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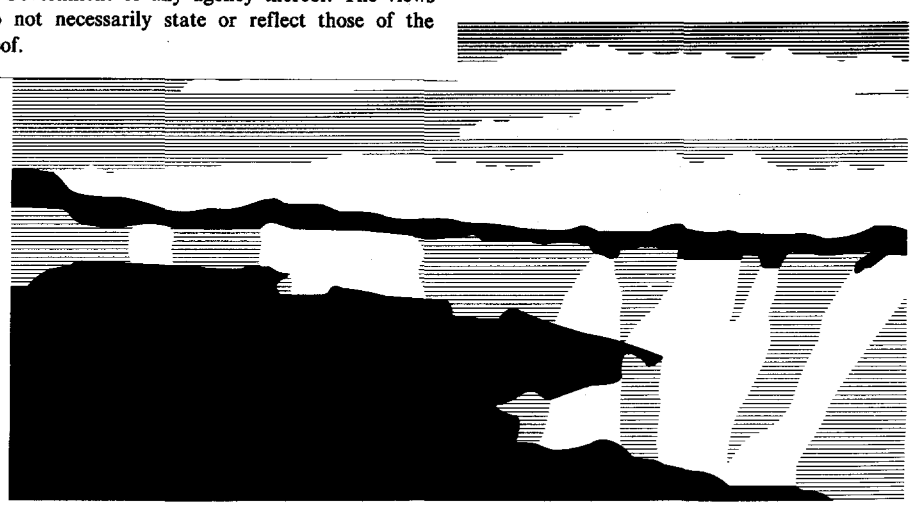

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A TWO-FOLD REDUCTION IN MEASUREMENT TIME FOR NEUTRON ASSAY: INITIAL TESTS OF A PROTOTYPE DUAL-GATED SHIFT REGISTER *

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ABSTRACT

Neutron coincidence counting (NCC) is used routinely around the world for nondestructive mass assay of uranium and plutonium in many forms, including waste. Compared with other methods, NCC is generally the most flexible, economic, and rapid. Many applications of NCC would benefit from a reduction in counting time required for a fixed random error. We have developed and tested the first prototype of a dual-gated, shift-register-based electronics unit that offers the potential of decreased measurement time for all passive and active NCC applications.

I. INTRODUCTION

A prototype dual-gated shift-register (DGSR) electronics package for NCC[1,2] has been designed, fabricated, and tested. The unit is identical to conventional shift-register (SR)[3] electronics with an additional SR to provide the capability for separate time settings of real-plus-accidental-coincidence (R+A) and accidental-coincidence (A) gate lengths.

The motivation for this project was to explore potential improvements in NCC measurement variance and, proportionally, counting time improvements that result from using a long accidentals gate. A long accidentals gate allows better sampling of the accidental coincidence counts. This, in turn, offers the possibility of improving the variance in the real coincidence counts R, which is determined from (R+A) - (A). Traditionally, the R+A and R gate lengths have been equal to simplify design and because potential benefits of the two gates were not known.

An initial set of measurements using the DGSR has been performed using Cf-252 and AmLi neutron sources, the High-Level Neutron Coincidence Counter (HLNC)[4] and the Active Well Coincidence Counter (AWCC).[5]

Initial results are encouraging, indicating a gain in counting time approaching a factor of two, obtained simply by using an optimum R+A gate (64 μs) and a long (1024 μs) A gate. As expected, the gain is dependent on the reals-to-accidentals (R/A) ratio. As the ratio approaches zero, the gain is maximized. Many measurements performed routinely for nuclear material verification fall into the R/A range where the DGSR can produce significant gains in measurement time.

II. PROTOTYPE ELECTRONICS

Figure 1 is a simplified diagram of the prototype DGSR circuitry. It is identical to a conventional SR circuit with the exception of a separate SR for the accidentals circuit. Separate settings may be used for the time width of each gate. For a neutron detector with a single, exponential die-away time τ, the minimum-variance R+A gate setting is 1.257τ. Results of measurements of Cf-252 and AmLi sources showed that for the A gate setting, the longer the gate the better, although a setting of 1024 μs is sufficient for minimum variance because an asymptotic value is reached.

