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EFFECTS OF GAS PRESSURE
AND PREAMPLIFIER CONFIGURATION
ON NEUTRON FISSION
CHAMBER PERFORMANCE FOR
COUNTING AND MSV OPERATION

HANFORD ENGINEERING DEVELOPMENT LABORATORY
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EFFECTS OF GAS PRESSURE
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By

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ABSTRACT

Counting and Mean Square Voltage (MSV) data were taken for three neutron measurement channels; (1) a charge sensitive, (2) a current sensitive with integration, and (3) a current sensitive plus a charge sensitive system. The effects of changing gas pressure on neutron and gamma sensitivity for each system were measured. Pressure changes for improving performance were discussed. Current sensitive systems can replace charge sensitive systems for many reactor applications without loss of sensitivity. For FFTF, 1.75 atmospheres fill gas pressure for the ex-vessel detectors will allow the system to meet specification of greater than $10^{-10} \langle v^2 \rangle / \text{nv}$.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	iii
LIST OF FIGURES	v
LIST OF TABLES	vi
INTRODUCTION	1
DISCUSSION	3
EXPERIMENTAL PROCEDURE	4
RESULTS	6
CONCLUSIONS	7
REFERENCES	9
APPENDIX A	27

LIST OF FIGURES

<u>FIGURE</u>	<u>Page</u>
1 Charge Sensitive Block Diagram	12
2 Current Sensitive Plus Integration Block Diagram	13
3 Current Plus Charge Sensitive Block Diagram	14
4 Pulse Circuit For Determination of System Transfer Function	15
5 D. C. Current Sensitivity	16
6 System Noise Referred To Cable Input	17
7 Average Neutron MSV Sensitivities.	18
8 Average Gamma MSV Sensitivities.	19
9 Average MSV Sensitivity Ratios	20
10 PuBe Pulse Counting Efficiency At Gamma Background Of 1 cps	21
11 PuBe Pulse Counting Efficiency At Gamma Background Of 1 cps	22
12 PuBe Pulse Counting Efficiency At Gamma Background Of 1 cps	23
13 Current Sensitive Plus Integration Counting Sensitivity vs Time Constant At 1 cps Gamma Background	24
14 Charge Sensitive Discriminator Settings vs Pressure	25
15 Current Sensitive Plus Integration Discriminator Settings vs Pressure	26
16 Current Plus Charge Sensitive Discriminator Settings vs Pressure	27

LIST OF TABLES

<u>Table</u>	<u>Page</u>
I Radiation Flux Levels	10
II Systems Transfer Function - H	11
A1 Pulse Counting Data	A-1
A2 DC Current With 700 V Applied To The Detector	A-2
A3 DC Current Sensitivities	A-3
A4 Raw MSV Gamma Data With 700 Vdc Detector Bias	A-4
A5 Raw MSV Neutron Data With 700 Vdc Detector Bias	A-5
A6 MSV Gamma Sensitivities	A-6
A7 MSV Neutron Sensitivities	A-7
A8 Neutron To Gamma Sensitivity Ratios	A-8
A9 MSV Time Constant Data For C & T at 1.75 atm	A-9

INTRODUCTION

Neutron fission counters will be used both in-vessel and ex-vessel for the neutron flux instrumentation systems of the Fast Flux Test Facility (FFTF) being constructed by the Westinghouse Hanford Company under contract with the U.S. Atomic Energy Commission. In-vessel detector parameters (gas type, pressure, and plate spacing) have been determined^{1,2} experimentally. These parameters have also been utilized for the ex-vessel detectors. This report presents experimental evidence of the FFTF ex-vessel detector performance and illustrates possible savings in time and money for future systems.

For the FFTF, the in-vessel detectors employ a 2 mg/cm^2 coating of ^{235}U , while the ex-vessel detectors employ a 1 mg/cm^2 ^{235}U coating depleted of ^{234}U . The preamplifiers and signal channels are also different for the ex-vessel and in-vessel channels. A charge sensitive preamplifier is utilized for the ex-vessel detectors and a current sensitive preamplifier is used for the in-vessel detector because a large bandwidth is required to obtain adequate performance in the presence of gamma radiation.¹ The charge sensitive preamplifier was utilized for the ex-vessel system because it was the only type of preamplifier which had been available with a Mean Square Voltage (MSV) channel. The equipment utilized for the different channels has been reviewed by other investigators³, but from the above discussion several questions arise. Is the optimum gas pressure for the in-vessel detectors the same for the ex-vessel detectors? Can the same basic electronic channels be used in-vessel and ex-vessel? How would such changes affect performance, cost and schedule?

