OPTIMAL DIFFERENTIAL DIE-AWAY EARLY GATE STUDY FOR DIFFICULT ASSAYS

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ABSTRACT

Recent studies [1,2] have described a technique for determining the Differential Die-Away (DDA) early gate delay, and early gate width, with respect to optimizing the Minimum Detectable Activity (MDA) for plutonium in relatively low density matrix drums. The present study implements a similar technique for higher density matrix drums, for instance sludge, loaded with plutonium as well as mass loadings of other Special Nuclear Material (SNM). Particular attention is applied to the analytical form of the interrogating background parameter and its dependence to other DDA parameters. Finally, the optimal gate settings for the reduced variance of the zero matrix calibration parameter is compared to the optimal gate settings obtained via the minimal MDA technique [2] applicable to a wide range of matrix types, and densities, as well as various mass loadings of SNM.

INTRODUCTION

The Differential Die-Away technique [5,6] exploits the difference in die-away time between the Fast Neutron Detector Packages (FNDP) of the interrogating neutron flux to the die-away time of the neutron flux generated from fission events involving isotopes of Special Nuclear Material (SNM). Although the interrogating neutron flux is nearly dissipated before the fission flux first appears there remains a portion of "interrogating background" which must be subtracted from the fission flux to obtain the net fission flux signal. The net fission flux is proportional to the equivalent mass of the SNM.

What plagues the analyst is that the "interrogating background", B_I, is not generally known for an assay. Past [5,6] and recent [2,7] attempts have limited success with finding an appropriate functional dependence for B_I. In general, the rate at which B_I contributes to the net shielded detector count rate depends upon the counter-matrix coupling, *i.e.*, moderation and absorption, properties of the drum. In principle, one can minimize the B_I contribution and lessen the contribution by delaying the start of the early gate but this can compromise the Minimum Detectable Activity (MDA) [2]. Increasing the length of the early gate also "softens" the contribution but that also yields a higher MDA which is undesired [2]. An alternative technique is to calibrate for every matrix type [7] but this can prove cumbersome and expensive and cannot be utilized in environments where the matrix is not known.

This paper involves; a new parametric version of the interrogating background; and optimizing the zero matrix efficiency calibration parameter (with respect to gate delay and gate width) utilizing Performance Demonstration Program (PDP) [8] SNM standards and containers for six matrix drums. An additional data set was included involving twelve matrix types but no SNM for additional interrogating background study. The data sets were kept separate since they involved measurements where the counter was elevated (several inches) and not elevated above the cement floor. The resultant interrogating background calibration was then applied to analyze difficult assays utilizing the gate delay, and width, determined by optimizing the zero matrix efficiency parameter.

INTERROGATING BACKGROUND

The most pristine assay is the non-interfering, or zero matrix, drum. With the system healthy, the shielded Multi-Channel Spectrum (MCS), for 964 mg Pu and no Pu, is shown in Fig. 1. The steep curve is representative of the die-away of the interrogating fast neutron flux. Note that the die-away constant for both the cases, *i.e.*, with and without the 964 mg Pu, are nearly identical. We found this to be true for all matrix drums, however, the die-away of the fast neutron interrogating flux within the shielded detectors, *i.e.*, FNDPs, does vary slightly depending on the moderation, and probably absorption, properties of the matrix. The region of interest, *i.e.*, the Pu fission signal, begins about channel 200 (400 μs) with a dominant amount of the signal completed by channel 550 (1100 μs). Extrapolation of the interrogating flux indicates that in the vicinity of channel 300 (600 μs) there is no more contribution. This implies that the overlap, for the zero matrix drum, is between 400 μs and 600 μs. The yield in this region, for drums containing no SNM, is defined as the interrogating background, B_I.

The basic concept is to remove the contribution due to the interrogating background from the SNM assay. For the zero matrix drum this is fairly easy as indicated in Fig. 1. However, the dynamics of other matrix types due to matrix counter coupling drastically changes the interrogating background, B_I. This fact is realized from Table II where the background interrogation and absorber index change abruptly when a matrix is introduced to the counter. An attempt was made to parameterize B_I with respect to the die-away of the fast neutron interrogating flux from the FNDPs. The effort was abandoned since the steep slope of the die-away and the slight variance between matrix types produced inconclusive results.