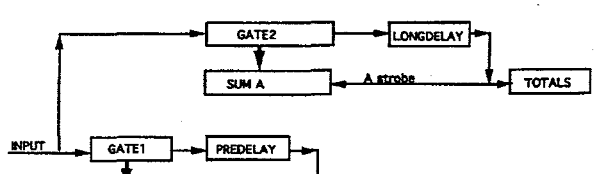

Fig. 1. Dual-gated shift register schematic diagram.

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III. MEASURED RESULTS

Various combinations of Cf-252 and AmLi sources were measured in two neutron coincidence counters with different efficiencies—the HLNC, with an efficiency of 17%, and the AWCC, with an efficiency of 25%. These measurement combinations produced a wide range of R/A ratios. The R/A ratio was used as an independent variable for comparing results. All results are tabulated in Table I and plotted in Fig. 2. The count-time reduction factor plotted in Fig. 2 is simply the ratio of R variances obtained from two sets of runs: the first set taken with equal gate lengths (64 μs) and the second set taken with a 1024-μs A gate. Measurement sets were large, 200-1600 repeated runs, selected in order to achieve an acceptably low relative error in the measured reals rate standard deviation. From Ref. 6, the relative errors in the measured standard deviation and variance are taken to be $[2(n-1)]^{-0.5}$ and $[2/(n-1)]^{0.5}$, respectively, where n is the number of repeat runs. From simple propagation of independent errors, the relative error in the ratio of R variances is then $2[(n-1)]^{-0.5}$ if the number of repeat runs n is the same for each of the two R measurements.

The behavior of the data shown in Fig. 2 is as expected. As the R/A ratio increases, the benefit of the long A gate is decreased because the accidentals counts play a smaller role in the R error. For small values of R/A, the A component of the R error dominates, approaching a maximum value. For independent Poisson errors in R+A and A, the maximum value would be exactly 2. It is well known that R+A and A are neither Poisson nor independent. However, the gain in counting time does actually approach a factor of two as the R/A ratio approaches zero.

IV. CONCLUSIONS

The results of this study show that there are significant gains in measurement time to be realized by extending the length of the accidentals gate for neutron coincidence counting applications where the R/A ratio is small. This includes many applications for active measurements of uranium using the AWCC and the Uranium Neutron Coincidence Collar (UNCL).[7] Additional active measurements should be performed to verify these conclusions.

This study also suggests that there could be other modifications to SR circuitry that could produce significant gains in measurement time. Extensions to multiplicity electronics and analysis should also be investigated. Thermal neutron multiplicity counting is currently limited for items with high accidental coincidence rates.

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TABLE I. Results of Cf-252 and AmLi Source Measurements with the DGSR