To evaluate the ex-vessel performance, a detector and measurement system similar to the plant units was assembled for evaluation. The results of this test were then compared with the data taken using an in-vessel type current preamplifier. The expected benefits from the elimination of one type of preamplifier include the simple reduction of the design and production costs. Technically, other benefits can be shown for the cable systems after a consideration of the performance requirements.

The in-vessel channel must count the number of neutron pulses from the detector. These pulses usually last less than 100 nsec and the system bandwidth

must be maintained to process this type of pulse because gamma pileup could otherwise impair the neutron detection efficiency.

The ex-vessel channel must also count neutron caused pulses from the detector. These pulses are fast, but the system bandwidth need not be maintained because gamma pileup is not a problem. However, in addition to a counting channel, the ex-vessel system has two other channels to consider, i.e. an MSV channel and a dc current channel. The dc current channel simply measures the dc current from the detector and is not unique with preamplifier types. Neither is the MSV channel, but this channel requires some mathematical consideration before this can be illustrated.

Theoretical development of the MSV system^{4,5,6} is based on Campbell's theorem. If $f(t)$ is the system response to a single pulse and n the average pulse rate, then a mathematical description of the output is given by equations 1 and 2.

$$\langle v(t) \rangle = n \int_0^{\infty} f(t) dt \quad (1)$$

$$\langle (v(t) - \langle v(t) \rangle)^2 \rangle = n \int_0^{\infty} f^2(t) dt \quad (2)$$

Here, the system has initial conditions zero at $t = 0$, $\langle v(t) \rangle$ is the average or dc voltage, and $\langle (v(t) - \langle v(t) \rangle)^2 \rangle$ is the Mean Square Voltage (MSV).

$$\begin{aligned} \text{MSV} &= \langle (v^2(t) - 2v(t)\langle v(t) \rangle + \langle v(t) \rangle^2) \rangle \\ &= \langle v^2(t) \rangle - 2\langle v(t) \rangle \langle v(t) \rangle + \langle v(t) \rangle^2 \\ &= \langle v^2(t) \rangle - \langle v(t) \rangle^2 \end{aligned} \quad (3)$$

So if there is a dc removing component in the system,

$$\text{MSV} = \langle v^2(t) \rangle = n \int_0^{\infty} f^2(t) dt. \quad (4)$$

If there are two types of pulses, $f_1(t)$ and $f_2(t)$, with average rates n_1 and n_2 respectively the theorem will yield

$$\langle v^2(t) \rangle = n_1 \int_0^{\infty} f_1^2(t) dt + n_2 \int_0^{\infty} f_2^2(t) dt. \quad (5)$$

So, an output voltage including components from neutron pulses and noise can be separated in the above manner. Notice that smaller pulses are discriminated against by the square of their amplitude, giving improved signal-to-noise ratios. MSV can be calculated by squaring the root-mean-square value of the function (V_T) and separated into the known components as follows

$$\langle v^2(t) \rangle = V_T^2 = V_n^2 + V_\gamma^2 + V_\alpha^2 \quad (6)$$

Where V_T is the total RMS component, V_n the RMS neutron component, V_γ the RMS gamma component and V_α is the lumped alpha and electronic noise RMS component.

By measuring the RMS voltage of a neutron detection system without radiation, V_α can be determined. Similarly the other components can be determined by appropriate measurements with neutron and gamma sources. The type of system is not important to the description, so either charge or current sensitive preamplifiers could be used. However, the system noise component, V_α , should be as small as possible.

