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PNNL-19110

^{3}He Neutron Detector Pressure Effect and Comparison to Models

Revision 0

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January 12, 2010

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Executive Summary

Radiation portal monitors used for interdiction of illicit materials at borders include highly sensitive neutron detection systems. The main reason for having neutron detection capability is to detect fission neutrons from plutonium. The currently deployed radiation portal monitors (RPMs) from Ludlum and Science Applications International Corporation (SAIC) use neutron detectors based upon ^{3}He-filled gas proportional counters, which are the most common large neutron detector. There is a declining supply of ^{3}He in the world, thus, methods to reduce the use of this gas in RPMs with minimal changes to the current system designs and detection capabilities are being investigated.

Reported here are the results of measurements performed to determine the efficiency of ^{3}He-filled proportional counters as a function of gas pressure in the SAIC system. Motivation for these measurements was largely to validate the current model of the SAIC system. Results from those simulations indicated that the neutron detection efficiency has a simple, logarithmic functionality with pressure. As for absolute performance, the model results indicated the ^{3}He pressure in the current SAIC system could not be reduced appreciably and still meet the required level of detection sensitivity. Thus, saving ^{3}He by reducing its pressure was predicted not to be a viable option in the current SAIC system.

The experimental measurements with ^{3}He tubes at various pressures show agreement with the logarithmic trend. For the absolute values of detection efficiency, however, the averaged measured efficiency was found to be ~10% higher than the efficiency calculated with the model. Although the measured efficiency is higher than what was predicted, it is advised that no reduction in ^{3}He pressure be considered for the SAIC system.

Acronyms and Abbreviations

ANSI	American National Standards Institute
atm	atmospheres
BF_3	boron trifluoride
CBP	Customs and Border Protection
cps	counts per second
DOE	U.S. Department of Energy
MCNP	Monte Carlo for Neutrons and Photons Transport Code
NIM	Nuclear Instrumentation Module
Pa	Pascal
PNNL	Pacific Northwest National Laboratory
PolyBox	polyethylene moderator/reflector box
POV	personally owned vehicle
PRB	Prototype Re-locatable Base
PVT	Polyvinyl Toluene (plastic) scintillation gamma detector
RPM	Radiation Portal Monitor
RSP	Radiation Sensor Panel
SAIC	Science Applications International Corporation

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1 Purpose

Radiation portal monitors used for interdiction of illicit materials at borders include highly sensitive neutron detection systems. The main reason for having neutron detection capability is to detect fission neutrons from plutonium. The currently deployed radiation portal monitors (RPMs) from Ludlum and Science Applications International Corporation (SAIC) use neutron detectors based upon ^{3}He-filled gas proportional-counter tube, which are the most common, large, neutron detectors.

Within the last few years, the supply of ^{3}He available for use in gas proportional-counter neutron detectors has become much reduced, while the demand has significantly increased, especially for homeland security applications (Kouzes 2009). In the near future, the limited supply is expected to curtail use of ^{3}He; therefore, alternative neutron detection technologies are being investigated for use in the radiation portal monitor (RPM) systems being deployed for border security applications (Van Ginhoven 2009).

The pressure of the ^{3}He gas in the currently deployed RPM systems is 304 kPa (3 atm or 2280 torr) per proportional-counter tube. One possible interim solution to saving ^{3}He would be to reduce the partial pressure of ^{3}He used per tube. Reported here are the results of tests of the efficiency of ^{3}He filled proportional counters as a function of the ^{3}He partial pressure. Previous model simulations predicted that for the current SAIC system, the pressure of ^{3}He could not be reduced appreciably without jeopardizing its absolute neutron detection sensitivity. The primary objective of the measurements reported here was to validate those model results and, thus, determine if reducing the ^{3}He partial pressure in the current SAIC system would be a viable interim solution until a replacement, ^{3}He-free neutron detection technology could be installed. The models only included the ^{3}He gas, and not the gas mixture.