Table II Interrogating background parameters for various matrix drums utilized in calibration for gate delay of 450 μs and a gate width of 600 μs. The first six were measured with the counter directly bolted to the cement floor. The last twelve drums were measured with the counter mounted several inches above the cement floor.

Matrix Type	B_I	σ_B	I_A	σ_I	AAS CF	σ_{CF}	§τ_{BL}	σ_τ
Empty	3.886E-02	1.099E-03	0.0928	0.0007	1.003	0.001	187.67	0.9
Combustibles	1.392E-02	5.676E-04	0.1775	0.0015	1.102	0.002	193.27	2.0
Metals	1.588E-02	8.071E-04	0.1877	0.0002	0.980	0.000	190.72	2.5
Glass	1.568E-02	1.177E-03	0.3438	0.0042	1.023	0.001	159.00	2.0
Inorganic Sludge	1.152E-02	7.721E-04	0.2636	0.0020	2.450	0.006	183.67	2.7
Organic Sludge	1.280E-02	7.544E-04	0.3229	0.0032	2.406	0.006	180.65	0.9
Empty-1	3.874E-02	1.850E-03	0.1008	0.0034	0.998	0.020	188.85	2.3
Empty-2	3.921E-02	1.934E-03	0.0925	0.0032	0.998	0.020	187.29	2.1
Combustibles	1.629E-02	1.862E-03	0.1623	0.0023	1.073	0.021	197.05	2.3
65 kg Poly+Vermiculite	1.384E-02	4.877E-05	0.1885	0.0000	1.921	0.038	210.45	2.7
29.5 kg Poly+Vermiculite	1.539E-02	1.021E-03	0.1438	0.0012	1.290	0.026	231.42	2.8
100 % Poly	1.262E-02	1.035E-03	0.2246	0.0098	2.454	0.049	182.08	2.3
Concrete	1.613E-02	1.155E-03	0.1984	0.0019	0.993	0.020	205.23	2.1
PDP Foam	1.714E-02	1.235E-03	0.1292	0.0012	1.000	0.020	282.92	3.1
Steel + Combustibles	1.466E-02	1.170E-03	0.2372	0.0024	0.970	0.019	178.59	2.3
Mixed Heterogeneous	1.556E-02	1.242E-03	0.1888	0.0020	1.914	0.038	177.97	2.0
Layered Heterogeneous	1.280E-02	1.056E-03	0.1815	0.0018	1.773	0.035	210.07	2.9
Sand	1.557E-02	1.387E-03	0.2255	0.0026	0.981	0.020	185.03	2.4

§The time per channel for the detectors was 2 μs per channel.

Indifferent to the shielded detectors, the barrel monitor "sees" the thermalized interrogating flux through the drum due to the cadmium collimators [3,4]. The barrel monitor is utilized to gauge the absorption of thermal neutrons through the drum thus producing the absorption index, I_A [5,6]. From Table II we also see that the decay constant, τ_{BL}, of the barrel monitor die-away heavily depends on the matrix.

Since the interrogating background depends on the matrix-counter coupling and the barrel monitor is designed to provide the matrix "strength" then it is clear that the interrogating background should be some function of the barrel monitor. The original methodology [5,6] describes an analytical function involving the absorber and moderator indices. Unfortunately, this analytical technique produced poor results for highly absorbing matrix drums like boron loaded glass. In addition, it was difficult, if not impossible, to come up with a single analytical calibration for high and low moderating drums. It appears that an additional dependency is required.

The most elemental form of calibrating the interrogating background is as a function of the absorber index, *i.e.*,

$$B_I = a + b \cdot \ln(I_A) \quad \text{Eq. 1}$$

The data in Table I was subjected to this analytical form and the results are shown in Fig. 2 and Fig. 3. The vector ***C***, in the figures, contains the fitted coefficients ***C*** = (*a*, *b*). The parameter α^{-1} is the covariance matrix for the fit. Abiding to the recommendation provided in [2], a gate delay of 450 µs and gate width of 600 µs was chosen and the data set in Table II reflects this.

