded in a 10 cm thick high density polyethylene (HDPE) moderator, and are located 1.1 cm from the inside wall of the sample cavity. The entire sample cavity and detector bank assembly is enclosed by an additional 30 cm thick HDPE moderator shield in order to minimize the neutron background from external sources. The signals from all the counting channels are 'OR'ed and processed using a Canberra™ JSR-14 multiplicity shift register which is a fully computer controlled neutron analyzer providing both neutron coincidence and multiplicity counting capabilities.

Table I. Distribution of ³He tubes around the HENC assay cavity

Bank Position	Number of Counting Channels	Number of ³ He Tubes	³ He Tube Active Lengths cm (inches)
Left Side	3	17	114.3 (45)
Right Side	3	17	106.7 (42)
Front (Load) Door	3	23	106.7 (42)
Rear (Unload) Door	3	23	106.7 (42)
Top	2	17	63.5 (25)
Bottom	2	16	73.7 (29)
Totals	16	113	

The HENC is equipped with a turntable/scale combination in the assay chamber on to which the drum is loaded, weighed, and rotated during assays. A conveyor and drawbridge system enables automated loading and unloading, and the system has the option of using both front and back doors depending on the facility throughput requirements. The AAS mechanism consists of a Cf-252 source (nominally 75 μCi) which is shielded in a HDPE storage module when not in use, and extended through a stainless steel tube using a Teleflex™ cable when exposure is required. The source can be moved to multiple positions using a motorized drive mechanism with typically 3-5 positions used per measurement. The positions run vertically along the central axis of one of the side walls of the assay cavity, and the rotation of the drum serves to average out the perturbative effect of the AAS. Full descriptions and performance evaluations of the counter can be found in [2, 3]. Figures 1 and 2 are photographs of two different HENCs; one used for in-situ operations and the other used for mobile assay operations.



Fig. 1. HENC assay system for installed operations.



Fig. 2. Mobile HENC assay system.

OPERATING PARAMETERS

The operating parameters for the HENC are typically determined using Cf sources at the factory prior to transport. A distinction is sometimes made between *characterization* parameters which are intrinsic to the general behavior of the counter, and *calibration* parameters which refer more to the expected assay sample. Calibration parameters are often re-determined after delivery and setup on site where representative plutonium standards are typically more readily available. The operating parameters will be compared for the different HENCs and the range of variation in the values will be examined. Some characterization parameters are set to prescribed values based on test measurements (pre-delay, gate-width) and so the range of variation will not be discussed for these parameters. For some parameters, such as the Reals-per-unit-mass calibration constant (cps/g Pu-240 effective), an initial determination is made at the factory using a Cf source and the extension is made to the Pu case based on nuclear data and a scale factor for the efficiency which is obtained using numerical calculations (typically with Monte Carlo methods). Once delivered to the site from the factory, this parameter is often re-determined with reference Pu samples. The rest of the parameters typically remain unchanged from the initial factory settings, but where both factory and on-site values are available for a given instrument, any differences will be discussed in the comparisons. For two of the HENCs (referred to as #1 and #2) only the factory parameter settings are available; for the other HENCs (#3, #4, and #5) both factory and current operating (or on-site) values are available.

Descriptions of the characterization procedure for typical neutron counters undertaken using Cf can be found in [4]. A more comprehensive calibration procedure particular to the HENC and using Pu standards can be found in [5]. A comparison of the factory characterization parameters for the different HENCs is given in Table II. Where available uncertainties in the values are reported as well.

Table II. A comparison of operating parameters for various HENCs

Parameter	HENC #1	HENC #2	HENC #3	HENC #4	HENC #5
High Voltage (Volts)	1760	1740	1720	1720	1720
Pre-delay setting (μ s)	4.5	4.5	4.5	4.5	4.5
Die-Away time (μ s)	50	50.2	49.2	51.97	48.6
Gate Width (μ s)	128	128	128	128	128
NCC [†] dead-time Parameter 'a' (μ s) b' (μ s ²)	a = 0.4502 b = 0	a = 0.4512 b = 0	a = 0.4621 b = 0	a = 0.4866 b = 0	a = 0.498 b = 1.61e-07*
Multiplicity dead-time Parameters (ns); 'c' - Doubles; 'd' - Triples	c = 88.80 d = 88.80	c = 89.39 d = 89.39	c = 97.94 d = 97.94	c = 115.2 d = 126.6**	c = 147 d = 147
Characteristic Multiplicity Dead-time parameter (δ - ns)	114	112	118	111	171
Efficiency (Pu volume average)	(30.85 \pm 0.49) %	(31.17 \pm 0.48) %	(31.33 \pm 0.20) %	(30.85 \pm 0.50) %	(29.44 % \pm 0.40)%
Doubles Gate Fraction (f_d)	0.6204	0.6259	0.6034	0.6147	0.6133