2 Test Hardware

2.1 SAIC RPM8 Detector

The SAIC RPM8 RSP employs a polyvinyl toluene (PVT) "plastic" scintillator for photon (gamma ray) detection and ^{3}He-filled proportional-counter tubes for neutron detection. One or two neutron-detector tubes are located inside a polyethylene moderator/reflector "PolyBox" of dimensions 0.13 m × 0.30 m × 2.21 m (5″ × 12″ × 87″).

The SAIC systems were purchased under a specification (Stromswold et. al., 2003) that requires each radiation sensor panel (RSP) to meet the following requirements:

"A ^{252}Cf neutron source will be used for testing neutron sensor sensitivity:

- To reduce the gamma-ray flux, the source shall be surrounded by at least 0.5 cm of lead. To moderate the neutron spectrum, 2.5 cm of polyethylene shall be placed around the source.
- The absolute detection efficiency for such a ^{252}Cf source, located 2 m perpendicular to the geometric midpoint of the neutron sensor, shall be greater than 2.5 cps/ng of ^{252}Cf. The neutron detector center shall be 1.5 m above grade for this test. (Note: 10 nanograms of ^{252}Cf is equivalent to 5.4micro-Ci or 2.1×10^4 n/s,[1] since ^{252}Cf has a 3.092% spontaneous fission (SF) branch and 3.757 neutrons/SF.)
- The neutron detector shall not generate alarms due to the presence of strong gamma-ray sources. The ratio of neutron sensor gamma-ray detection efficiency to neutron detection shall be less than 0.001."

In addition, these systems are required to meet all requirements of the ANSI N42.35 standard (ANSI 2004). A summary of neutron detection systems in RPMs can be found in Kouzes et al. (2007).

The test configuration used for the measurements reported in this document was a single SAIC RPM8 RSP in its steel support stand and mounted on a Prototype Re-locatable Base (PRB). On that base, the support stand was approximately 0.2 m above the pavement, and also approximately 0.2 m from two large (0.22 m diameter) steel bollards. The RSP was oriented in the bottom cargo position (that is with the electronics at the bottom of the panel). The left side of Figure 2.1 shows a picture of the RSP in its testing configuration with the source holder in the foreground. The right side of Figure 2.1 shows a model of this test configuration that was used to estimate the degree to which the results from the lower, bollard-equipped test configuration would differ from the bottom cargo RSP in its standard curb-side deployment.

For these tests, the RPM8 PolyBox was not modified except by the replacing (or adding to) the original, single 304 kPa (3 atm or 2280 torr) ^{3}He tube with identically manufactured tubes at lower ^{3}He partial pressures. Thus, the physical capability of the "stock" PolyBox to moderate and reflect neutrons was not altered. However, external electronics were used for most of the measurements to provide a bias to the ^{3}He tubes and record the data. The SAIC electronics were not used for the tests, since a larger high-voltage range was required than what could be supplied and some tubes produced pulses that were not handled properly by the SAIC system.

[1] The value of 2.1×10^4 n/s quoted in the reference has now been corrected to 2.3×10^4 n/s.