The noise of preamplifiers has been analyzed⁷ and can be readily measured. A well designed charge sensitive amplifier has a better signal-to-noise ratio than a well designed current sensitive amplifier. However, the noise ratio of a current sensitive amplifier does not change as fast with loading on the input as it does for a charge sensitive preamplifier. If low noise is required and a very short cable is connected to the detector then charge sensitive operation is preferred, but if the length of cable is long the performance of the two systems approach each other. In a reactor situation, where long cables are used, an analysis of the input loading must be performed or experimental data must be compared.

DISCUSSION

It has been shown² for current sensitive operation, that for a nuclear interaction within the detector the current from a fission counter can be calculated to be

$$\begin{aligned}
i_m(t) = I_0 & \left(\left(\frac{t_c + Z_{01}C}{t_c} \right) \left[1 - \exp\left(\frac{-t}{Z_{01}C}\right) \right] - \right. \\
& \left. \frac{t}{t_c} - u(t-t_c) \left\{ \frac{Z_{01}C}{t_c} \left[1 - \exp\left(\frac{-t + t_c}{Z_{01}C}\right) \right] + \right. \right. \\
& \left. \left. \frac{t - t_c}{t_c} \right\} \right)
\end{aligned} \tag{7}$$

Where C is a capacitance determined by the detector, t_c the electron collection time, I_0 the initial current, Z_{01} the characteristic impedance of the cables and $u(t-t_c)$ a unit step function starting at $t = t_c$. If the above equation is integrated, the charge in the pulse is found to be

$$Q = I_0 \frac{Z_{01}^2 C^2}{t_c} \left(\exp\left(\frac{t_c}{Z_{01}C}\right) - 1 \right) \tag{8}$$

Here I_0 is a function of the fill gas pressure, p , and the electron drift velocity, v . Using the simplest⁽²⁾ assumptions for the functional relationships, a partial differentiation of Equation 8 with respect to plate spacing yields conditions for a maximum value of Q . These conditions are

$$\exp\left(\frac{-1}{K}\right) = 1 - \frac{0.6}{K} \tag{9}$$

where K is equal to $Z_{01}C/t_c$. A value of K equal to 0.8879 is a solution with sufficient accuracy. A similar analysis for current sensitive operation yielded a value of the ratio $Z_{01}C/t_c$ equal to 4.1 for the highest peak value of the current. Thus, an optimum value of the pressure should exist for ex-vessel operation and should be experimentally examined.

EXPERIMENTAL PROCEDURE

The investigation for selection of the appropriate fill-gas pressure for the ex-vessel detector and for comparison of charge sensitive vs current sensitive methods was conducted in the HEDL ⁶⁰Co Gamma Facility. An 80 gm PuBe source provided the low neutron flux for counting purposes and a 1.0 mg

^{252}Cf source provided the high neutron flux for the MSV measurements.

The detector chosen for the tests was the same unit utilized previously² for FFTF current sensitive counting experiments. This detector has a plate spacing of 0.08 inch and a sensitive coating of 2.0 mg/cm^2 ^{235}U for neutron detection. As the coating is twice as thick for the test detector as for the ex-vessel detectors, two changes were expected in the operation. The test detector would be more sensitive than a FFTF detector and the gamma-caused pileup would differ for the two detectors. However, such changes would not affect the conclusions from the low gamma tests, so the use of the unit was justified.

Measurements were made for the detector filled with Ar-7% N_2 at pressures of 0.5, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00 and 2.25 atmospheres pressure. At each pressure, counting and MSV data were taken at high gamma fields and low gamma fields with and without neutrons. Table I shows the radiation levels utilized.

Figure 1 shows a block diagram of the charge sensitive system used. The system is the same as that described previously^{1,2} except for the portion within the dashed area (i.e. the preamplifier and the RMS voltmeter). For the preamplifier, a commercial unit was modified to meet the FFTF specifications for gain, rise time, and decay time. These values for the unloaded preamplifier were 970 mV/pcoul, 20 nsec, and 330 nsec, respectively. The RMS voltmeter was a Hewlett Packard 3400A. All data taken with this system are identified by C in the tables and figures.

Figure 2 shows how the dashed area of Figure 1 was changed to form the current sensitive plus integration system. The preamplifier is the same current sensitive unit utilized to optimize the in-vessel detector pressure⁽²⁾. Amp #1, a Hewlett Packard 5582A, was utilized to introduce the integration time constant. The RMS voltmeter was the same as above. All data taken with this system are identified by C & 1 in the tables and figures.