For the first data set, shown in Fig. 2, the algorithm is somewhat adequate, *i.e.*, the trend is correct, for all drums except the glass and zero matrix drum. The second data set, shown in Fig. 3, exhibits the correct trend but it also demonstrates troublesome drums including the zero matrix drum. The fit for both data sets is poor as the two sigma "envelope" indicates in the plots. It is interesting to note that as more points are added the fit actually worsened for the second data set. Ultimately, utilizing the algorithm in Eq. 1 will lead to an elevated MDA as well as a considerable bias for low SNM mass situations (0 – 100 mg equivalent mass).

The original DDA parameterization of the background interrogation included a moderator term and this slightly improved the fit but it could not reveal the glass and zero matrix drum. In response to this deficiency, a new algorithm was generated involving the barrel monitor decay constant. This algorithm has the form,

$$B_I = a + b \cdot \ln(I_A) \cdot \frac{1 + c \cdot I_M}{1 + d \cdot I_\tau} \qquad \text{Eq. 2}$$

Where *a*, *b*, *c*, and *d* are adjustable parameters. The moderator index, I_M, is calculated from the passive assay using an interrogating external Cf-252 source Add-a-Source (AAS). The moderator index is defined as,

$$I_M = 1 - \frac{1}{CF_{AAS}} \qquad \text{Eq. 3}$$

Where CF_{AAS} is the AAS Totals, *i.e.*, Singles rate, correction factor. The newly introduced index, I_τ, is a gauge, or perturbation, of the barrel monitor die-away, τ_{BL},

$$I_\tau = 1 - \frac{\tau_o}{\tau_{BL}} \qquad \text{Eq. 4}$$

Where τ_o is taken as the empty drum value or left as an adjustable parameter in the fitting process. The barrel monitor die-away, or decay constant, is determined from the region defined by the early gate.

When this algorithm is applied to the data set in Table I the improved fit for the glass and empty drum is dramatic as shown in Fig. 4 and Fig. 5. Several matrix drums in the high absorber index region also show significant improvement. A few drums, like the combustibles were actually worse. These drums, in particular, have questionable moderator indexes and this will be investigated in the future.

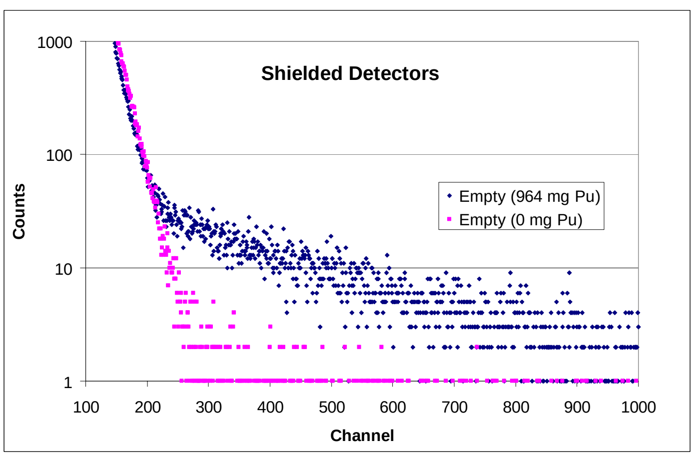

Fig. 1 Multi-channel spectrum from the shielded detectors for the zero matrix drum and 964 mg Pu

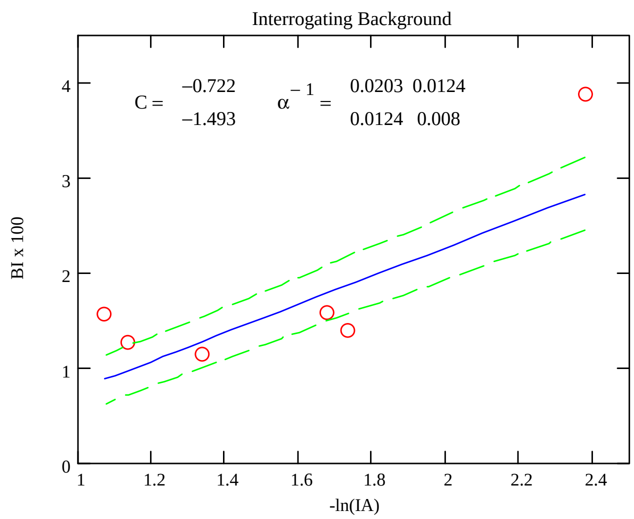

Fig. 2 Interrogating background as a function of absorber index for the first six data in Table II using Eq. 1.

