Advances in the Design and Fabrication of Electronics for Neutron Multiplicity Counters

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Abstract

This paper presents the results of counting rate and deadtime performance measurements of an upgraded high efficiency multiplicity counter called the Plutonium Scrap Multiplicity Counter (PSMC) that uses a high number of compact KM-200 preamplifiers. The measurements were intended to compare the PSMC's performance between the original configuration with A-111 preamplifiers and after its upgrade with KM-200 preamplifiers. The modified system had improved deadtime with lower deadtime losses. Detector characterization measurements are currently in progress to finalize the detector operating parameters. The new preamplifiers have the potential to allow measurements in difficult environments that could extend the range of operation of the neutron multiplicity technique to spent fuel debris and vitrified waste. The upgraded PSMC also solves many crosstalk and electrical connectivity issues that limit the old design.

I Introduction.

Neutron Multiplicity counters are very well-established technology for quantitative measurements of special nuclear material. Their basic structure, which includes junction box design, with high voltage (HV) circuitry separated by a metal plate from the A-111 based JAB-01 electronics board, has been in use since the early eighties [1]. The size of the boards and signal crosstalk between them limited the number of amplifiers that can fit inside high efficiency counters such as the ENMC and PSMC. This has significantly affected the dead time optimization options, since pulse pileup and dead time losses can be reduced by having higher amplifier to detector ratio.

In this paper we present the design details and performance measurement for a high efficiency multiplicity counter called the Plutonium Scrap Multiplicity Counter (PSMC), which features compact electronics (HV and signal distribution board and KM-200 preamplifiers). The new electronics and design allow for higher amplifier density, free of crosstalk and double pulsing, and implements a novel dead time self-calibration method.

The PSMC upgrade is based on the recent development of our KM-200 electronics [2,3] with compact footprint and with the new capability to reject double pulsing artifacts. This design enables the reduction of the number of tubes per amplifier and thus the deadtime and allows a shorter pre-delay, which increases the fraction of correlated counts that are recorded. A review of different low deadtime approaches, including one with no deadtime losses is presented in [4].

The well-established empirical approach for correction of deadtime losses, using paired neutron sources, singles to doubles ratio, etc. provided excellent results for samples with activity in the range of calibration sources and low (few %) deadtime losses [1]. But it is difficult to apply to high count rate applications such as: spent fuel, plutonium waste and MOX storage canisters, where the sample activity and neutron energy and correlation characteristics differ from that of typical calibration sources.

The new understanding of deadtime behavior over a wide range of count rates [5] and development of novel approach for using the measured item itself as a calibration source for deadtime loss correction [6] enabled accurate deadtime correction for high activity samples. However, the two consecutive measurement method has more strict requirements for noise and gain (plateaus) due to the higher capacitance of more tubes per amplifier during the deadtime measurement. Prior work on the implementation of this method by KM-200 plug-in replacement of A-111 in an AWCC indicated insufficient ground coupling (the electronic plates were only grounded to the junction box periphery) between the He-3 tubes and the KM200 board stack for switching the He-3 tubes signals. Therefore, the electronics ground plates in the upgraded PSMC were replaced with high voltage (HV) distribution boards with KM-200 electronics on the top and metal standoffs providing direct ground coupling between the preamplifiers and tubes. The higher noise will be mitigated by a higher KM200 threshold.

II PSMC upgrade

Two representative designs: LANL owned PSMC built by Canberra [7] and INL owned PSMC build by ANTEC [8]) with different wiring diagrams were selected for upgrading (Fig.1).

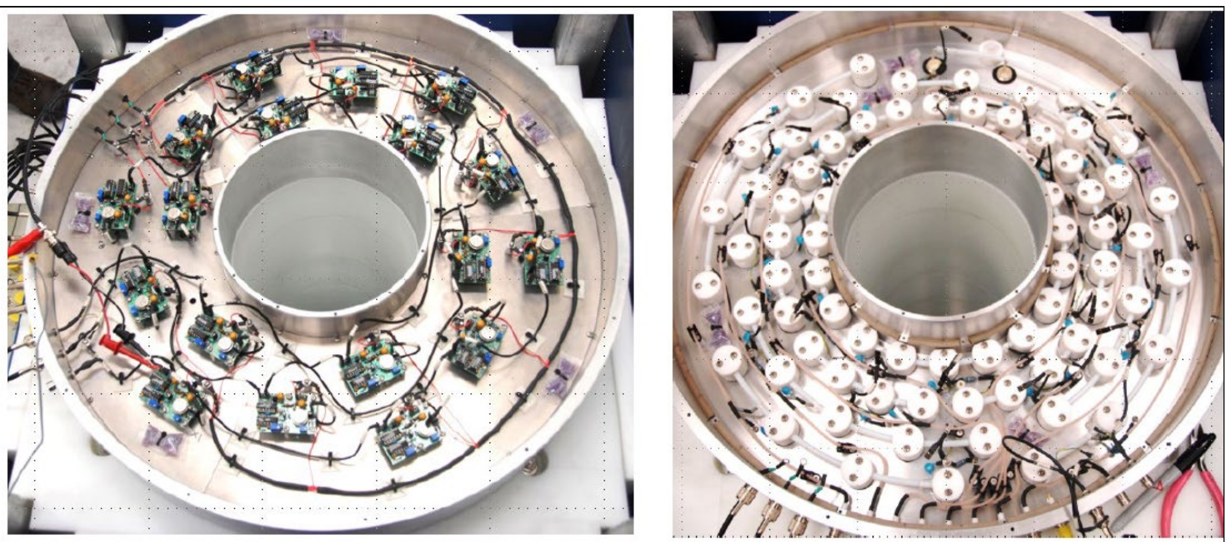


Fig.1 Left: Electronics compartment of Canberra PSMC. Right: HV compartment of ANTECH PSMC

Canberra's PSMC design has 10atm He-3 tubes with approximately balanced count rate (and therefore deadtime) per amplifier whereas the ANTECH design has 4atm He-3 tubes and 18 preamp boards wired for equal number of tubes per preamp. We have selected the first approach (balancing the count rate per amplifier) and distributed 42 amplifiers in the four sings based on MCNP calculated counting rate ratios shown in table 1.