Triples Gate Fraction (f_t)	0.4201	0.4356	0.4040	0.4198	0.4039
Cf-252 ρ_0	0.2934	0.2968	0.2951	0.2925	0.2817
Cf-252 'g _{Cf} ' (cps / ng Cf-252)	205.38 ± 1.29	213.63 ± 1.34	209.03 ± 1.25	203.95 ± 2.6	193.7 ± 0.56
Pu-240 ρ_0	0.1654	0.1672	0.1663	0.1648	0.1587 [‡]
Pu-240 'g' (cps / g Pu-240 effective)	53.06 ± 0.33	55.19 ± 0.35	54.00 ± 0.32	52.69 ± 0.67	50.04 ± 0.14

[†] NCC – Neutron coincidence counting

* The value of the NCC dead-time Parameter 'b' is typically set to zero in most cases; for the count rates encountered in most HENC applications the small non-zero value for 'b' has a negligible effect as will be shown later in the text.

** The multiplicity dead-time Parameter 'd' is typically set equal to the value of the parameter 'c'. The effect of variations in these values are discussed in detail in the text.

[‡] The original factory determined value for ρ_0 (Pu-240) for HENC #5 was not available, but as it is derived from the value obtained for Cf it was re-evaluated in a straightforward manner. The derivation is shown in the text.

In order to quantify the variations amongst the HENC settings for each parameter in Table II, a mean value was calculated by taking a simple average of all the HENC settings for that parameter. Table III then shows the variations of the individual values from the mean value for each parameter. In cases where the value for one HENC is quite different from the others the mean is necessarily biased and the individual variations will appear to be larger. These cases will be discussed individually. It must also be noted that the uncertainties in the parameter values are ultimately tied to the uncertainties in the sources used for the characterization, and the statistical uncertainties in the measurements. Uncertainties in the factory Cf sources that are used for these measurements are typically no worse than 2% at the one-sigma level. For cases where multiple sources are needed, as in the dead-time measurements, the use of additional sources sometimes involves including sources with larger uncertainties. Typically in the measurements with multiple sources, minimization techniques are used to obtain the final value for the parameter so the effect of the sources with the larger uncertainties tends to be minimized. Even so there will always be a limitation in reducing the uncertainty with which a given parameter can be determined.

Table III. Deviation from mean value for HENC operating parameters

Parameter Deviation from Mean (%)	HENC #1	HENC #2	HENC #3	HENC #4	HENC #5
High Voltage	1.62%	0.46%	-0.69%	-0.69%	-0.69%
Pre-delay time	0.00%	0.00%	0.00%	0.00%	0.00%
Die-Away time	0.01%	0.41%	-1.59%	3.95%	-2.79%
Gate Width	0.00%	0.00%	0.00%	0.00%	0.00%
NCC Dead time Parameter 'a'	-4.14%	-3.92%	-1.60%	-4.22%	6.04%

Multiplicity Dead time Parameter 'c'	17.52%	16.97%	9.03%	7.00%	36.53%
Dead time parameter 'δ'	9.14%	10.51%	5.61%	11.31%	36.57%
Efficiency (Pu volume average)	0.40%	1.44%	1.96%	0.40%	-4.19%
Doubles Gate Fraction (f_d)	0.79%	1.68%	-1.97%	-0.14%	-0.36%
Triples Gate Fraction (f_t)	0.82%	4.54%	-3.04%	0.75%	-3.07%
Cf-252 ρ_0	0.51%	1.68%	1.10%	0.21%	-3.49%
Cf-252 'g'	0.12%	4.14%	1.90%	-0.58%	-5.58%
Pu-240 ρ_0	0.55%	1.64%	1.10%	0.20%	-3.50%
Pu-240 'g'	0.12%	4.14%	1.90%	-0.58%	-5.58%