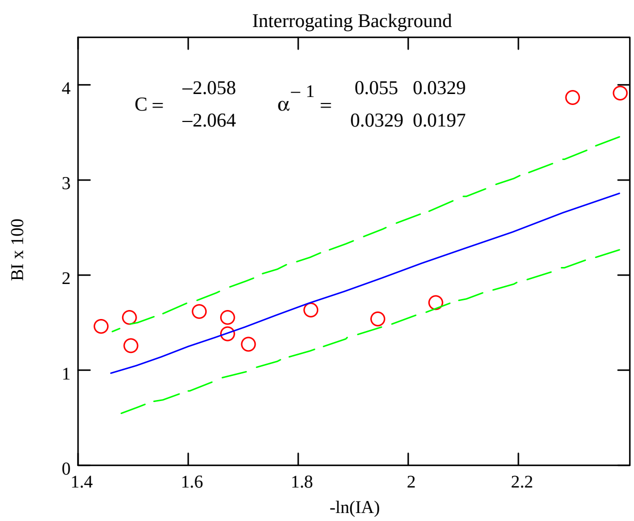

Fig. 3 Interrogating background as a function of absorber index for the last twelve drums in Table II using Eq. 1

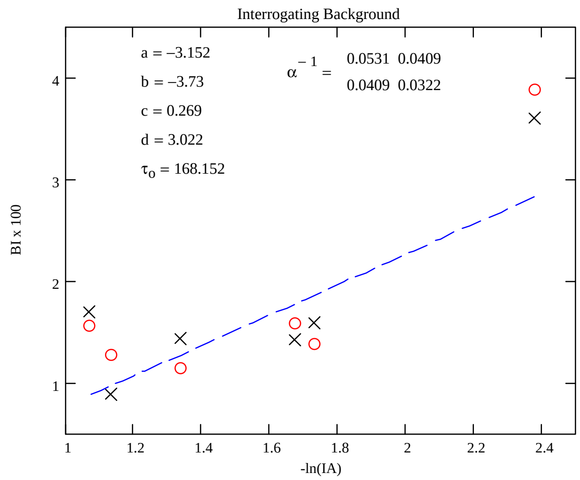

Fig. 4 Interrogating background as a function of absorber index for the first six drums in Table II using Eq. 2.

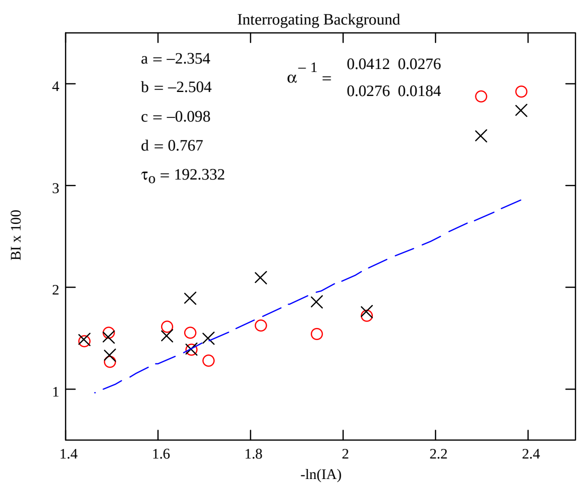

Fig. 5 Interrogating background as a function of absorber index for the last twelve drums in Table II Using Eq. 1.

OPTIMAL ZERO MATRIX CALIBRATION

Inspired by the optimal MDA study [2] an investigation was performed to search for the optimal gate delay, and gate width, that minimizes the variance of the zero matrix calibration parameter, a_{zero}. The relationship between the zero matrix calibration parameter and the equivalent mass, m_{eq}, of the SNM is defined as,

$$m_{eq} = \frac{\frac{R_{SH}}{\phi} - B_I}{a_{zero}} \cdot CF \text{ (g)} \qquad \text{Eq. 5}$$

where R_{SH} is the net shielded detector rate, a_{zero}, is the zero matrix mass calibration parameter, ϕ is the flux monitor rate, and CF is the matrix correction factor. The relative variance in the zero matrix calibration factor is then written as,

$$\left(\frac{\sigma_{a_{zero}}}{a_{zero}}\right)^2 = \frac{\frac{\sigma^2_{R_{SH}}}{\phi^2} + \sigma^2_{B_I} + \frac{R^2_{SH}}{\phi^4}\cdot\sigma^2_{\phi}}{\left(\frac{R_{SH}}{\phi} - B_I\right)^2} \qquad \text{Eq. 6}$$