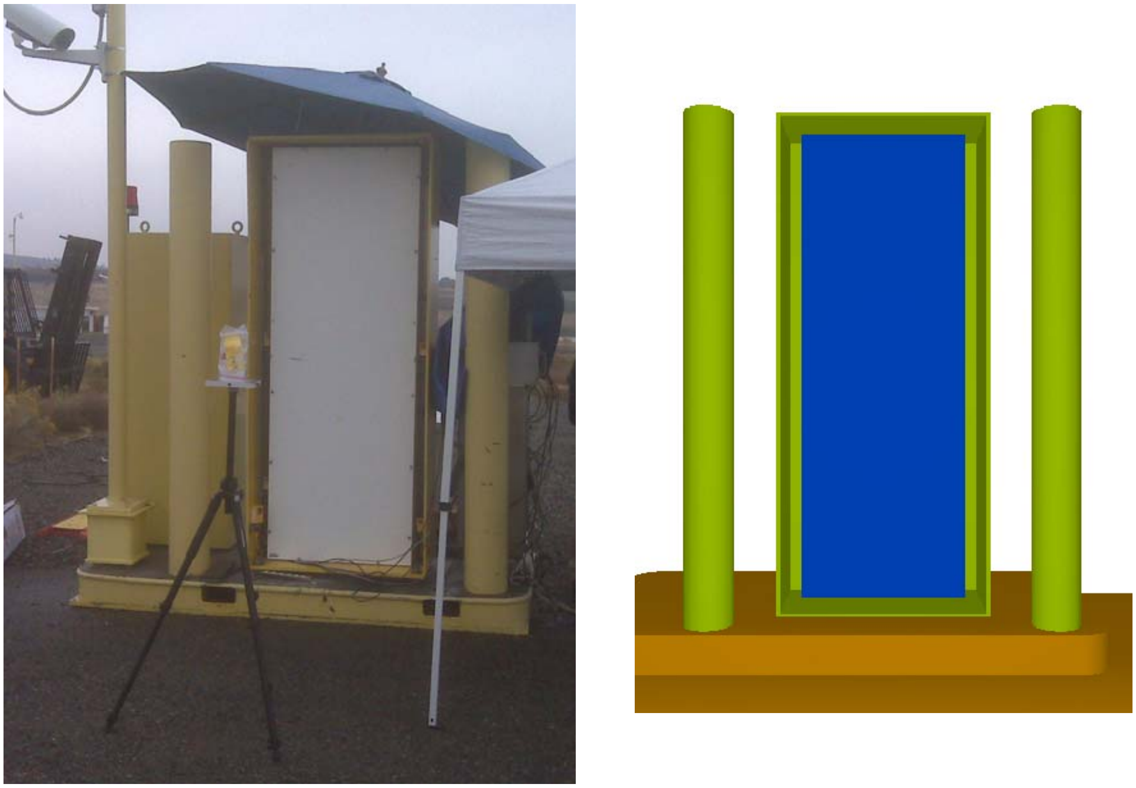

Figure 2.1. Configuration used for tests and corresponding model of bottom Cargo RPM8 in its Support Stand mounted on the Prototype Re-locatable Base.

2.2 ^{3}He Tubes

The tests were conducted with a total of six tubes, taken in pairs or individually. These included two 304 kPa, two 101 kPa tubes; and single 203-, 253-, and 304-kPa tubes, all manufactured by LND. The 304 kPa tubes were manufactured in 2004 while the other tubes were manufactured in 2009. The testing consisted of adding or swapping tubes in the PolyBox of the test-configured RSP. Table 2.1 gives the serial numbers and parameters for the six LND tubes tested. The ^{3}He partial pressures are given in kPa and atmospheres. Argon is used as an inert fill gas additive, plus CO_2 is used in small amounts as a quench gas.

Table 2.1. ^{3}He Tube Parameters

Serial Number	^{3}He Partial Pressure, kPa (atm)	Total Pressure, kPa	Gas Mixture	Recommended Operating Voltage
325177	101 (1.0)	203	^{3}He, Ar, CO_2	1151
325180	101 (1.0)	203	^{3}He, Ar, CO_2	1174
325186	203 (2.0)	253	^{3}He, Ar, CO_2	1014
325183	253 (2.5)	253	^{3}He, CO_2	908
102439	304 (3.0)	304	^{3}He, CO_2	1080
102345	304 (3.0)	304	^{3}He, CO_2	1080

Four sets of measurements were performed to address various problems that arose in the measurement campaign. For the first set of tests, measurements were made for one and two 304 kPa (3 atm) tubes and for the 101 kPa (1 atm) tube without problems; but, the 203 kPa (2 atm) and 253 kPa (2.5 atm) tubes both exhibited the problem of producing excessively large pulses at the recommended operating voltage. The 203 kPa (2 atm) tube seemed to work correctly for ~10 minutes before demonstrating this behavior, which was interpreted as voltage breakdown. The 253 kPa (2.5 atm) tube yielded large pulses immediately. Usable data were obtained at 850 V, even though this was below the plateau region as defined by the manufacturer. Further investigation of this problem showed the tubes functioned correctly in the laboratory. Connector breakdown may have been the cause of the problem.