PSMC configuration								
	4atm Pu		10atm Pu		4atm Cf		10atm Cf	
Ring	Tally	relative uncertainty	Tally	relative uncertainty	Tally	relative uncertainty	Tally	relative uncertainty
1	2.14E-01	0.0002	2.50E-01	0.0003	2.09E-01	0.0002	2.44E-01	0.0002
2	1.87E-01	0.0002	2.05E-01	0.0003	1.84E-01	0.0002	2.02E-01	0.0002
3	8.32E-02	0.0003	9.03E-02	0.0005	8.30E-02	0.0002	9.03E-02	0.0002
4	4.89E-02	0.0003	5.47E-02	0.0006	4.98E-02	0.0003	5.58E-02	0.0003
Total	5.33E-01	0.0001	6.00E-01	0.0002	5.26E-01	0.0001	5.92E-01	0.0001

The specific of how the amplifiers are distributed in different rings and their count rate loading are shown in Fig.1.

ANTEC PSMC Counter					Canberra PSMC Counter					LANL Upgraded PSMC Counter				
	Relative Count Rate per Amplifier					Relative Count Rate per Amplifier					Relative Count Rate per Amplifier			
	4 atm		10 atm			4 atm		10 atm			4 atm		10 atm	
Number of A111s per Ring	Pu	Cf-252	Pu	Cf-252	Number of A111s per Ring	Pu	Cf-252	Pu	Cf-252	Number of A111s per Ring	Pu	Cf-252	Pu	Cf-252
4	1.00E-01	9.95E-02	1.04E-01	1.03E-01	7	5.74E-02	5.69E-02	5.95E-02	5.89E-02	19	2.11E-02	2.10E-02	2.19E-02	2.17E-02
6	5.84E-02	5.82E-02	5.70E-02	5.68E-02	6	5.84E-02	5.82E-02	5.70E-02	5.68E-02	13	2.69E-02	2.69E-02	2.63E-02	2.62E-02
4	3.91E-02	3.95E-02	3.76E-02	3.81E-02	4	3.91E-02	3.95E-02	3.76E-02	3.81E-02	6	2.60E-02	2.63E-02	2.51E-02	2.54E-02
4	2.29E-02	2.36E-02	2.28E-02	2.36E-02	3	3.06E-02	3.15E-02	3.04E-02	3.14E-02	4	2.29E-02	2.36E-02	2.28E-02	2.36E-02

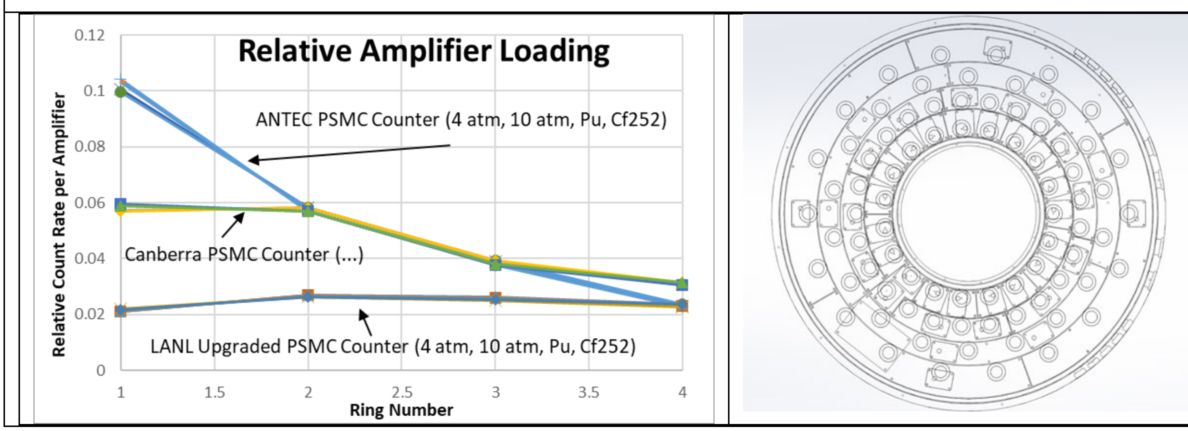


Fig 1. Top – simulated results for relative count rates per amplifier (amplifier loading) for three PSMC amplifier choices, tube pressures of 4 atm or 10 atm, and neutron energies from Pu source or Cf252 sources; Bottom left: plot of amplifier loading for all nine PSMC configurations showing much more even distribution in the LANL PSMC. Pressure and energy don't affect amplifier loading significantly; Bottom left: preamplifiers placement in the LANLPSMC junction box.