The result in Eq. 6 allows the optimal gate delay, and gate width, study to commence without calibrating for the actual value of the zero matrix calibration parameter or the matrix correction factor *CF*. The technique then applies to a wide range of SNM loadings and matrix types. For this reason, and to minimize unknowns, the simplest drum was selected for the study; the zero matrix drum.

Utilizing the 964 g Pu PDP standard in the zero matrix drum the relative variance of the zero matrix calibration as a function of gate delay is shown in Fig. 6. The gates utilized for the gate delay study are shown in Table I. The results with respect to gate width (fixed gate start) are shown in Fig. 7. The "Error Term" indicated in Fig. 6 and Fig. 7 is the numerator in Eq. 6. The gates utilized for the gate width study involved a fixed gate delay of 450 µs and an increasing the gate width starting at 200 µs with increments of 200 µs ending at 2200 µs.

Inspection of Fig. 6 reveals that the optimal gate start is about 450 µs ± 25 µs which is identical to the optimal MDA study [2]. The gate width study suggests a gate width of 1600 µs ± 500 µs. The optimal MDA study indicated 600 µs ± 50 µs. The relative variance in the zero matrix calibration factor is relatively flat in the region 600 µs to 1600 µs changing by only 20 %. In contrast to this the optimal MDA is very sharp [2]. For this reason it is recommended that the gate width be set at 600 µs ± 50 µs while still retaining a reasonable reduced variance for the zero matrix calibration parameter.

It is interesting to note that the "Error Term" is the dominating factor. From the prior study [2] it was found that the denominator in Eq. 6 also has a minimum in the same gate delay and gate width region, although not as sharp. This reinforces confidence in the selection of the optimal gate width and delay for the zero matrix calibration parameter.

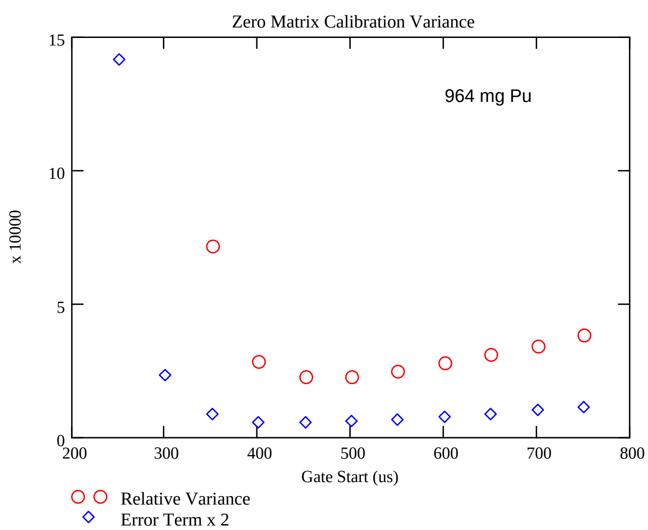

Fig. 6 Optimal relative variance study as a function of gate delay for 964 mg Pu in the zero matrix drum.

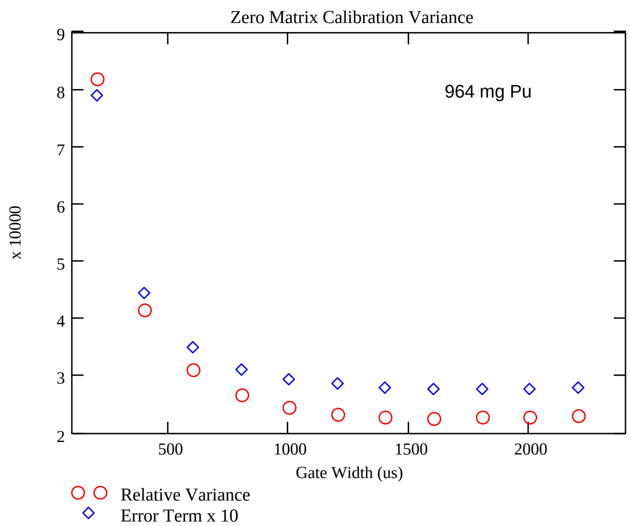

Fig. 7 Optimal relative variance study as a function of gate width for 964 mg Pu in the zero matrix drum.