The subsequent measurements were performed with the same tubes with external electronics to bias the tubes and record the data. The external electronics were used to increase the range of available voltages and to prevent the SAIC electronics from affecting the results. The second set of measurements was performed without difficulty. However, the value obtained for the single 304 kPa (3 atm) tube did not provide the expected trend, so a third set of measurements was performed. The third set gave the expected trend, but raised the question of whether one of the two 304 kPa (3 atm) tubes was at fault, so the fourth set of measurements was made to see if the results from the two 304 kPa (3 atm) tubes were consistent.

2.3 Test Facility

The test was performed at PNNL at the 331G Integration Test Facility located in Richland, WA. The first test was performed on Monday, August 10, 2009. The second test was performed on Wednesday, October 21, 2009. The third test was performed on Thursday, November 5, 2009. The fourth test was performed on Monday, November 9, 2009.

2.4 Neutron Sources

The neutron sources used for these tests were ^{252}Cf sources purchased from the Eckert & Ziegler Isotope Products Laboratory (IPL) in Valencia, CA. For the first test, the source used had a PNNL ID # 6028-16, and the IPL "Nominal Data Sheet" for that source showed it to have an activity of 20.0 ± 3.0 µCi (i.e. a 15% uncertainty) on February 15, 2009. These values give an activity of 17.6 ± 2.7 µCi on August 10, 2009. On November 11, 2009, this particular source was cross-calibrated against an IPL NIST traceable ^{252}Cf source that had an uncertainty of 5.7% and that comparison found PNNL source #6028-16 to have on that date an activity of 18.85 ± 1.1 µCi. With this user calibrated value, the ^{252}Cf isotope in PNNL source #6028-16 had an activity of 20.13 ± 1.15 µCi on August 10. 2009. The conversion values stated above gives an activity of 20.13 µCi or an estimated 37.3 ng of ^{252}Cf and an emanation rate of $8.6 \pm 0.5 \times 10^4$ n/s. This source was used in the shielded and un-shielded configurations, where the shielding was created by placing the source into a small cylindrical "pig" that had a 25.4 mm thick outer wall of polyethylene and a 6.4 mm thick lead lining. For all the tests, the source was placed on a tripod located 2 m from the front of the RSP

For the second through fourth tests, a different source with a PNNL ID #60208-44 was used. This source was calibrated within a 5.7% uncertainty at NIST on October 1, 2009 to have a ^{252}Cf activity of 21.91 ± 1.25 µCi on October 1, 2009. For the testing dates of October 21, 2009, November 5, 2009, and November 9, 2009, the ^{252}Cf activities in this source were calculated to be 21.59 µCi, 21.38 µCi, and 21.31 µCi, respectively. With the conversion factors stated above, this source was estimated to have an average mass of ^{252}Cf of 39.7 ± 0.5ng and an average emanation rate of $9.1 \pm 0.5 \times 10^4$ n/s for the test dates.

3 Modeling Results

In a previous study (Kouzes and Siciliano 2009), a series of calculations with the Monte Carlo N-particle neutrons and photons transport code (MCNP 2003) were reported for models constructed to simulate the currently deployed standard cargo (four-panel) RPM systems from Ludlum and SAIC, mounted on simple 0.25 m high concrete curbs. Those simulations evaluated the effects on the neutron detection efficiency of the bottom RSP by changing the ^{3}He partial pressure in its tubes, as well as replacing the ^{3}He gas with BF_3. Only pure gases were used in these calculations; the effects of the gas mixtures were not included. The effects of some simple modifications to the SAIC PolyBox in that model system were also simulated to estimate if such changes might improve its performance. For comparison to the measurements reported here, however, only the results for the stock SAIC PolyBox ^{3}He simulations in that study are reproduced.