Figure 3 shows how the dashed area of Figure 1 was changed to form the current plus charge sensitive system. All the equipment is the same as described above. All data taken with this system were identified by C + C in the tables and figures. No time constants were introduced into the system except that of the charge preamplifier which had the 330 nsec decay time indicated above.

Figure 4 shows the pulse circuit for determining the transfer functions for the three systems. Table II shows the measured values for each system.

RESULTS

For each Ar-7% N₂ pressure, dc current and RMS voltage was recorded with each measurement system. All of these data are presented in Appendix A. Also integral bias curves were taken. Appendix A shows the counting rates taken from these curves at the discriminator setting for the one count per second gamma backgrounds.

Figure 5 shows the dc current sensitivity to gamma radiation. The gamma sensitivity is a linear function of pressure and is essentially the same for all systems.

Figure 6 shows the noise for the three types of systems. As expected, the charge sensitive system is less noisy than the other two systems. From these data, a ratio of V_{α}^2 can be determined for the various configuration. V_{α}^2 is approximately three times less for the charge sensitive system than for the current sensitive plus integration system. Thus, the minimum detectable neutron flux will be less for the charge sensitive system. However, for these tests, twenty one feet of RG/U-71 was used for the cable. For this condition, only about 350 pF of cable capacitance is introduced. Approximately twice this capacitance is utilized for FFTF. As the equivalent noise charge is approximately linear with capacitance for a charge sensitive system, the noise component, V_{α}^2 , would increase a factor of four. Thus, not much difference in the minimum detectable value of flux would be expected.

Figure 7 shows the average neutron MSV sensitivities as a function of gas pressure. The charge sensitive system (C) is approximately 15% more sensitive than the current sensitive plus integration (C & I). Thus, a larger percentage of the total charge available is collected and measured with the charge sensitive system.

Figure 8 shows the average gamma MSV sensitivity as a function of gas pressure. Again the charge sensitive system has the highest values.

Figure 9 shows the neutron to gamma sensitivity ratio as a function of gas pressure. The ratio is higher at the lower pressures for all systems.

Figure 10 shows the change in MSV sensitivities with time constant for C + I and 1.75 atm. pressure. As shown, the ratio remains nearly constant over the test span.

Figures 11, 12 and 13 show the results for the counting channels. Figure 14, 15 and 16 show the discriminator settings vs pressure at which the counting data were recorded. The counting data are similar to data previously obtained^{1,2}. To obtain the best counting efficiency at approximately 10^4 R/hr a pressure of 1.75 atm would be suitable for the charge sensitive system.

CONCLUSIONS

For these tests, the dc current and discrimination settings proved to be a reliable check on the fill gas pressure. With the gauge readings observed at the time the detector was filled a check of the pressure could be made at any time during the experiment. By checking the pressure before and after each experiment, any pressure changes or incorrect discriminator settings would have been detected. Plots of these parameters vs pressure should be utilized for any future work.

Better MSV sensitivity is observed with increasing pressure. System noise does not increase significantly with pressure, so the best performance would be expected at higher pressures. Also an increased MSV sensitivity is observed with increasing time constant. However, as the FFTF ex-vessel detector also provides counting information, the improvements observed for the MSV mode must be considered with the effects on the counting channel.

For the detector at position 8 as defined in Table I the sensitivity generally increases with pressure. This is consistent with the expected low gamma response^{1,2} and is the most important for FFTF since the ex-vessel detectors will operate with low gamma background.

Thus, improved performance can probably be achieved for the FFTF ex-vessel detectors by increasing the gas pressure above the present 1.75 atm. However, an analysis of the exact systems, including dynamic ranges, minimum detection levels and noise, should be completed prior to such a change. Finally, the pressure should not be less than approximately 1.75 atm, because the counting efficiency decreases rapidly with pressure below this level as shown in Figure 8.

The time constant of 200 nsec provide a larger signal-to-noise ratio than the other time constants used for the current sensitive plus integration system. The FFTF value of 250 nsec $\pm 20\%$ for this parameter is very nearly optimum for the test system.