Table I Early gate delay and stops utilized for the MDA as a function of gate delay study.

GD (µs)	Gate Stop (µs)	GW (µs)
250	2000	1750
300	2000	1700
350	2000	1650
400	2000	1600
450	2000	1550
500	2000	1500
550	2000	1450
600	2000	1400
650	2000	1350
750	2000	1250
850	2000	1150

Difficult Assays

To evaluate the effectiveness of the optimal gate width and the new parametric representation of the interrogating background for difficult assays an unknown data set was identified for study. A set of fourteen assay sequences, all with high moderator and absorber indices and low equivalent masses were selected with, and without, a high α-n background. The equivalent mass range was 50 mg to 2 g with one exception (about 4 g).

Two analyses were performed; one with the a gate delay of 450 µs and a gate width of 600 µs and the other utilizing a gate delay of 650 µs and a gate width of 1350 µs. The shorter gate delay was chosen since it represents the optimal MDA and zero matrix variance domain. In addition, the new background interrogation (Eq. 2) technique, utilizing the decay constant index, I_τ, was included in calculating the interrogating background. The 650 µs gate delay employed the old technique for interrogating background calculation (Eq. 1).

The active DDA results for all fourteen drums are shown in Table IV with the corresponding passive results depicted in Table III. The active DDA results include the barrel monitor decay constant, net flux, barrel and shielded detector rates, calculated interrogating background (Eq. 2 for 450 µs and Eq. 1 for 650 µs), limit of detection [2] and specific MDA [2]. Each set of parameters in Table includes results for both gates utilized in the study with the exception of the barrel monitor decay constant since this parameter was only applied to the short gate delay (450 µs). The passive results in Table III include the coincidence (Reals) and singles (Totals) Add-a-Source (AAS) correction factors as well as the Singles, Doubles and Triples count rates.

Table III Passive neutron results for difficult assays.

Assay Sequence	AAS CF Reals +/-		AAS CF Totals +/-		Singles +/- (cps)		Doubles +/- (cps)		Triples +/- (cps)	
1	4.70	0.17	2.416	0.014	390.28	1.11	0.06	0.31	-0.15	0.16
2	4.68	0.17	2.371	0.014	90.42	0.87	-0.47	0.19	-0.24	0.17
3	5.03	0.18	2.479	0.014	40.38	0.82	-0.53	0.18	0.05	0.20
4	4.57	0.16	2.430	0.014	35.87	0.82	-0.76	0.18	-0.43	0.14
5	4.52	0.16	2.278	0.013	9.33	0.79	-0.84	0.18	-0.46	0.14
6	4.93	0.18	2.345	0.013	104.63	0.88	0.05	0.20	-0.17	0.15
7	4.01	0.15	2.317	0.014	52.27	0.83	-0.02	0.18	0.15	0.16
8	4.22	0.16	2.275	0.013	77.31	0.86	-0.29	0.18	-0.23	0.14
9	4.64	0.17	2.397	0.014	19.42	0.79	-0.68	0.17	-0.24	0.15
10	4.56	0.16	2.432	0.014	120.67	0.90	-0.24	0.20	-0.17	0.16
11	4.60	0.17	2.387	0.014	80.02	0.87	-0.19	0.19	-0.42	0.12
12	4.50	0.25	2.250	0.013	7325.59	3.56	13.36	3.84	-4.13	3.05
13	4.68	0.24	2.360	0.013	2820.35	2.28	-0.92	1.62	-0.66	0.83
14	4.63	0.32	2.400	0.018	12976.46	4.73	13.57	7.04	-4.70	6.71

Table IV Differential Die-Away results for difficult assays.