The high voltage setting is determined by a plateau measurement and is typically set at 40 volts above the knee of the plateau curve in order to give a stable operating point that is still far below the γ -ray break-away region in normal operating environments. The value is therefore not critical. The variation in this value, which is tied to the collective response of the ^3He tubes and the gain settings on the pre-amplifier boards as well as to the intrinsic efficiency of each counter, is seen to be small varying less than 2% from the mean setting for all five HENCs. The pre-delay setting is typically chosen based on measurements made with an AmLi source and for the HENCs has always been set to 4.5 μs . The measurements are used to confirm the absence of bias between the Reals + Accidentals (R+A) and the Accidentals (A) gates, and a setting of 4.5 μs is large enough to achieve this. The die-away time (determined by measurements made at various gate widths) is affected most by the physical layout of the HENC including the placement of ^3He tubes and the moderating material in which they are embedded. The variation across counters is seen to be at most 4% from the mean, most likely reflecting manufacturing tolerances in the components, and variations in density for the (HDPE) obtained from suppliers. Given the die-away time the gate-width setting is chosen based on an analysis of the same data and reflects a compromise choice between maximizing the Reals precision and minimizing the effects of background.

The rest of the parameters are determined based on multiple measurements with different sources. The efficiency is quoted for a point source in the center of the assay volume, where a weighted average is taken of the efficiencies obtained from the different source measurements. In addition to the uncertainty associated with the source pedigrees, the effect of Cf-250 build-up relative to Cf-252 must be taken into account if the sources are old. The efficiency determined with the Cf source is scaled by a factor of 1.02 for Pu, where the factor is obtained from numerical modeling. In addition the point source efficiency is scaled by another factor of ~ 1.015 to obtain a volume-averaged efficiency for a 55-gallon drum. Where possible the efficiency is verified on site using Pu calibration samples. The efficiencies for four of the HENCs are found to be tightly grouped

within 2% of the mean value. The efficiency for HENC #5 is found to be 4% different from the mean. This is most likely explained by the fact that HENC #5 was the first HENC built and was originally constructed with less HDPE in front of the ^3He tubes. The HDPE thickness was later modified (and now matches the HDPE thickness in the other HENCs) and the efficiency value re-determined and used in the field is $(30.40 \pm 0.50)\%$. This value is an increase of ~ 1.03 over the original value, and brings the efficiency for HENC #5 within 2% of the mean value discussed above.

By ensuring that the inventory of sources used has a wide range in neutron emission rates, the dead-time parameters can be obtained for both the neutron coincidence counting (NCC) and multiplicity counting scenarios. For the NCC case the parameters are obtained by fitting the corrected Reals to Totals ratios to a constant value. For the different HENCs the values for 'a' are found to be within 4% of the mean for four of the HENCs but 6% different for HENC #5. The parameter 'b' is typically found to be best set to zero using a chi-squared minimization technique, but is set to a non-zero value for HENC #5. The difference in values, however, has a negligible effect on the final result. The NCC deadtime correction factors CF_T (for the Totals) and CF_R (for the Reals) take the forms shown in equations (1) and (2).

$$CF_T = e^{(a+bT)T/4} \quad (\text{Eq. 1})$$

$$CF_R = e^{(a+bT)T} \quad (\text{Eq. 2})$$

Here T is the measured Totals rate. Even for a Totals rate as high as 100,000 counts/sec a value for 'a' of $0.45 \mu\text{s}$ results in corrections of 1.011 for CF_T and 1.046 for CF_R . Using a value for 'a' of $0.50 \mu\text{s}$ as an upper bound for the variation across the HENCs, the correction factors change by less than 0.50%. The result of using the non-zero value for 'b' has even less of an impact.

In the case of the multiplicity dead-time corrections three parameters are used. The parameter τ is the primary correction parameter and is tied to the alpha and beta matrixes. Here the variations from the mean are clearly biased by the value for HENC #5, without which the variations in values amongst the other four HENCs are found to be within 4% of the mean value. The remaining parameters c and d serve as correction factors to the measured doubles and triples rate respectively. Typically the value 'd' is set equal to the value 'c'. Here larger variations are seen between the values; HENCs #1 through #3 have values for this parameter that are closer, but HENC #5 has a value that is vastly different from the other settings. Without including the value for HENC #5 in the mean, the variations between the other four HENCs are found to be within 15% of the mean value. The large difference in dead-time values for HENC #5 is presumably due to the fact that it was the original HENC and was not equipped with de-randomizer boards thus giving a larger dead-time. (The TTL pulse width from each pre-amplifier/discriminator board is nominally set to 52 ns.) As in the case for NCC, the dead-time corrections in the multiplicity case are rarely accuracy limiting for the normal domain of HENC applications. The deadtime correction factors CF_S (for Singles), CF_D (for Doubles), and CF_{Tr} (for Triples) are given in equations (3)-(5).