Operation of the current sensitive plus integration and current sensitive plus charge sensitive systems was similar. An optimum preamplifier could probably be developed using better techniques than were used here. Possibly this could be achieved if the time constants could be established earlier in the channel.

Current sensitive MSV and counting systems perform in the same manner as charge sensitive systems. For each system the noise must be considered with respect to the desired minimum sensitivity. The charge sensitive system is less noisy unless the cable capacitance is large (around 700 pF), then the systems should have approximately the same performance.

The cables used with current sensitive systems normally have a characteristic impedance which is smaller than that used with charge sensitive systems. Assuming the same voltage, this will result in lower electric fields applied to the cable dielectric because the center conductor is larger. Such a cable is easier to build and could operate at higher temperatures and voltages than previously possible.

A measurement with an exact FFTF system should be completed before it is known whether a current sensitive preamplifier and channel could be used. From the data presented, it seems very possible that this system could be used. The minimum detectable neutron level and the sensitivity of an exact system would have to be known before a discision could be made. At this time cost savings would not be significant, but if this decision is made soon enough in future LMFBRs, the cost of preamplifier and cable systems will be reduced.

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TABLE 1
RADIATION FLUX LEVELS

TEST FACILITY TUBE POSITION	^{60}C FLUX (R/hr.)	PuBe THERMAL FLUX (nv)	^{252}Cf THERMAL FLUX (nv)
7	6.07×10^5	4.0×10^3	5.12×10^5
8	9.47×10^3	4.3×10^3	5.48×10^5

TABLE II
SYSTEMS TRANSFER FUNCTIONS - H

Systems	$H = \frac{V_{\text{peak out}}}{\text{Charge in}}$ (v/pc)
Charge Sensitive (C)	0.35440
Current + Charge Sensitive (C + C)	7.28438
Current + Integrator (C + I) ($\tau = 200$ nsec)	8.35561
Time Constant Experiment (C+I)	
$\tau = \text{out}$	12.5704
$\tau = 20$ nsec	11.5017
$\tau = 50$ nsec	10.9688
$\tau = 100$ nsec	9.8642
$\tau = 500$ nsec	5.8335
$\tau = 1000$ nsec	4.2338
$\tau = 2000$ nsec	2.9470
$\tau = 5000$ nsec	1.8617

FIGURE 1. Charge-Sensitive Block Diagram.

FIGURE 2. Current-Sensitive Plus Integration Block Diagram.

FIGURE 3. Current Plus Charge-Sensitive Block Diagram.

FIGURE 4. Pulse Circuit for Determination of System Transfer Function.

FIGURE 5. D. C. Current Sensitivity.

FIGURE 6. System Noise Referred to Cable Input.

FIGURE 7. Average Neutron MSV Sensitivities.

FIGURE 8. Average Gamma MSV Sensitivities.

FIGURE 9. Average MSV Sensitivity Ratios.

FIGURE 10. Average C + 1 MSV Data vs. Integration Time Constant.

FIGURE 11. PuBe Pulse Counting Efficiency at Gamma Background of 1 cps.

FIGURE 12. PuBe Pulse Counting Efficiency at Gamma Background of 1 cps.

FIGURE 13. Current-Sensitive Plus Integration Counting Sensivity vs Time Constant at 1 cps Gamma Background.

FIGURE 14. Charge-Sensitive Discriminator Settings vs Pressure.

FIGURE 15. Current-Sensitive Plus Integration Discriminator Settings vs Pressure.

FIGURE 16. Current Plus Charge-Sensitive Discriminator Settings vs Pressure.