Assay Sequence	Gate Delay (µs)	§τ_{BL} (Channels)	σ_τ (Channels)	S_{FL} (cps)	σ_{FL} (cps)	S_{BL} (cps)	σ_{BL} (cps)	S_{SH} (cps)	σ_{SH} (cps)	I_A	σ_I	B_I	σ_B	L_d (cps)	MDA_{spec} (g/g)
	¶450			2231.85	17.61	9263.08	35.89	150.99	12.52	0.2409	0.0021	0.0098	0.002	41.79	0.323
1	£650	194.5	3.4	759.63	6.85	3077.02	13.82	35.54	8.94	0.2469	0.0025	0.0068	0.0006	29.26	0.963
	450			2244.64	17.66	8914.93	35.20	1067.93	14.19	0.2518	0.0022	0.0101	0.002	28.97	0.028
2	650	184.8	2.9	753.81	6.82	2812.52	13.20	200.54	6.53	0.268	0.0027	0.0065	0.0006	18.42	0.094
	450			2239.58	17.64	10588.94	38.35	257.58	6.60	0.2115	0.0018	0.0133	0.0021	19.45	0.085
3	650	190.8	3.7	775.86	6.92	3407.65	14.51	48.17	2.73	0.2277	0.0023	0.0071	0.0006	7.53	0.177
	450			2260.56	17.72	10709.00	38.57	164.88	5.00	0.2111	0.0018	0.0126	0.0021	17.82	0.131
4	650	196.4	4.0	773.58	6.91	3554.77	14.81	29.61	1.73	0.2176	0.0021	0.0073	0.0006	4.49	0.187
	450			2211.81	17.53	10267.32	37.76	124.57	4.31	0.2154	0.0019	0.0122	0.0021	17.11	0.175
5	650	196.9	3.9	747.53	6.79	3357.06	14.40	25.39	1.51	0.2227	0.0022	0.0072	0.0006	3.83	0.191
	450			2173.85	17.38	9511.35	36.35	117.03	4.19	0.2286	0.002	0.0124	0.002	16.62	0.184
6	650	185.4	3.2	728.23	6.70	2999.34	13.61	21.21	1.43	0.2428	0.0025	0.0069	0.0006	3.78	0.233
	450			2034.17	16.81	8885.93	35.13	80.11	3.45	0.2289	0.0021	0.0143	0.002	15.74	0.308
7	650	174.5	2.6	643.33	6.30	2633.17	12.75	13.44	1.13	0.2443	0.0027	0.0068	0.0006	3.21	0.355
	450			2134.68	17.22	9458.96	36.25	291.68	6.58	0.2257	0.002	0.0136	0.002	17.05	0.065
8	650	180.5	2.9	693.79	6.54	2926.27	13.44	51.99	2.19	0.2371	0.0025	0.007	0.0006	4.89	0.104
	450			2272.08	17.76	11102.81	39.27	145.69	4.69	0.2046	0.0018	0.0127	0.0021	17.95	0.154
9	650	201.2	4.4	777.59	6.93	3733.15	15.18	25.23	1.60	0.2083	0.002	0.0074	0.0006	4.27	0.220
	450			2192.64	17.45	9396.07	36.13	137.00	4.60	0.2334	0.0021	0.0116	0.002	16.87	0.151
10	650	186.5	3.2	726.79	6.70	2948.42	13.49	23.68	1.64	0.2465	0.0025	0.0068	0.0006	4.45	0.237
	450			2115.69	17.14	9075.10	35.50	114.24	4.09	0.2331	0.0021	0.0135	0.002	16.14	0.188
11	650	176.0	2.7	669.88	6.43	2730.45	12.98	19.47	1.30	0.2453	0.0026	0.0068	0.0006	3.33	0.224
	450			2096.21	17.06	8773.83	34.91	447.86	8.11	0.2389	0.0022	0.0133	0.002	16.80	0.040
12	650	174.1	2.5	674.46	6.45	2626.21	12.73	73.59	2.56	0.2568	0.0028	0.0067	0.0006	5.31	0.077
	450			2227.36	17.59	9765.01	36.83	364.99	7.31	0.2281	0.002	0.0118	0.002	17.38	0.051
13	650	189.4	3.4	747.72	6.79	3106.73	13.85	61.73	2.31	0.2407	0.0024	0.0069	0.0006	4.87	0.086
	450			2140.03	17.24	10114.04	37.52	119.72	15.97	0.2116	0.0019	0.0127	0.0021	53.61	0.580
14	650	195.0	3.7	725.68	6.69	3273.29	14.27	14.98	11.72	0.2217	0.0023	0.0072	0.0006	38.67	3.965

§The time per channel for the detectors was 2 µs per channel.