$$CF_S = e^{\delta S} \quad (\text{Eq. 3})$$

$$CF_D = (1 + cS)e^{\delta S} \quad (\text{Eq. 4})$$

$$CF_{Tr} = (1 + dS)e^{\delta S} \quad (\text{Eq. 5})$$

where S is the measured Singles rate. Choosing a Singles rate of 100,000 counts/sec as in the previous example, the variations in correction factors based on the variations seen in the HENC values for 'δ', 'c', and 'd' are found to be less than 1%.

The gate fractions used in the multiplicity analysis are obtained from the measured Doubles to Singles ratios (for f_d), and the measured Triples to Singles ratios (for f_t), available from the measurements with the multiple sources. For f_d the values for all the HENCs are within 2% of the mean value, and for f_t the values for all the HENCs are within 5% of the mean value.

The quantity ρ_0 is used to calculate the multiplication correction in the standard NCC (known alpha) method. It is determined by measuring the Reals/Totals ratios for several Cf-252 sources and provides a reference value for the M=1 multiplication case from which the sample multiplication can be determined. The reference value determined for Cf-252 ($^{Cf-252}\rho_0$) can then be used to obtain a value for Pu-240 ($^{Pu-240}\rho_0$) based on the known multiplicity moments for Cf-252 and Pu-240 as shown in equation (6).

$$^{Pu-240}\rho_0 = ^{Cf-252}\rho_0 \frac{\overline{v_{240}(v_{240}-1)}}{v_{252}(v_{252}-1)} \cdot \frac{v_{252}}{v_{240}} \cdot 1.02 \quad (\text{Eq. 6})$$

Here the subscripts '240' and '252' indicate the spontaneous fission moments for Pu-240 and Cf-252 respectively, and the factor of 1.02 is a correction to the Cf-252 response used for applicability to the Pu-240 case. Since $^{Cf-252}\rho_0$ and $^{Pu-240}\rho_0$ are related by constant values obtained from the known nuclear data, a comparison of either of the parameters is sufficient to examine the consistency among the different HENCs. For HENC #5 the factory value for $^{Pu-240}\rho_0$ determined at the time of the original calibration was not available, so the value in Table II was obtained from $^{Cf-252}\rho_0$ using Eq. (6). For HENC #4 the factory calculated value for $^{Pu-240}\rho_0$ was quoted as 0.1616, but a determination from the quoted value of $^{Cf-252}\rho_0$ using Eq. (6) gives instead a value of 0.1648. This discrepancy is possibly due to the use of slightly different values for the spontaneous fission moments (possibly obtained from a different reference than used in this study). For consistency in the comparison here, the re-calculated value was used. Based on the values in Table II and the deviations in Table III, the $^{Cf-252}\rho_0$ values (and similarly the $^{Pu-240}\rho_0$ values) are found to be within 4% of the mean for all five HENCs.

The calibration parameter 'g', is the relation between the measured Reals rate and the expected mass value. It is experimentally determined for cps/ng Cf-252 based on the measurements with the Cf sources, where the reference rates (and consequently masses) of the sources are obtained from certificates. An average value is obtained from the collection of sources used in the measurements. Since it is the Pu-240 effective calibration value (cps/g Pu-240 effective) that is used in operation, a value for $^{Pu-240}g$ is then quoted by adjusting $^{Cf-252}g$ for the differences in spontaneous fission moments and inherent fission rates as shown in equation (7).

$$^{Pu-240}g = ^{Cf-252}g \frac{\overline{v_{240}(v_{240}-1)}}{v_{252}(v_{252}-1)} \cdot \frac{473.5}{622.3} \cdot (1.02 \cdot 1.015)^2 \quad (\text{Eq. 7})$$

Note that in equation (7) a factor of 10^9 has been absorbed in the Cf-252 fission rate to account for the difference in quoting $^{Cf-252}g$ in cps/nanogram and $^{Pu-240}g$ in cps/gram. The calibration parameter $^{Pu-240}g$ is typically re-evaluated on site using certified reference Pu samples.

The comparison between all five HENCs shows that the values for $^{Cf-252}g$ are within 6% of the mean value with the HENC #5 value being most different. Without including this value in the mean the deviation amongst the other HENCs reduces to 3%.