The symbols in Figure 3.1 show the calculated neutron detection efficiencies for one and two LND ^{3}He tubes in the bottom RSP of the standard SAIC cargo model evaluated over ^{3}He partial pressures from 101 to 304 kPa (1 to 3 atm; 760 to 2280 torr). The single-tube calculated data point results are indicated by circular symbols and the two-tube results by square symbols. The solid symbols are used for the shielded source (labeled “w/Pig”), and the hollow symbols for the un-shielded source (“w/o Pig”). The curves in this figure show the family of two-parameter, logarithmic fits to the calculated values with a linear regression fit to the numerical points.

For the single ^{3}He tubes in the stock PolyBox, the simulated absolute efficiency was shown to range from 0.076% at 101 kPa to 0.118% at 304 kPa for the standard “w/Pig” moderated source, and to drop to a range of 0.057% to 0.089% when the source was un-shielded “w/o Pig.” For two ^{3}He tubes, the absolute efficiency “w/Pig” is seen to range from 0.124% to 0.179%, and drop to a range of 0.092% to 0.135% for the “w/o Pig” evaluations. Also note from Figure 3.1 that the simple, two-parameter logarithmic curves describe the shape of all four of the calculated cases extremely well, i.e. with coefficients of determination factors ("R^2") of 99 % or better. For later reference, the numerical values for the “w/Pig” results shown in Figure 3.1 are also listed in Table 3.1.

Besides the apparently simple logarithmic behavior, three additional observations can be made from the results. The first observation is the absolute value prediction that, for the stock PolyBox SAIC configuration, the single-tube ^{3}He partial pressure must be kept above 2.6 atm (263 kPa) to meet the performance specification for that system. A second observation is made by noting that there is only an increase by a factor of ~1.6 in total efficiencies by doubling the number of tubes. This indicates the degree to which two 50.8 mm (2.0-inch) diameter tubes in the small 63.5 mm x 203 mm PolyBox interior shadow shield each other from the neutrons being reflected from the back and sides. Nevertheless, the two-tube configuration "w/Pig" is above the spec value even at 101 kPa (1 atm). The final observation is the effect of the source-moderating pig on the efficiencies, where the simulations predict an approximate increase of ~33% by going from the bare source to the “w/Pig” cases. Measurements supporting this behavior would help validate the models ability to simulate the moderating affects of the additional 25.4 mm of polyethylene of the pig.

To estimate the change in the above results that might arise from the difference between the standard cargo curb and the lower, bollard-equipped PRB, a model of this base was constructed (shown in Figure 2.2). That version of the SAIC model was used to recalculate the one and two tube configurations, and the numerical results are listed in the last two columns of Table 3.1 below. Comparison of the values listed in the table shows that at the same ^{3}He partial pressure, with the PRB may give at most a 1% increase over the same tests performed in the bottom RSP in the standard configuration.