APPENDIX A. TABULAR DATA

TABLE A1. PULSE COUNTING DATA

Pressure Ar -7% (v) (atm)	C				C+I				C+C			
	Disc. setting Tube 8(v)	Disc. Setting Tube 7 (v)	PuBe cps Tube 8	PuBe cps Tube 7	Disc. Setting Tube 8(v)	Disc. Setting Tube 7(v)	PuBe cps Tube 8	PuBe cps Tube 7	Disc. Setting Tube 8(v)	Disc. Setting Tube 7(v)	PuBe cps Tube 8	PuBe cps Tube 7
0.50	1.60	2.80	1705	560.2	2.50	4.40	1344.	383.4	2.30	4.05	920.3	241.7
0.75					2.60	5.20	2243.	540.9	2.40	4.80	1679.	359.5
1.00	1.85	4.03	3431.	858.5	2.80	6.25	2871.	559.8	2.55	5.85	2285.	324.7
1.25	2.00	4.75	3676.	870.1	3.10	7.10	3228.	644.7	2.70	6.70	2743.	357.3
1.50	2.10	5.35	3824.	868.4	3.30	8.20	3457.	608.0	2.85	7.40	2989.	374.5
1.75	2.24	5.90	3864.	932.6	3.35	8.80	3613.	686.2	2.96	8.10	3239.	352.2
2.00	2.30	6.45	3766.	891.3	3.40	9.55	3802.	676.5	3.05	9.25	3282.	308.7
2.25	2.35	7.00	3987.	888.8	3.60	10.4	3584.	620.0	3.05	9.70	3412.	344.9

1. Discriminator setting for 1 cps γ count rate.
2. Neutron countrate at above disc. setting.

PRELIMINARY DATA

TABLE A2. CURRENT WITH 700 V APPLIED TO THE DETECTOR

Pressure Ar -7% N ₂ (atm)	C Charge Sensitive			C+I Current Sensitive & Integrator			C+C Current & Charge Sensitive		
	out of pit (nA)	Tube 8 (μ A)	Tube 7 (μ A)	out of pit (nA)	Tube 8 (μ A)	Tube 7 (μ A)	out of pit (nA)	Tube 8 (μ A)	Tube 7 (μ)
0.50	1.83	.327	21.8	1.88	.316	21.5	1.89	.323	21.7
0.75				2.74	.448	31.4	2.78	.434	32.0
1.00	3.49	.586	42.8	3.53	.572	41.2	3.52	.577	41.9
1.25	4.43	.705	49.9	4.38	.693	49.2	4.40	.698	50.6
1.50	5.03	.813	59.0	5.16	.795	59.8	5.16	.810	57.9
1.75	5.82	.955	67.3	5.83	.899	65.5	5.85	.906	67.8
2.00	6.19	1.05	76.8	6.47	1.06	73.4	6.47	1.05	77.0
2.25	7.23	1.18	81.2	7.10	1.14	82.3	7.09	1.14	81.3

PRELIMINARY DATA

TABLE A3. DC CURRENT SENSITIVITIES

Pressure Ar -7% N ₂ (atm)	C		C+I		C+C	
	Average Sensitivity 10 ⁻¹⁰ A/(R/hr)	% Diff. Tube 8-Tube 7	Average Sensitivity 10 ⁻¹⁰ A/(R/hr)	% Diff. Tube 8-Tube 7	Average Sensitivity 10 ⁻¹⁰ A/(R/hr)	% Diff. Tube 8-Tube 7
0.50	.3522	4	.3439	6	.3492	5
0.75			.4952	9	.4927	15
1.00	.6619	14	.6414	12	.6498	13
1.25	.7833	10	.7712	11	.7829	12
1.50	.9152	13	.9123	17	.9046	12
1.75	1.059	9	1.014	14	1.036	16
2.00	1.187	14	1.164	8	1.189	14
2.25	1.292	7	1.272	13	1.272	11

TABLE A4. RAW MSV GAMMA DATA WITH 700 Vdc DETECTOR BIAS

Pressure Ar -7% N ₂ (atm)	C Noise+Alpha (10 ⁻⁶ V ²)	² γ ₈ (10 ⁻⁶ V ²)	² γ ₇ (10 ⁻⁶ V ²)	C+I Noise+Alpha (10 ⁻⁶ V ²)	² γ ₈ (10 ⁻⁶ V ²)	² γ ₇ (10 ⁻⁶ V ²)	C+C Noise+Alpha (10 ⁻⁶ V ²)	² γ ₈ (10 ⁻⁶ V ²)	² γ ₇ (10 ⁻⁶ V ²)
0.50	2.856	.6035	34.96	6512.	244.4	14,510.	6162.	205.8	12,610.
0.75				6707.	398.9	26,050.	6352.	355.5	22,890
1.00	3.423	1.46	92.62	6609.	632.3	39,190.	6304.	534.9	34,500.
1.25	3.686	1.93	121.75	6856.	870.6	53,660.	6448.	742.9	48,310.
1.50	3.960	2.49	159.88	6856.	1154.	77,660.	6561.	1008.	62,610.
1.75	4.080	3.16	197.56	7056.	1335.	87,810.	6398.	1153.	77,120
2.00	4.326	3.91	242.20	6839.	1884.	106,730.	6708.	1537.	98,270.
2.25	4.623	4.43	266.50	7327.	1927.	125,170.	6872.	1758.	113,540.