Add-a-Source Correction Factor

The Add-A-Source (AAS) option provides a correction to the measured activity in order to account for matrix perturbations typically from hydrogen loading. The technique is fully described in [5]. The correction factor CF_{AAS} is defined as

$$CF_{AAS} = 1 + y \quad (\text{Eq. 8})$$

where 'y' is defined as the volume perturbation, and is tied to the AAS perturbation 'x' as shown in equation (9).

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 \quad (\text{Eq. 9})$$

The parameters a_i ($i=0,1,2,3$) are determined during the factory calibration by measuring the volume averaged drum response for various matrices relative to an empty drum ('y'), and correlating the response with the measured AAS perturbation ('x') also relative to an empty drum. The parameters a_i are then obtained by performing a fit to the data points, thereby producing the AAS calibration *curve* defined by equation (9). Figure 3 shows the AAS calibration curves for the different HENCs.

From Fig. 3 it is seen that as the AAS perturbation increases (corresponding to an increase in matrix moderation), the spread in the volume perturbation correction for the different HENCs increases as well. It should be noted that not all systems were calibrated with the same number and range of materials, and Fig. 3 does not show the raw data points which in fact give a reasonable dispersion depending on matrix uniformity and fill height. The data points also have an inherent uncertainty in the value of the AAS perturbation which is sensitive to the position of the AAS (within the guide tube) and reflector, relative to the matrix drum. In addition the fits are empirical polynomials through the origin and are either second or third order. The intertwining and crossing of the AAS curves would indicate that even though there is a range of dispersion, the calibrations are in broad accord.

In Table IV the range of volume perturbation values over all five HENCs is quantified for AAS perturbation values ranging from 0.2 to 1.0. Beyond an AAS perturbation value of 1.0 (which corresponds to a polyethylene matrix of density ~ 0.3 g/cc), the shape of the curve (a function of the order of the polynomial) drives the dispersion. In some applications a limit on CF_{AAS} can be set for the application of the AAS correction in order to preserve the total measurement uncertainty, and an alternative matrix correction technique may be used.