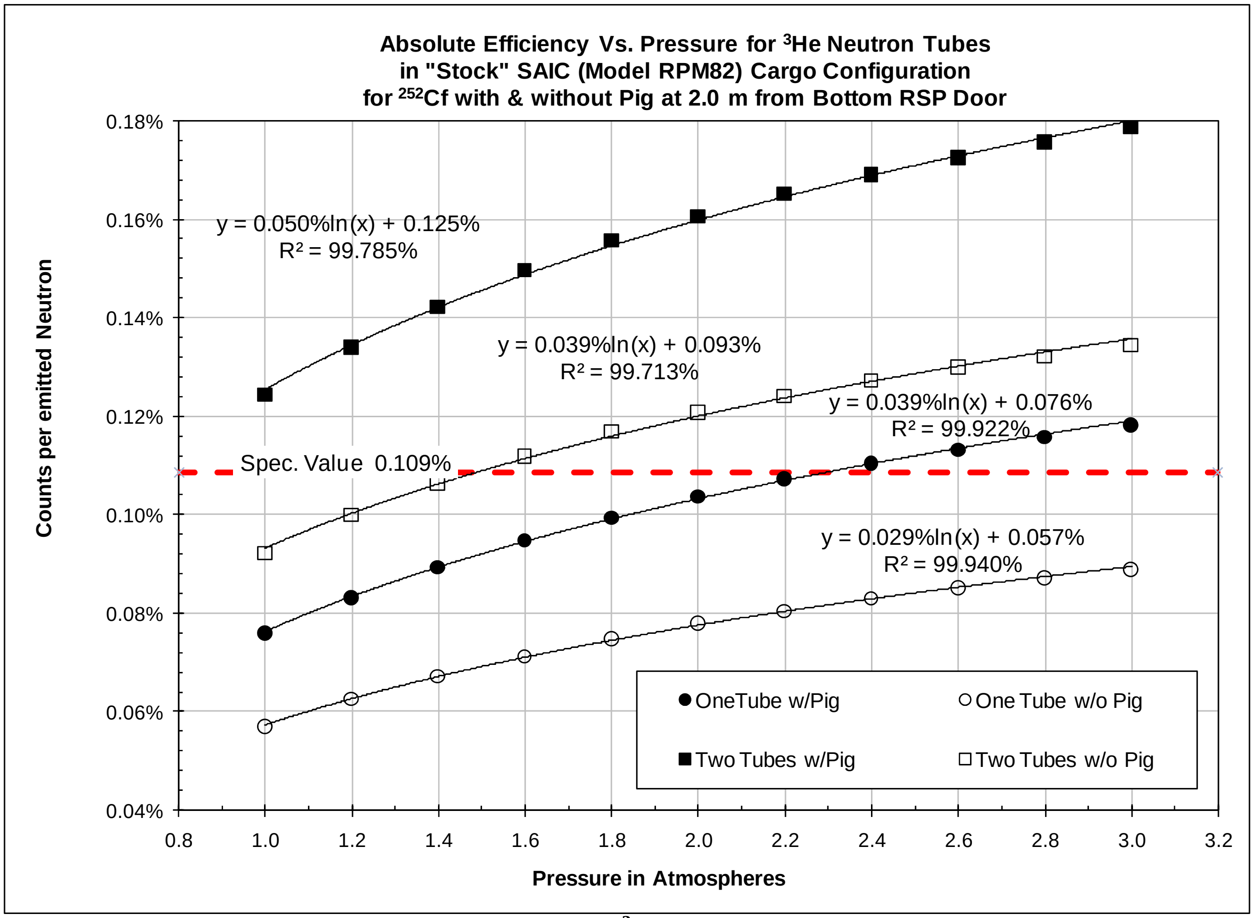

Figure 3.1. Absolute Detection Efficiency versus ^{3}He Partial Pressure. Symbols show values where computations were performed. Lines are two-parameter logarithmic fits.

Table 3.1. Absolute efficiency versus ^{3}He partial pressure for shielded ^{252}Cf source simulations using the SAIC Standard Cargo and Prototype Re-Locatable Base models

		Standard Cargo Configuration		Mounted on PRB	
Pressure	Pressure	One Tube	Sum of Two Tubes	One Tube	Sum of Two Tubes
(atm)	(kPa)	(Counts/emitted n)		(Counts/emitted n)	
1.0	101	0.076%	0.124%	0.077%	0.125%
1.2	122	0.083%	0.134%	0.084%	0.135%
1.4	142	0.089%	0.142%	0.091%	0.144%
1.6	162	0.095%	0.150%	0.096%	0.151%
1.8	182	0.100%	0.156%	0.101%	0.157%
2.0	203	0.104%	0.161%	0.105%	0.162%
2.2	223	0.108%	0.165%	0.109%	0.166%
2.4	243	0.111%	0.169%	0.112%	0.171%
2.6	263	0.113%	0.173%	0.115%	0.174%
2.8	284	0.116%	0.176%	0.117%	0.177%
3.0	304	0.118%	0.179%	0.119%	0.180%

4 Test Limitations

There were a number of limitations for this test and results may change with different conditions.