Date	Detector	Source(s)	repeat runs	gate 1 (µs)	gate 2 (µs)	Singles rate	std. dev. Singles	Reals rate	std. dev. Reals	std. dev. error	variance Reals	variance ratio	ratio error	R/A
12/12/95	HLNC	CR10	200	64	64	51321	17.7	9338	51.1	2.56	2.61E+03			5.54E-02
			200		1024	51316	21.5	9476	38.4	1.92	1.47E+03	1.77	0.25	5.62E-02
12/12/95	HLNC	CR10	200	64	64	51327	14.4	9430.2	34.3	1.72	1.18E+03			5.59E-02
			200		1024	51320	13	9388	27.9	1.40	7.78E+02	1.51	0.21	5.57E-02
12/14/95	HLNC	CR7	200	64	64	3822.2	5.5	675.4	4.7	0.24	2.21E+01			7.22E-01
			200		1024	3814.5	5.3	674.2	3.9	0.20	1.52E+01	1.45	0.21	7.24E-01
12/14/95	HLNC	CR11	200	64	64	133750	32.4	23748	134	6.70	1.80E+04			2.07E-02
			200		1024	133755	28.7	23558	104.8	5.24	1.10E+04	1.63	0.23	2.06E-02
12/14/95	HLNC	CR6	200	64	64	1599	3.3	300.4	2.258	0.11	5.10E+00			1.84E+00
			200		1024	1587	3.6	297.3	2.205	0.11	4.86E+00	1.05	0.15	1.84E+00
12/14/95	HLNC	CR6	200	64	64	1595	3.6	301	2.464	0.12	6.07E+00			1.85E+00
			200		1024	1592	3.5	298	2.029	0.10	4.12E+00	1.47	0.21	1.84E+00
12/15/95	AWCC	CR6+2AmLi	200	64	64	7528.4	6.2	485.2	6.84	0.34	4.68E+01			1.34E-01
			200		1024	7526.2	6	480.97	5.93	0.30	3.52E+01	1.33	0.19	1.33E-01
12/15/95	AWCC	CR6+2AmLi	200	64	64	7553	6.9	479.9	7.721	0.39	5.96E+01			1.31E-01
			200		1024	7563.3	6.99	473.99	5.266	0.26	2.77E+01	2.15	0.30	1.29E-01
12/15/95	AWCC	CR10+2AmLi	200	64	64	71349	24.4	14428	73.7	3.69	5.43E+03			4.43E-02
			200		1024	71332	23.9	14460	57	2.85	3.25E+03	1.67	0.24	4.44E-02
12/15/95	AWCC	CR10	200	64	64	66036	24.6	14488	70.5	3.53	4.97E+03			5.19E-02
			200		1024	65990	22.3	14539	56.9	2.85	3.24E+03	1.54	0.22	5.22E-02
12/15/95	AWCC	CR6	200	64	64	2240	4.543	480.4	3.127	0.16	9.78E+00			1.50E+00
			200		1024	2236.6	4.1	478.97	2.826	0.14	7.99E+00	1.22	0.17	1.50E+00
12/29/95	AWCC	CR11	400	64	64	168721	26.5	34386	116.4	4.12	1.35E+04			1.89E-02
			400		1024	168667	25.9	34390	93.9	3.32	8.82E+03	1.54	0.15	1.89E-02
12/29/95	AWCC	CR11	400	64	64	168726	26.6	34635	125.1	4.42	1.57E+04			1.90E-02
			400		1024	168687	25.4	34474	91.7	3.24	8.41E+03	1.86	0.19	1.89E-02
12/30/95	AWCC	CR11+MRC19	400	64	64	236780	26.6	20589	140.4	4.96	1.97E+04			5.74E-03
			400		1024	236770	26.3	20630	107.2	3.79	1.15E+04	1.72	0.17	5.75E-03
12/30/95	AWCC	CR11+MRC19	400	64	64	236753	25.3	20628	136.4	4.82	1.86E+04			5.75E-03
			400		1024	236768	25	20565	111.1	3.93	1.23E+04	1.51	0.15	5.73E-03
12/31/95	AWCC	CR9+MRC19	400	64	64	126180	18.1	3350.3	70.6	2.50	4.98E+03			3.29E-03
			400		1024	126208	19.4	3430.6	53.8	1.90	2.89E+03	1.72	0.17	3.37E-03
12/31/95	AWCC	CR9+MRC19	400	64	64	126194	17.6	3568.7	73.4	2.60	5.39E+03			3.50E-03
			400		1024	126206	18.7	3453.5	52.2	1.85	2.72E+03	1.98	0.20	3.39E-03
1/2/95	AWCC	CR8+MRC19	400	64	64	115223	17.5	1515.3	61.2	2.16	3.75E+03			1.78E-03
			400		1024	115184	16.8	1622.6	46.1	1.63	2.13E+03	1.76	0.18	1.91E-03