III PSMC electronics

KM200 for implementation in the PSMC multiplicity counter:

The KM200 is a set of electronics for ^{3}He detectors and other proportional counters that features high noise immunity and suppression of double pulsing artifacts as described in [9]. By changing some components, we can also customize the KM200's shaper time constants. In the PSMC upgrade project we selected shaper time constants that are suitable for both 10 atmosphere and 4 atmosphere tubes.

The original high power TTL output driver in the KM200 was replaced by more efficient CMOS driver in the PSMC upgrade version because these signals only had to drive a derandomizer and a buffer for a list mode module (figure 3). The derandomizer's aggregates the sum of all logic pulses and individual rings [10] producing a sequential TTL output that can be connected to multiplicity counting electronics.

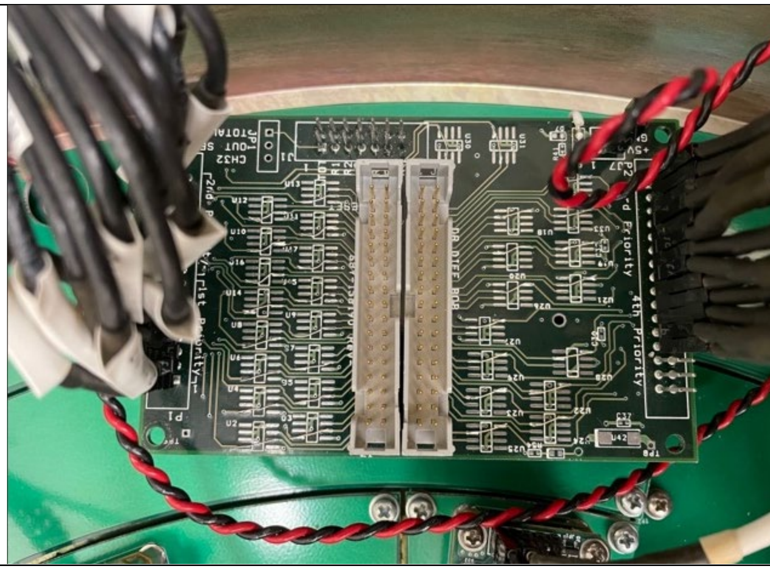


Fig. 2 Derandomizer board with summed logic outputs and a breakout board for list mode ribbon cable connection.

HV distribution board

Hand wiring HV circuitry with custom-made signal feedthroughs in the electronics ground plate becomes very labor intensive with increasing of tubes and preamplifiers in high efficiency counters. Also, the switching of fragile anode signals requires better coupling between ground plate and tubes. This, and the difficulty with crosstalk, are some of the main reasons a higher density of amplifiers was never achieved with the old A111 electronics and the construction methods used before the PSMC upgrade.

We implemented a different approach: a stack of segmented printed circuit boards for each ring: HV distribution and switching relay circuitry and KM200 amplifiers and +5V distribution circuitry that serves also as shielding for the low level He-3 tube signals as shown in Fig 3. Both the anodes of the He-3 tubes and the KM200 preamplifiers are connected to the HV distribution board via pogo pins and gold contact pads.

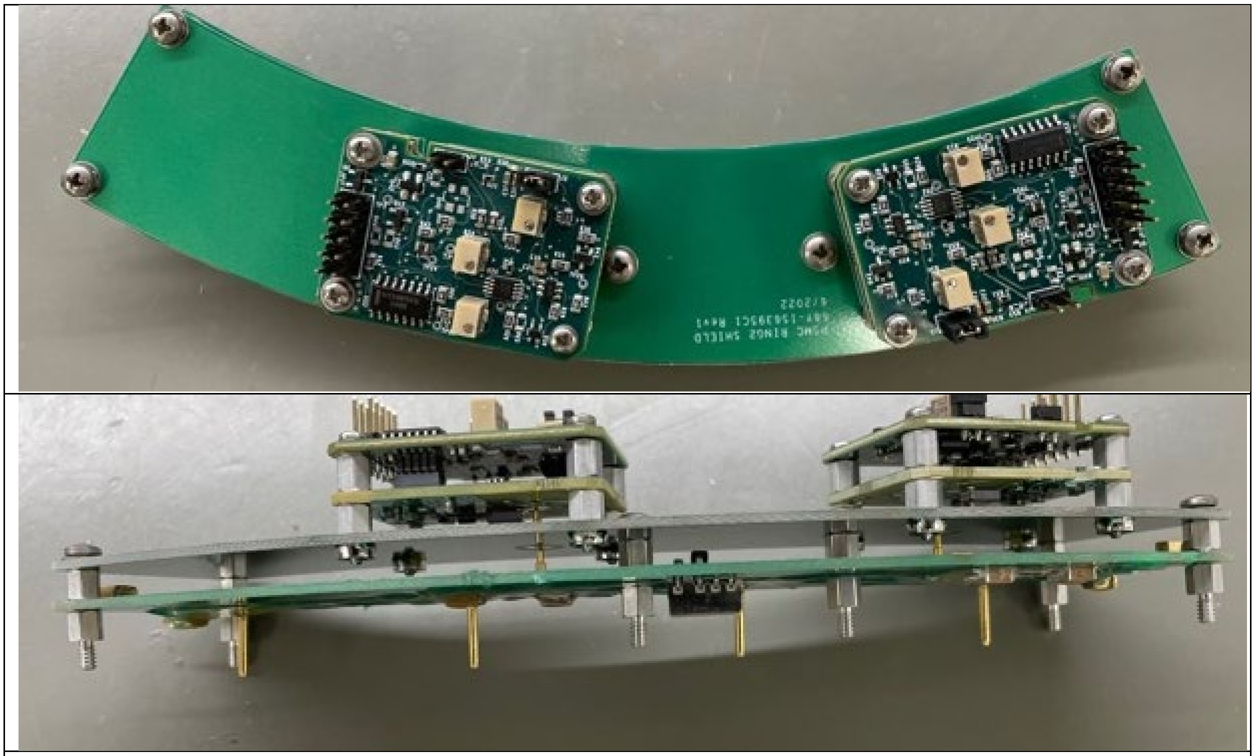


Fig.3 Ring3 HV boards stack with KM200 preamplifiers. The side view shows the HV pins for connection to the HN tube receptacles, mounting standoffs for direct connection to the bottom of the junction box, switching relays and HV components. The side view shows the top board with mounted preamplifiers.