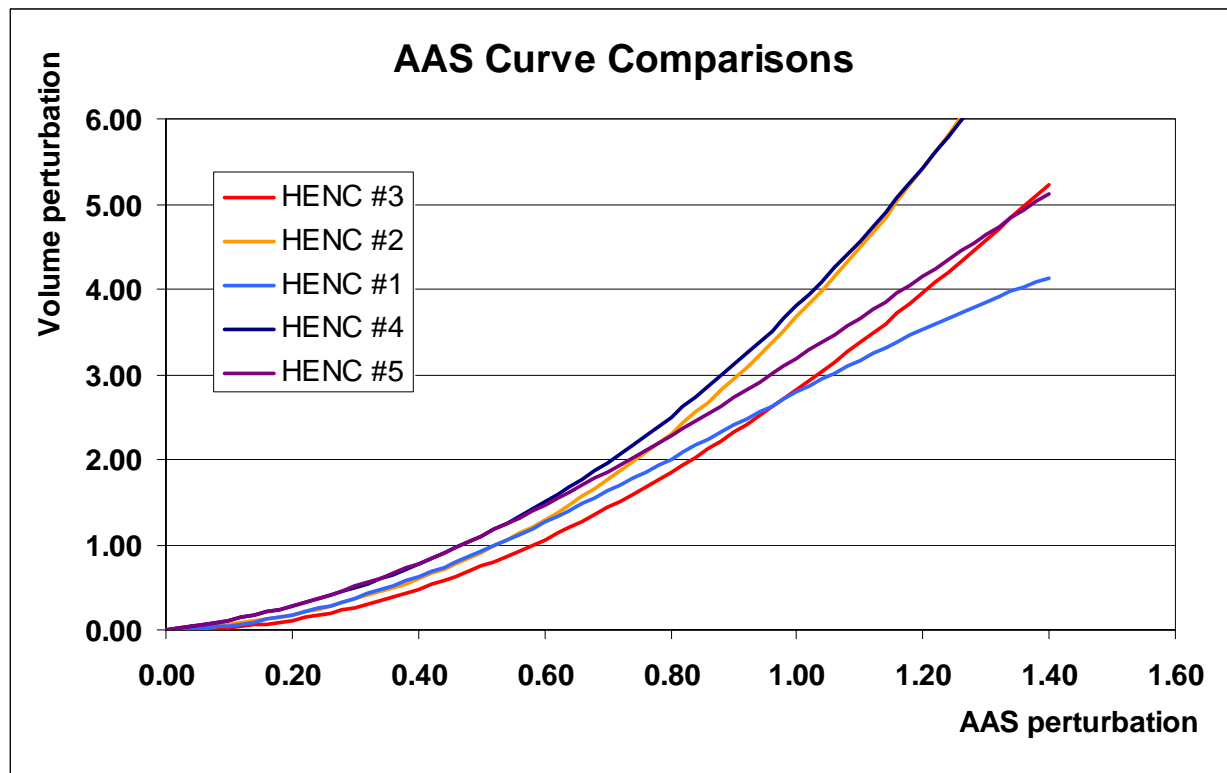


Fig. 3. Comparison of the operational AAS correction curves for different HENCs.

Table IV. Range of volume perturbation corrections for the different HENCs as a function of the AAS perturbation.

AAS Perturbation	0.20	0.40	0.60	0.80	1.00
Maximum volume perturbation	0.28	0.78	1.50	2.50	3.80
Minimum volume perturbation	0.12	0.48	1.06	1.85	2.79

If the range of AAS calibration curves in Fig. 3 is seen as an envelope that reflects the uncertainties discussed above, based on Fig. 3 and the values in table IV an ‘average’ curve can be constructed to approximately represent the midpoints of the range of values for all the curves. This ‘average’ curve may then be thought of and used as a default AAS calibration curve applicable to any HENC system, and within the bounds discussed the different systems would appear to perform equally. Depending on the accuracies sought in the application it may be acceptable to substitute this default curve for the typical calibration curve which is obtained by the extensive AAS calibration measurement process. The default curve may then be applied for a few test cases with reference samples and if the results prove to be acceptable the arduous AAS calibration process can be replaced.

CONCLUSIONS

A performance review of five (essentially) identical High Efficiency Neutron Counters (HENCs) has been undertaken in order to create a database of the fundamental operating parameters for waste drum assays. The review covers five HENCs manufactured over a span of about ten years. A comparison of operating parameters shows that for the high voltage, pre-delay, and gate-width settings the values chosen are either the same (by convention) or very similar (by design and build). The intrinsic efficiencies and die-away times for each of the counters were found to be within a few percent of each other. For the dead-time parameters and the gate fractions the values were seen to be very similar for four of the HENCs, but quite different for one instrument which is ascribed to a different electronics set-up. The multiplication correction parameter was found to be similar for three of the instruments, and different in varying degrees for the other two instruments. Finally, the calibration parameter relating the measured Reals rate to mass value was found to be very consistent among the five instruments. It should be noted that not all of the variation observed is due to manufacturing variances. Over the years the Cf-reference sources used to establish the factory calibrations and other parameters such as dead-time have been replaced or supplemented as they have decayed. Also for given applications different surrogate matrix sets with different materials and heterogeneity, including fill height variations, have been used.

Although some variability is seen in a few of the parameters for one instrument (for reasons that are understood), and in one parameter for two instruments, overall the database of available parameter settings can indeed be used both for type testing new instruments and for providing initial settings. Given the complexity of the instrument, however, a basic suite of measurements should still be made in order to confirm the choice of settings and establish confidence in the correct operation of the instrument. The desired accuracy to which the various settings must be known for a given instrument is ultimately dependent on the application in which the HENC is used. Bearing in mind the limitations in certification and availability of the calibration sources and possible statistical limitations in counting, the choice must be made on site if further measurements are required in order to better identify a given parameter over and above the value available for that parameter in the database. Typically relatively simple measurements can establish refined parameters for a particular instrument.

By establishing that the values for most parameters are similar between instruments (where design differences such as the presence or absence of a de-randomizer board do not exist), the database serves as the type test reference for future such systems. By demonstrating that the HENC instrument can be manufactured reproducibly, it follows that many basic properties of the counter, such as the relative spatial dependence which factors into the Total Measurement Uncertainty (TMU) estimator, are characteristic of the type; they do not need to be re-measured afresh for each new instrument built. It then becomes sufficient to undertake only basic functionality tests in order to confirm that the instrument meets the standard specifications. In addition this database can be used to obtain justifiable initial settings for the operating parameters for new instruments. This allows a speedy alternative to the typical characterization and calibration procedure in cases where either time constraints are prohibitive or where reference calibration samples cannot be procured. The instrument could be put into service following suitable verification checks with an allowance for the uncertainties on the key parameters based on the observed variation for the type.

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