PRELIMINARY DATA

TABLE A5. RAW MSV NEUTRON DATA WITH 700 Vdc DETECTOR BIAS

Pressure Ar -7% N ₂ (atm)	C			C+I			C+C		
	n_8^2 (10 ⁻⁶ V ²)	n_7^2 (10 ⁻⁶ V ²)	$\frac{\Delta(n^2)}{n^2 \text{ min}}$	n_8^2 (10 ⁻¹ V ²)	n_7^2 (10 ⁻¹ V ²)	$\frac{\Delta(n^2)}{n^2 \text{ min}}$	n_8^2 (10 ⁻¹ V ²)	n_7^2 (10 ⁻¹ V ²)	$\frac{\Delta(n^2)}{n^2 \text{ min}}$
0.50	150.9	136.4	0.096	0.645	0.602	0.719	0.5663	0.5305	0.067
0.75				1.154	1.005	0.149	1.055	0.8772	0.203
1.00	352.4	374.8	0.064	1.536	1.621	0.056	1.398	1.356	0.031
1.25	487.2	465.1	0.048	2.141	2.027	0.057	1.794	1.680	0.068
1.50	633.6	576.0	0.100	1.775 ¹	2.499	0.406 ¹	2.316	2.096	0.104
1.75	700.32	710.4	0.014	3.315	3.186	0.191	2.972	2.494	0.041
2.00	787.0	796.8	0.012	3.537	3.750	0.060	3.554	3.333	0.066
2.25	933.4	914.7	0.020	4.641	4.151	0.118	3.946	3.696	0.068

PRELIMINARY DATA

TABLE A6. MSV GAMMA SENSITIVITIES

Pressure Ar-7%N ₂ (atm)	C			C+I			C+C		
	$\gamma_8^2/(S_8 H^2)$ (10 ⁻⁹ (pc) ² /(R/hr))	$\gamma_7^2/(S_7 H^2)$ (10 ⁻⁹ (pc) ² /R/hr)8-7	% Diff.	$\gamma_8^2/(S_8 H^2)$ (10 ⁻⁹ (pc) ² /(R/hr))	$\gamma_7^2/(S_7 H^2)$ (10 ⁻⁹ (pc) ² /R/hr)8-7	% Diff.	$\gamma_8^2/(S_8 H^2)$ (10 ⁻⁹ (pc) ² /(R/hr))	$\gamma_7^2/(S_7 H^2)$ (10 ⁻⁹ (pc) ² /R/hr)8-7	% Diff.
0.5	0.507	0.459	10.4	0.3692	0.3424	7.9	0.410	0.3915	4.7
0.75				0.6027	0.6157	1.8	0.707	0.7107	0.6
1.00	1.227	1.215	0.9	0.9553	0.9248	3.4	1.064	1.071	0.1
1.25	1.648	1.597	3.1	1.315	1.2662	3.9	1.478	1.499	1.4
1.50	2.093	2.591	0.2	1.744	1.8325	5.0	2.005	1.944	3.1
1.75	2.656	2.591	2.5	2.019	2.072	6.0	2.295	2.394	4.3
2.00	3.287	3.176	3.5	2.847	2.518	13.0	3.059	3.051	0.2
2.25	3.724	3.500	2.6	2.911	2.954	1.3	3.499	3.525	0.7