We have simplified this approach in the next revision of HV distribution board. It combines the HV and Preamplifier rings boards in one sector board (see Fig.4) minimizing the interconnections; providing better ground coupling between the preamplifiers and tubes. Additionally the new HV distribution boards (four sectors for all counter) incorporate charge injectors to each preamplifier allowing fast and convenient threshold setting with the LANL Charge Calibrator.

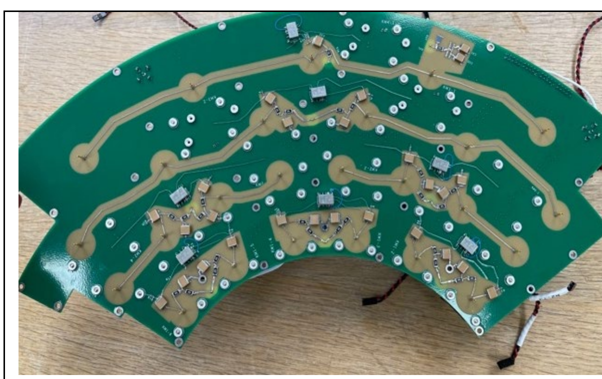


Fig 4 Left: bottom view of R2 HV distribution board

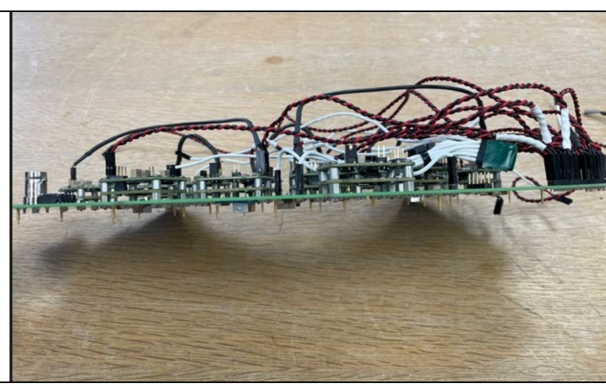


Fig 4 Right: bottom view of R2 HV distribution board

IV Experimental results

Comparison count-rates measurements of Canberra built PSMC and first prototype of upgraded PSMC electronics.

The comparison experiment was caried out with. USMR module and INCC-6 software with Cf-252 sources. Table 1 shows the data taken with INCC6. The data in green is with the KM200 and the remainder is with A-111.