1/3/95	AWCC	CR8+MRC19	400	64	64	115176	17.2	1639.3	59.8	2.11	3.58E+03			1.93E-03
			400		1024	115183	17.2	1560.8	49.3	1.74	2.43E+03	1.47	0.15	1.84E-03
1/2/95	AWCC	CR7+MRC19	400	64	64	109704	16.2	544.4	64.2	2.27	4.12E+03			7.07E-04
			400		1024	109698	15.6	477.2	42.3	1.50	1.79E+03	2.30	0.23	6.20E-04
1/3/95	AWCC	CR7+MRC19	400	64	64	109682	17	470.5	60.6	2.14	3.67E+03			6.11E-04
			400		1024	109694	17.2	566.8	44.3	1.57	1.96E+03	1.87	0.19	7.36E-04
1/6/95	AWCC	CR7	400	64	64	4650.6	4.52	1067.2	4.24	0.15	1.80E+01			7.71E-01
			400		1024	4644.9	4.2	1060.9	3.23	0.11	1.04E+01	1.72	0.17	7.68E-01
1/6/95	AWCC	CR7	400	64	64	4645.6	4.7	1063.8	4.23	0.15	1.79E+01			7.70E-01
			400		1024	4644.3	4.7	1063.4	3.55	0.13	1.26E+01	1.42	0.14	7.70E-01
1/7/95	AWCC	CR8	400	64	64	11702	7.43	2694.4	9.238	0.33	8.53E+01			3.07E-01
			400		1024	11697	6.87	2674.2	7.896	0.28	6.23E+01	1.37	0.14	3.05E-01
1/7/95	AWCC	CR8	400	64	64	11691	6.62	2688	9.58	0.34	9.18E+01			3.07E-01
			400		1024	11691	6.87	2680.6	7.45	0.26	5.55E+01	1.65	0.17	3.06E-01
1/11/95	AWCC	CR9	400	64	64	25897	9.9	5870.8	20.3	0.72	4.12E+02			1.37E-01
			400		1024	25875	10.75	5870	15.72	0.56	2.47E+02	1.67	0.17	1.37E-01
1/11/95	AWCC	CR9	400	64	64	25857	17.2	5861.8	20.69	0.73	4.28E+02			1.37E-01
			400		128	25810	9.93	5862.8	18.39	0.65	3.38E+02	1.27	0.13	1.38E-01
			400		256	25811	10.1	5864.4	18.11	0.64	3.28E+02	1.31	0.13	1.38E-01
			400		512	25812	10.31	5876.8	15.68	0.55	2.46E+02	1.74	0.17	1.38E-01
			400		1024	25808	6.52	5850.5	12.83	0.45	1.65E+02	2.60	0.26	1.37E-01
1/12/95	AWCC	CR9	1000	64	64	25808	6.52	5850.5	12.83	0.29	1.65E+02			1.37E-01
			1000		1024	25788	7.03	5844.3	10.8	0.24	1.17E+02	1.41	0.09	1.37E-01
1/13/95	AWCC	CR9	1600	64	64	25785	5.34	5842.7	10.38	0.18	1.08E+02			1.37E-01
			1600		1024	25771	5.1	5829	7.85	0.14	6.16E+01	1.75	0.09	1.37E-01
1/14/95	AWCC	CR9	800	64	64	25764	7.43	5861.9	13.9	0.35	1.93E+02			1.38E-01
			800		1024	25770	7.3	5858	11.58	0.29	1.34E+02	1.44	0.10	1.38E-01
1/15/96	AWCC	CR11	1600	64	64	167593	12.9	34438	60.54	1.07	3.67E+03			1.92E-02
			1600		1024	167648	12.7	34352	48.34	0.85	2.34E+03	1.57	0.08	1.91E-02
1/16/96	AWCC	CR11	1600	64	64	167629	13.1	34412	60.72	1.07	3.69E+03			1.91E-02
			1600		1024	167591	12.64	34368	47.93	0.85	2.30E+03	1.60	0.08	1.91E-02
1/17/96	AWCC	CR5	1600	64	64	820.9	0.9	182.4	0.576	0.01	3.32E-01			4.23E+00
			1600		1024	820.6	0.9	183.2	0.525	0.01	2.76E-01	1.20	0.06	4.25E+00
1/19/96	AWCC	CR5	1600	64	64	819.5	0.95	182.2	0.561	0.01	3.15E-01			4.24E+00
			1600		1024	818.6	0.91	181.5	0.52	0.01	2.70E-01	1.16	0.06	4.23E+00
1/23/96	AWCC	CR5+MRC19	1600	64	64	106553	7.9	35.42	27.932	0.49	7.80E+02			4.87E-05
			1600		1024	106537	7.7	50.705	20.778	0.37	4.32E+02	1.81	0.09	6.98E-05
1/23/96	AWCC	CR5+MRC19	1600	64	64	106578	7.97	48.412	29.363	0.52	8.62E+02			6.66E-05
			1600		1024	106561	8.37	25.489	21.203	0.37	4.50E+02	1.92	0.10	3.51E-05