PRELIMINARY DATA

TABLE A7. MSV NEUTRON SENSITIVITIES

Pressure Ar -7% N ₂ (atm)	C			C+I			C+C		
	$n_8^2/(S_8 H^2)$ (10 ⁻⁹ (pc) ² /nv)	$n_7^2/(S_8 H^2)$ (10 ⁻⁹ (pc) ² /nv)	% Diff. 8-7	$n_8^2/(S_8 H^2)$ (10 ⁻⁹ (pc) ² /nv)	$n_7^2/(S_8 H^2)$ (10 ⁻⁹ (pc) ² /nv)	% Diff. 8-7	$n_8^2/(S_8 H^2)$ (10 ⁻⁹ (pc) ² /nv)	$n_7^2/(S_8 H^2)$ (10 ⁻⁹ (pc) ² /nv)	% Diff. 8-7
0.50	2.192	2.121	3.2	1.686	1.684	0.1	1.948	1.953	0.3
0.75				3.016	2.811	6.8	3.628	3.229	12.3
1.00	5.120	5.828	12.1	4.015	4.534	11.4	4.808	4.991	3.8
1.25	7.078	7.233	2.1	5.596	5.671	1.3	6.170	6.184	0.3
1.50	9.205	8.957	2.6		6.991		7.964	7.715	3.2
1.75	10.175	11.047	7.9	8.665	8.913	2.8	10.221	9.180	11.3
2.00	11.434	12.390	7.7	9.245	10.491	13.4	12.222	12.268	0.4
2.25	13.561	14.224	4.7	12.130	11.613	4.5	13.570	13.604	0.3

PRELIMINARY DATA

TABLE A8. NEUTRON TO GAMMA SENSITIVITY RATIOS

Pressure Ar-7% N ₂ (atm)	C		C+I		C+C	
	Noise/H ² 10 ⁻⁵ (pc) ²	Average n ² /nv Average $\gamma^2/(R/hr)$ (R/hr)/nv	Noise/H ² 10 ⁻⁵ (pc) ²	Average n ² /nv Average $\gamma^2/(R/hr)$ (R/hr)/nv	Noise/H ² 10 ⁻⁵ (pc) ²	Average n ² /nv Average $\gamma^2/(R/hr)$ (R/hr)/nv
0.5	2.413	4.472	9.318	4.694	12.476	4.875
0.75			9.597	4.78	11.985	4.83
1.00	2.893	4.487	9.456	4.549	11.895	4.592
1.25	3.115	4.412	9.810	4.362	12.166	4.153
1.50	3.360	4.334	9.810	3.915	12.380	4.033
1.75	3.448	4.043	10.106	4.298	12.100	4.136
2.00	3.656	3.688	9.785	3.673	12.657	4.009
2.25	3.907	3.845	10.484	4.049	12.966	3.931

A-8

PRELIMINARY DATA

TABLE A9. MSV TIME CONSTANT DATA FOR C & T AT 1.75 atm.

Integration Time Constant (nsec)	Noise H^2 $10^{-5}(\text{pc})^2$	$\gamma_8^2/(S_8 H^2)$ $10^{-9}(\text{pc})^2/(\text{R/hr})$	$\gamma_7^2/(S_7 H^2)$ $10^{-9}(\text{pc})^2/(\text{R/hr})$	% Diff 8-7	$n_8^2/(S_8 H^2)$ $10^{-9}(\text{pc})^2/\text{nv}$	$n_7^2/S_7 H^2$ $10^{-9}(\text{pc})^2/\text{nv}$	% Diff 8-7	average n^2/nv average $\gamma^2/(\text{R/hr})$ (R/hr)/nv
out	8.812	1.304	1.506	15.5	5.926	5.364	10.4	4.017
20	9.827	1.900	1.871	1.0	7.698	7.127	8.0	3.931
50	8.988	1.714	1.861	8.4	7.786	7.186	8.3	4.189
100	9.081	1.481	2.020	36.4	7.964	7.224	10.2	4.338
200	9.578	2.281	1.991	14.5	8.418	7.797	7.9	3.798
500	12.958	2.360	2.370	0.4	9.992	9.209	8.4	4.056
1000	17.752	3.038	3.061	0.7	12.788	11.707	9.2	4.017
2000	27.646	4.703	4.584	2.6	19.436	17.525	10.8	3.978
5000	57.907	7.593	9.599	26.4	40.603	38.637	5.1	4.612

A-9

PRELIMINARY DATA

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