Table 1 Counting Rates from 252Cf sources in PSMC

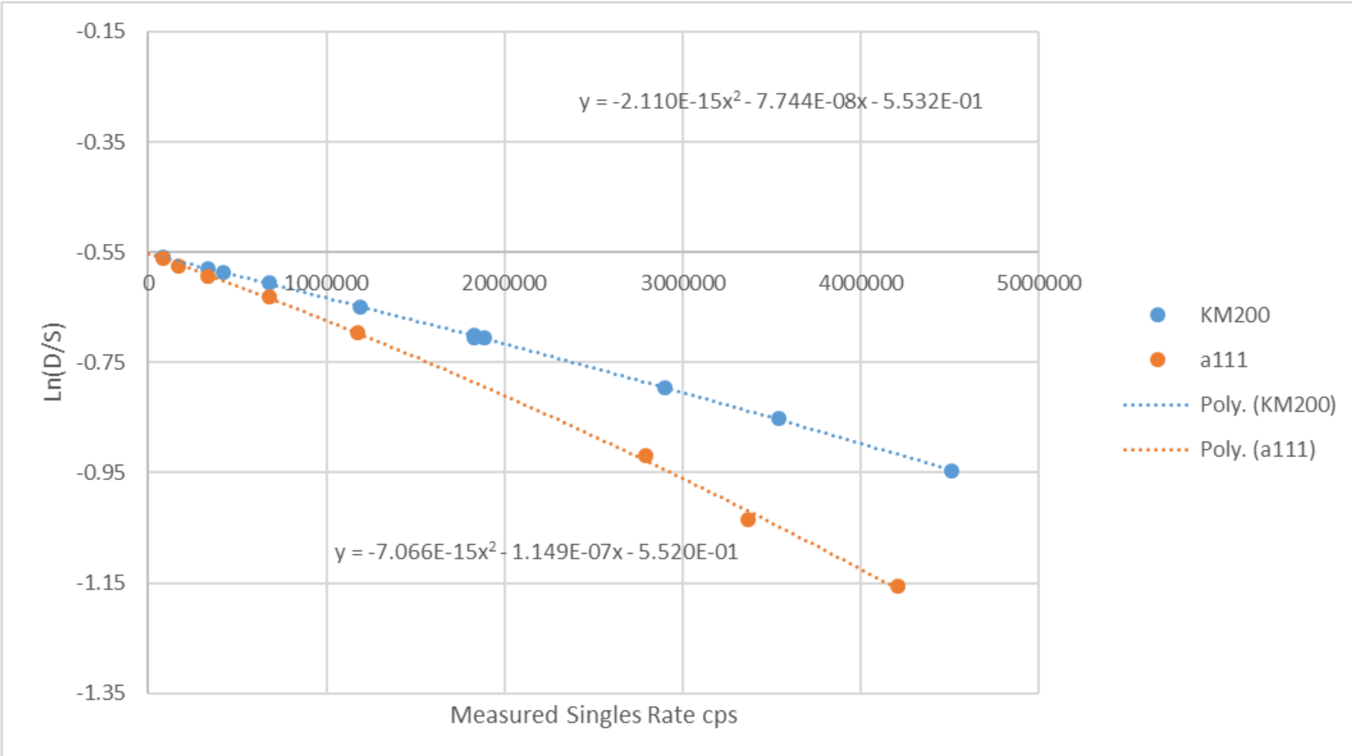
Item ID			Singles	Singles Error	Doubles	Doubles Error	Triples	Triples Error	Count Time	ln(D/S)
R2-456 + dummy +R2-460 dual source calib			2900152	94.857	1307952	1267.025	-19623.2	13755.53	90	-0.7963
Dummy T +R2-457 M + dummy B dual source calib			1889396	93.88	933262.6	881.402	119669.9	12220	90	-0.70533
R2-456 T +Dummy M + dummy B dual source calib			1826548	78.108	906218.2	862.714	113744.5	5507.607	90	-0.7009
R2-456 T +R2-457 M + dummy B dual source calib			3539617	45.735	1510714	1842.995	-110283	15299.71	90	-0.85144
R2-456 T +R2-457 M + R2-460 B dual source calib			4511431	167.212	1751107	2290.505	15050661	147541.4	90	-0.94637
dummy (top) +R2-464 (bott) dual source calib			2.7	0.113	0.02	0.007	0	0.004	90	
dummy (top) +R2-464 (bott) dual source calib			85067.3	15.465	48599.42	67.628	15603.24	124.902	90	-0.55983
R2-448 (top) +dummy (bott) dual source calib			337106.4	28.308	188720.4	117.385	53599.01	1009.126	90	-0.58013
R2-448 (top) +R2-464 (bott) dual source calib			420644.9	28.832	234042.5	243.569	65369.03	1025.048	90	-0.58629
dummy (top) +R2-452 (bott) dual source calib			683639.5	34.297	373658.7	400.205	93257.07	2588.458	90	-0.60409
R2-460 (top) +dummy (bott) dual source calib			1187812	41.41	619836.3	642.211	107161.4	3066.4	90	-0.65041
R2-460+R2-452			1921261	63.889	1101049	1164.069	231473.4	11392.14	90	
R2-460 (top) +R2-452 (bott) dual source calib			1828900	57.842	904104.9	956.16	106372.2	9719.009	90	-0.70452
TestKM200-Bkg			1.2	0	0	0	0	0	10	
TestKM200-Bkg			6.2	0.391	0	0	0	0	10	
R2-456 +R2-457			3363933	99.78	1194854	6008.071	-333633	13550.7	90	-1.03509
R2-456 +R2-460			2795612	149.938	1114929	2150.79	-200822	8064.397	90	-0.91926
R2-456 + R2-457 +R2-460			4210427	91.38	1326698	5013.082	-402217	36843.8	90	-1.15487
bacgr			2.4	0.033	0.02	0.006	0	0.002	90	
R-464			85366.2	10.484	48716.89	43.796	15561.57	86.427	90	-0.56092
R-462			168272.4	27.999	94735.43	93.711	29306.06	380.115	90	-0.5745
R-448			338223.9	23.882	186759.6	248.895	51145.14	639.516	90	-0.59389
R-452			681377.9	48.377	362625.8	352.808	77716.76	2691.37	90	-0.63075
R-460			1176090	38.63	587134.2	885.213	66004.51	2017.217	90	-0.6947
R-456			1792303	61.092	823090.9	1899.557	10339.02	5922.241	90	

The fit to the data is shown in the next figure. The fitted polynomial parameters are used to determine the deadtime constants used in the standard deadtime correction equations:

$$S_0 = S_m \exp\left(\frac{(A + BS_m)S_m}{4}\right)$$

$$D_0 = D_m \exp\left((A + BS_m)S_m\right)$$

Where S_0 and D_0 are the corrected rates and S_m and D_m are the measured rates.



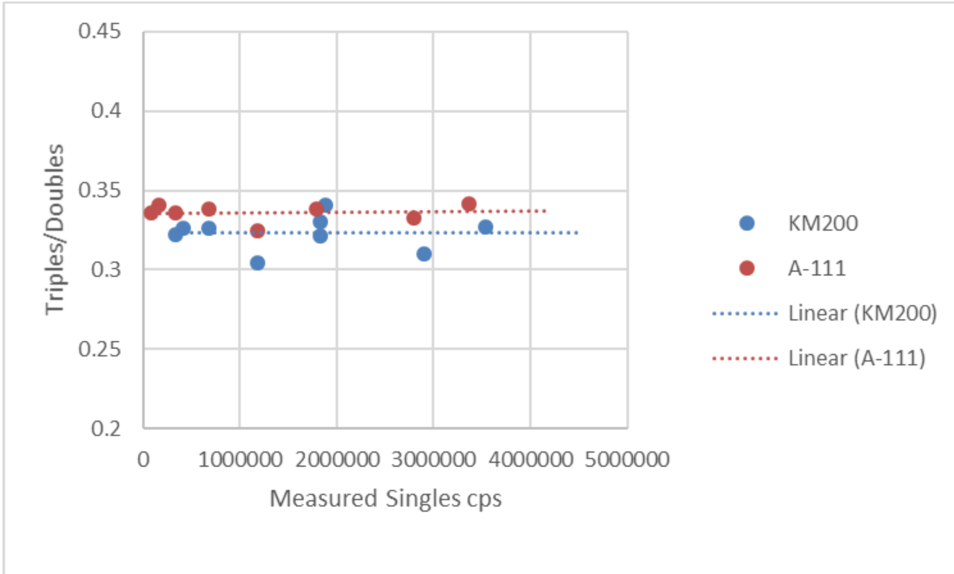
The results from the fit are shown results for the A-111:

	INCC6	
	KM200	A-111
x^2 coeff	-2.11E-15	-7.07E-15
x coeff	-7.74E-08	-1.15E-07
A	1.03E-07	1.53E-07
B	2.81E-15	9.42E-15
k(*A^2/4)	1.06	1.61

The deadtime A for the KM200 system is about 67% of the deadtime A of the A-111 system. The B coefficient comes out to 1.06*A^2/4 for the KM-200 and about 1.4 times A^2/4 for the A-111. This difference is because the A^2/4 approximation is only good for low deadtimes (~10% on Singles →40% on Doubles). The overall deadtime of the KM200 system is lower than that of the A-111 system and so the approximation is better.

Triples deadtime

The triples count rate is corrected using the method of Dytlewski. [13]. A good way to determine the triples deadtime is to examine the Triples/Doubles ratio for a set of ^{252}Cf sources (when the doubles rate has already been corrected as above) as a function of singles counting rate and make the deadtime corrected T/D flat. The figure below shows results of multiplicity deadtime (d) = 27.8 ns for KM200 and 44.4 ns for A-111.



(The highest counting rate measurement in both cases had to be excluded because the multiplicity distribution overflowed the 255 recording limit of the system.)

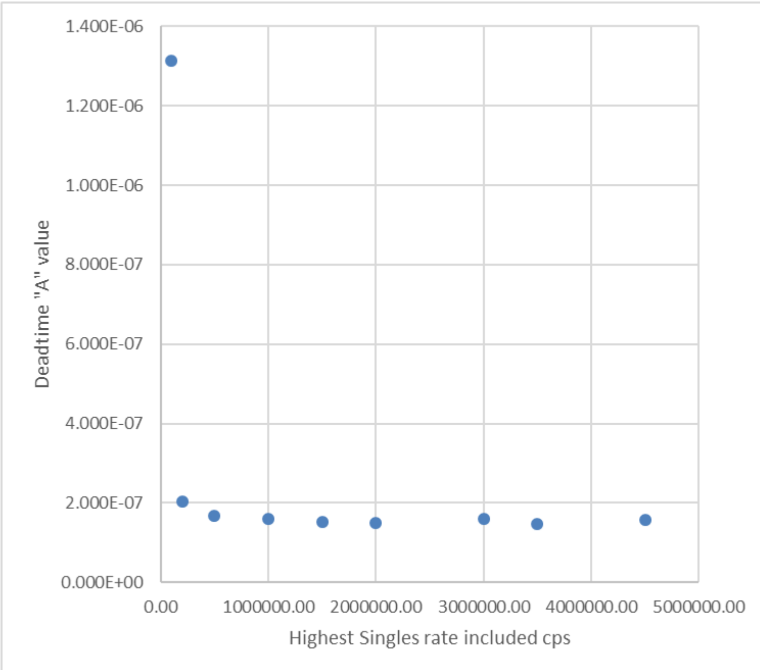
Results from Paired Sources

With paired sources we assume some relationship between A and B. If we take $B=A^2/4$, we obtain the following results using doubles rates to determine A.

Sources	Amplifier	Max Singles(meas)	A µs
456 +457	KM200	3539617	0.103
(456 +457) + 460	KM200	4511430	0.104
452 + 460	KM200	1828900	0.106
(456 +457) + 460	A-111	4210427	0.160
452 + 460	A-111	1834917	0.168

Effect of Maximum Count Rate on Value of A

It is interesting to consider the minimum counting rate that can be used to determine the deadtime. The figure below shows the value of A determined by including higher and higher counting rate data. The results seem to be reasonable with even just a few percent Singles deadtime.



Count rates measurements with second prototype of upgraded PSMC electronics

One sector of the HV ring boards was replaced with the new HV distribution board for performance comparison as shown in Figure 4.

These results are very consistent with the results obtained from the multiple source measurements.

Effect of Maximum Count Rate on Value of A

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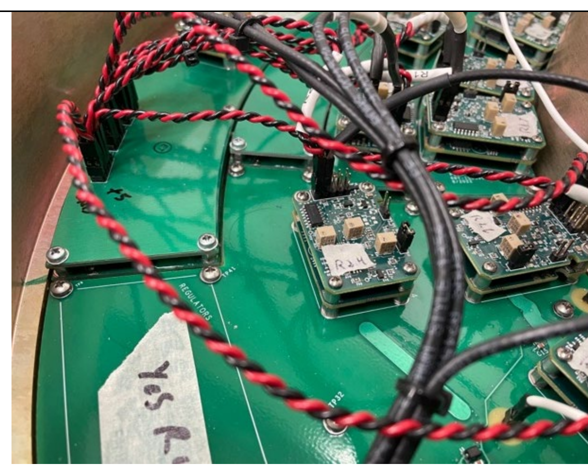

Fig 5 Top view of the counter	Enlarged view of new HV distribution board

All preamplifiers were set with 200mV threshold and 1.5V Double Pulsing Filter (DPF). The HV operation voltage was selected as 1680V based on the normalized plateaus shown in Fig.6.