¶Gate width utilized was 600 µs.

£ Gate width utilized was 1350 µ

From the AAS correction factors we see that the unknown drums are highly moderating and from the absorber indexes we can infer that the matrix is highly absorbing. This indicates sludge type waste drums. Note the homogeneity of the moderator and absorber indices, however, that the barrel monitor decay constant varies. This implies that there are matrix dynamics present other than the moderator and absorber indices. Perhaps the barrel monitor decay constant is revealing partially filled drums. The moderator index, derived from the AAS is insensitive to partially filled drums since it samples the drum directly underneath (for optimal geometrical coupling). This potential effect will be investigated in a future study.

When comparing the limit of detection and specific MDA between the two gate analyses sets the results are very promising. In general the specific MDA is 33% to 66% lower for 450 µs gate delay than for 650 µs gate delay. Although the limit of detection, in counts per second (cps), is 2 to 3 times larger than that for 650 µs gate delay, the net shielded rate is 5 to 8 times larger for the shorter gate width. It is best to normalize the limit of detection to the net flux monitor rate and when this is done the shorter gate delay limit of detection is comparable to the long delay.

Assay sequences 12 and 14 involve high α-n situations since the Singles to Doubles ratio and Doubles and Triples uncertainties are high as seen in Table III. Note that the impact, for these particular assays, to the limit of detection and specific MDA is considerable more for the longer gate delay than for the shorter gate delay.

CONCLUSION

This study has extended the matrix range, specifically highly absorbing matrix drums, for Differential Die-Away (DDA) assays. We define, Eq. 4, a new DDA parameter, I_τ, called the barrel monitor decay constant index which can provide additional absorber information in addition to the absorber index, I_A.

The interrogating background, B_I, has a dependency on the barrel monitor decay constant index, I_τ. The analytical dependency is described in Eq. 2. For the high and low absorbing matrix drums this algorithm appears to be very satisfactory. However, in the mid-range absorbing drums (combustibles) the algorithm is less satisfactory.

The variance in the zero matrix calibration parameter, a_{zero}, is optimal, *i.e.*, minimized, when the gate delay is 450 µs ± 25 µs and a gate width of 1600 µs ± 500 µs. This result for the gate delay is identical to the result previously published for optimal MDA [2]. However, the optimal gate width is significantly larger and not sharp like the gate width study for the optimal MDA. Since the sensitivity of the zero matrix variance was found to be relatively flat in the region 600 µs to 2200 µs and the MDA sharp at 600 µs then it is recommended that the gate width be set to 600 µs with minimal loss (20 %) in optimal reduced variance of the zero matrix calibration parameter.

The application of the shorter gate delay of 450 µs and shorter gate width 600 µs to difficult assays involving unknown matrix content and SNM loading has lead to a significant reduction in the MDA with little, if any, compromise to the limit of detection. This reduction is especially realized for high α-n conditions which is a very common problem in waste assay environments.

FUTURE STUDIES

This study represents a significant advance in the level of scrutiny to which DDA has been subjected. Our aim is to develop advanced next generation tools to handle difficult assays. The study could be augmented in the following ways:

- Measure matrix drums with increasing boron loadings while holding the moderator constant. This data set should truly reveal the dependency of the barrel monitor decay constant with respect to the interrogating background and provide further verification of the new algorithm (Eq. 2).

- Explore further, the correlation, if any, between the interrogating background, B_I, and the shielded detector fast neutron interrogating flux die-away.

- Generate a chi-squared density plot to investigate minima of the adjustable parameters in Eq. 2. This study should also include the barrel monitor decay constant, τ_o, (Eq. 4) as a free parameter.

- Determine if there is a dependence between partially filled drums, of the same matrix type, and the die-away, τ_{BL}, of the barrel monitor.

Several other DDA counters have been constructed by Canberra Industries and are currently in the field in operation. There is a vast database of data available for these counters that can be utilized to verify the conjectures made in this, and prior papers. In addition, a new, very interesting DDA counter is currently under construction by Canberra Industries and the author will be involved with the calibration process so particular attention will be made to exploit the results reported here.

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