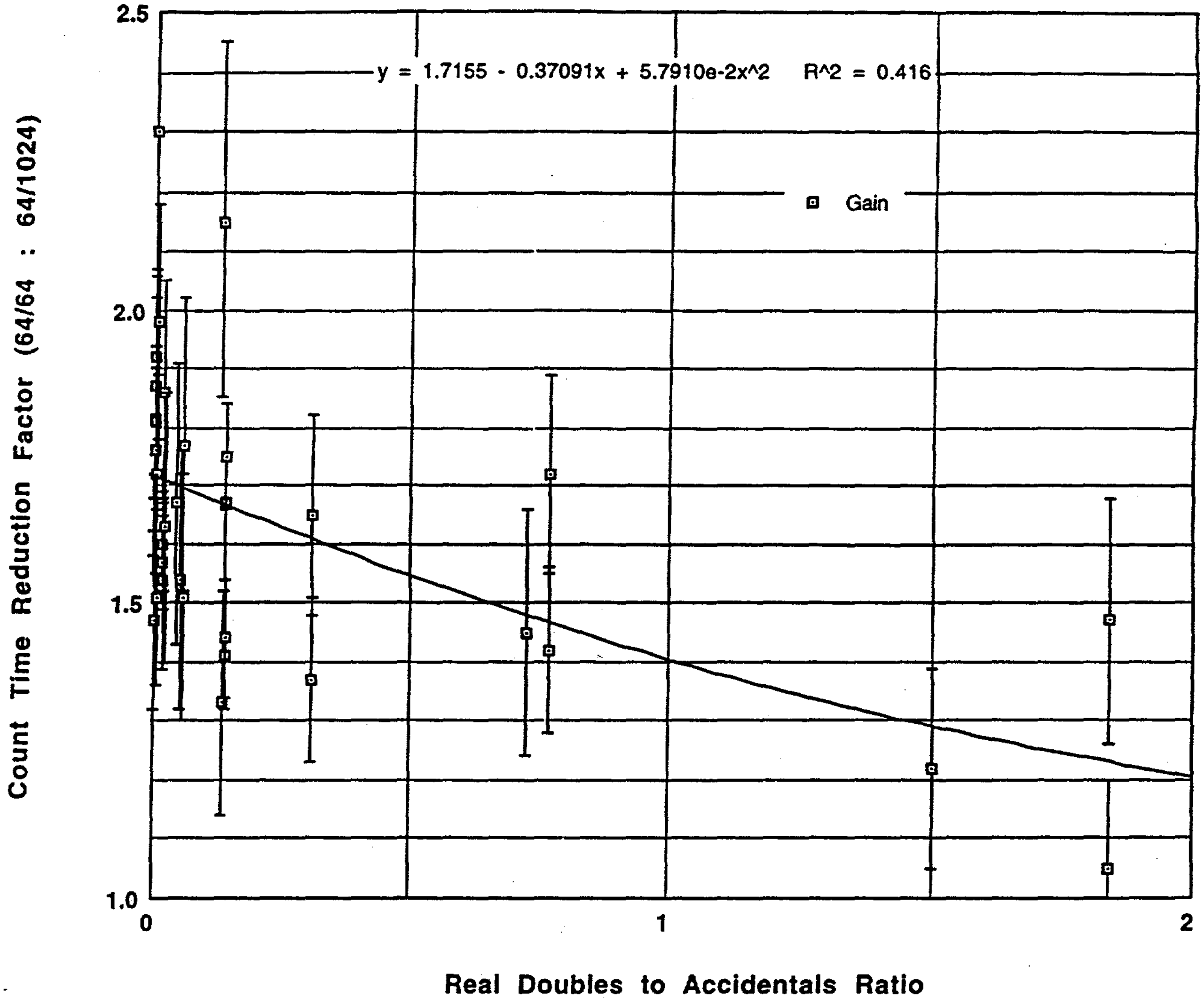

Fig. 2. Counting-time reduction with dual-gated shift register.