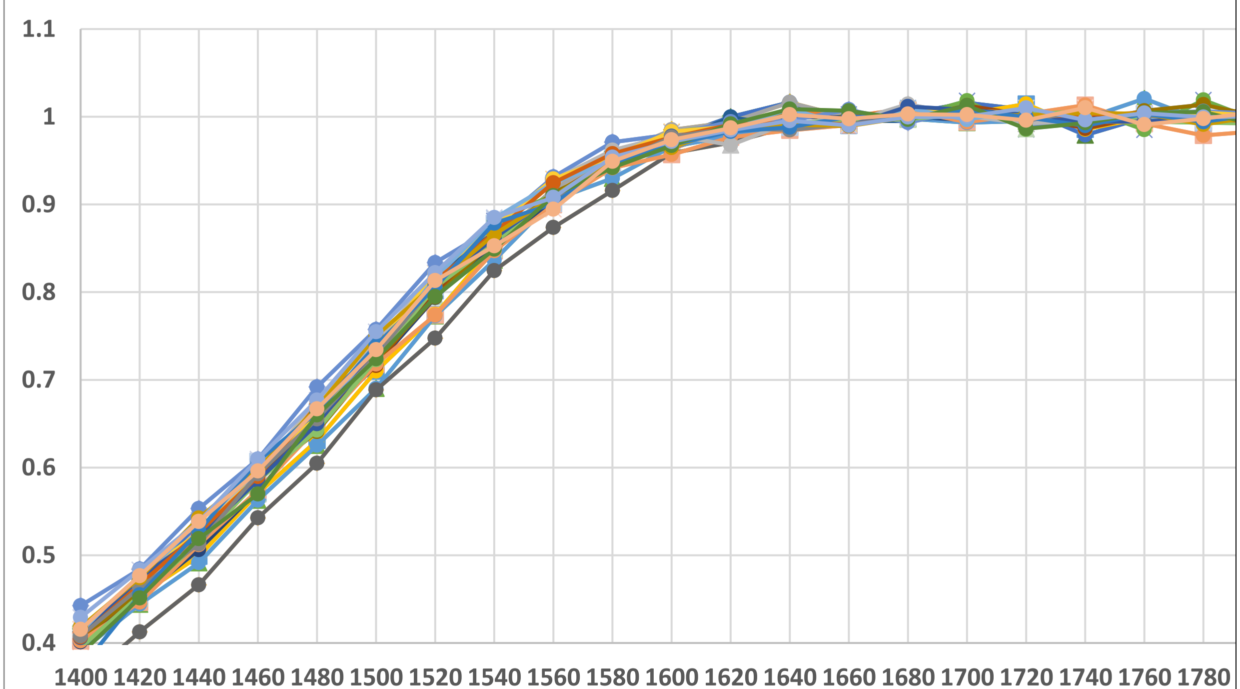

Fig 6. KM-200: Thr=200mV; DPF=1.5V Normalized HV Plateaus

The predelay was set at 1µs based on the normalized time interval histogram (TIH) data taken with a ^{252}Cf source 20V above the HV setpoint of 1680V as shown in Fig. 5.

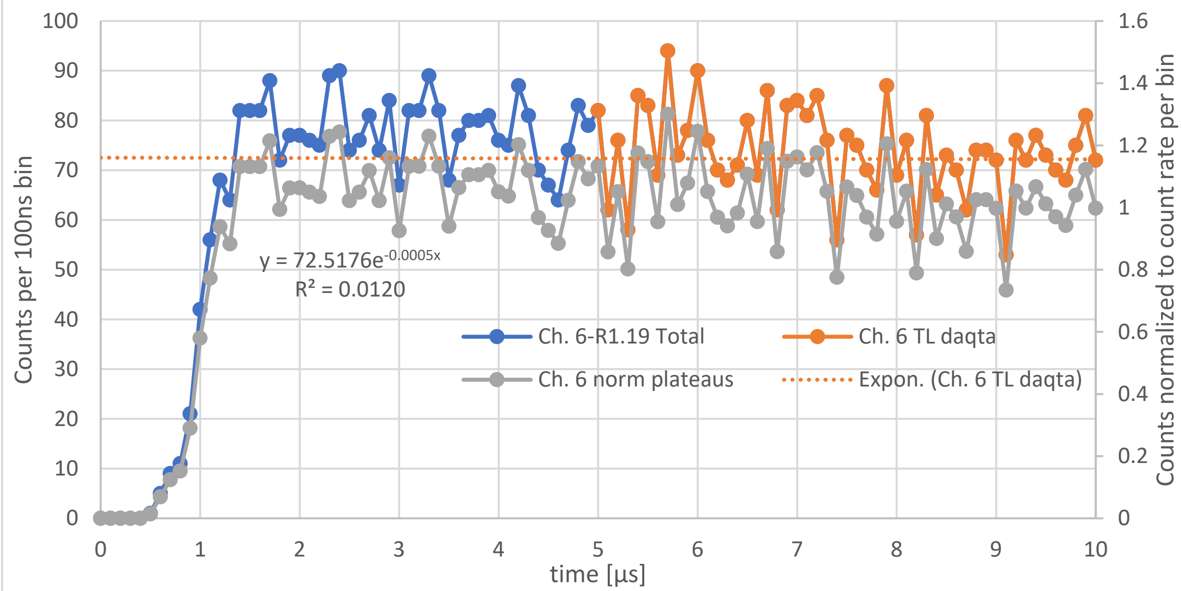

Figure 5. Time interval histogram (TIH) for one of the channels of the upgraded PSMC. 1µs is the time when pileups result in dead time losses.

The deadtime parameter settings used for the upgraded LANL PSMC are compared to the deadtime parameters settings for the original 4 atm [11] and 10 atm [12] Canberra PSMC in Table 2.

Table 3 shows the DT calibration measurements with the upgraded PSMC. Each measurement is 90sec long

Item ID	Singles	Singles Error	Doubles	Doubles Error	Triples	Triples Error	ln(D/S)
R2-460+R2-456+R2-457	3064909	92.8	1125391	1721.5	-107699	14584	-1.00189
R2-460+R2-456+Dummy	1948955	97.9	809018	742.4	31770	7822	-0.87923
R2-460+Dummy+Dummy	785809	55.2	367143	645.2	71323	1742	-0.76096
Dummy+R2-456+R2-457	2383890	161.7	944271	1293.9	10578	11060	-0.92608
Dummy+Dummy+R2-457	1252910	99.6	558098	792.3	71656	5939	-0.80869
Dummy+R2-456+Dummy	1215138	128.1	542996	962.6	81724	2917	-0.80551
R2-460+Dummy+R2-457	1983451	85.9	818567	938.0	40628	4794	-0.88504
R2-464+Dummy+Dummy	55717	17.7	28026	28.9	8295	63	-0.68716

The measured deadtime parameters are compared in Table 4.

DT Parameters			
Parameters	Original A-111 PSMC	First prototype KM200 PSMC	Second prototype KM200 PSMC
A	1.53 µs	1.03E-07	1.08 µs
B	0.009 μs^2	0.0028 μs^2	0.0029 μs^2
Gate Width	46 µs	46 µs	32 µs
Multiplicity deadtime (d)	44.4 ns	27.8 ns	29ns

The dead time of KM200 prototype show about 33% lower DT than original A-111 PSMC instrument. The results for the technique for determine the dead time loses loss calibration using the measurement sample as a DT calibration standard will be reported in the presentation.

V. Relevant future work and studies

Engineering design work is still on-going for the KM-200. A placement of the current 1.2”by 1.6” by 2” high horizontal KM-200 board stack with 4 mounting holes is not practical for the next generation multiplicity counters with high density pattern of He-3 tubes, such as the ORNL high efficiency counter. LANL is currently developing a new vertical shielded package with smaller footprint and only two mounting holes powered by a new HV bias and +5V distribution board (Figure 4). Here the fragile SMD potentiometers in the horizontal package are replaced with standard easy adjustable potentiometers.

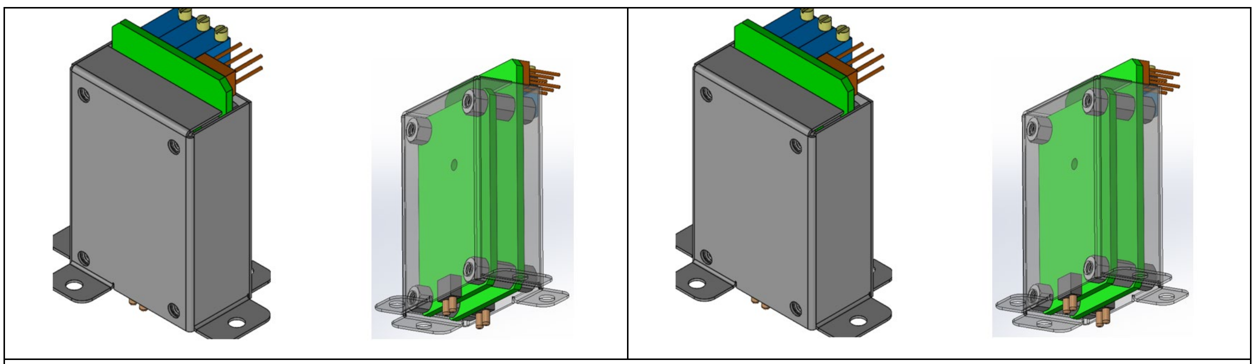

Figure 4. Compact vertical package of the KM200 electronics for higher density designs.

We are also developing preamplifiers that can allow measurement to be made in extreme conditions, such as a neutron and gamma sensor operating in an environment of tens of thousands R/h gamma dose rate for measuring hot samples of decommissioning of nuclear facilities, or the coincidence counting of special nuclear material at high temperature and high gamma dose rate for vitrified waste or spent fuel debris.

VI. Summary and Conclusions

Multiplicity counting of special nuclear material has worked successfully in many applications for several decades using the A-111 preamplifier, which represented a major step forward when it was introduced in the 1980s. Measurements in new and more challenging situations, however, such as spent fuel debris or items with high gamma dose rates have not been possible. The optimal performance of a new generation of neutron multiplicity counters can be achieved with one preamplifier per ^{3}He tube and list mode readout of each channel. The latest generation of KM-200 preamplifiers with their smaller footprint, lower deadtime and double-pulsing rejection provide an important component of such a system.

VII Acknowledgments

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