- Only one test location was used, with the corresponding background. Since the testing was focused on net results (background subtracted) this should have little effect on the overall results.

- One tube of each pressure was tested, and tube-to-tube variations might be seen. The gas mixture differed for the tubes at different pressures, which might affect the results compared to the models, where it was assumed that only ^{3}He gas was present at the specified pressure.

- Problems were observed with two of the tubes in initial testing. As discussed above, those tubes appeared to break down at the recommended voltage, resulting in the use of a voltage below the recommended range from the vendor. This problem was eliminated in the later testing using external electronics.

- One PolyBox design was used in the modeling and experiment. The intent of the test was to use the available polyethylene box available in SAIC RPMs (which is very different from the Ludlum moderator).

5 Experiment Equipment and Setup

Static measurements were performed for all of the experiments. The neutron source was located 2 m from the center of, and perpendicular to, the front face of the SAIC RSP corresponding to the RPM specification requirements (Stromswold, 2003) for all the measurements. The height of the source was 1.35 m above the local grade to locate the source at the mid-height of the panel.

Two configurations of the neutron source were used: 1) the ^{252}Cf source shielded by placing it within a pig that provided 6.4 mm lead and 25.4 mm polyethylene as required in the specification, and 2) the un-shielded or "bare" ^{252}Cf source. All of the tests were performed with the shielded source because that configuration provided data for the specification requirements. Because tests with the bare source provided information to be used primarily for model validation purposes, a fewer number of those were performed. In addition to the neutron source measurements, background (no source) measurements were taken for each detector configuration.

For each source and detector configuration, a data collection period of five minutes was used. The data were collected with the standard SAIC electronics and software for the first test, and with external electronics and software for later tests.

6 Results and Data Analysis

Between the dates of August 10, 2009 and November 9, 2009, four campaigns of test measurements were carried out on ^{3}He tubes having partial pressures of 101, 203, 253, and 304 kPa (1, 2, 2.5, and 3 atm). For the second through fourth test campaigns, external NIM electronics were used to take the data in order to avoid limitations in the SAIC electronics.

6.1 First Test Campaign

For the data collected on the ^{3}He tube with the SAIC electronics, the count rates were collected in 30-s intervals for a total of five minutes and averaged to give counts per second (cps) for background and the two source configurations. The net count rates recorded at different tube pressures are listed (with uncertainties in parentheses) in Table 6.1 and shown in Figure 6.1. The error bars in this figure result mostly from the 5.7% uncertainty associated with the NIST traceable source used to cross-calibrate the source used for this test. The values shown for counts per second per nanogram are the renormalized results. The dashed line at 2.5 cps/ng is the efficiency required by the RPM specification. The value for the 203 kPa (2 atm) tube appears low; this tube showed apparent breakdown problems during testing and the data taken before and after the breakdown were not consistent.

Table 6.1. Measurement results for first test.

			w/Pig		**w/o Pig**	
One Tube	**Tube ID***	**Partial Pressure kPa (atm)**	**Net cps**	**Net cps/ng**	**Net cps**	**Net cps/ng**
	325177	101 (1.0)	68.0(5)	1.71	52.8(4)	1.33
	325186	203 (2.0)	67.2(5)	1.69	57.8(4)	1.45
	325183	253 (2.5)	93.2(6)	2.35	70.1(5)	1.77
	102439	304 (3.0)	106.6(6)	2.68	73.0(5)	1.84
Two Tubes						
Left	unknown	304 (3.0)	76.6(5)	2.05	57.8(4)	1.55
Right	unknown	304 (3.0)	75.2(5)	2.02	56.0(4)	1.50
Total		304 (3.0)	151.8(7)	4.07	113.8(6)	3.05
*) See Table 2.1.						

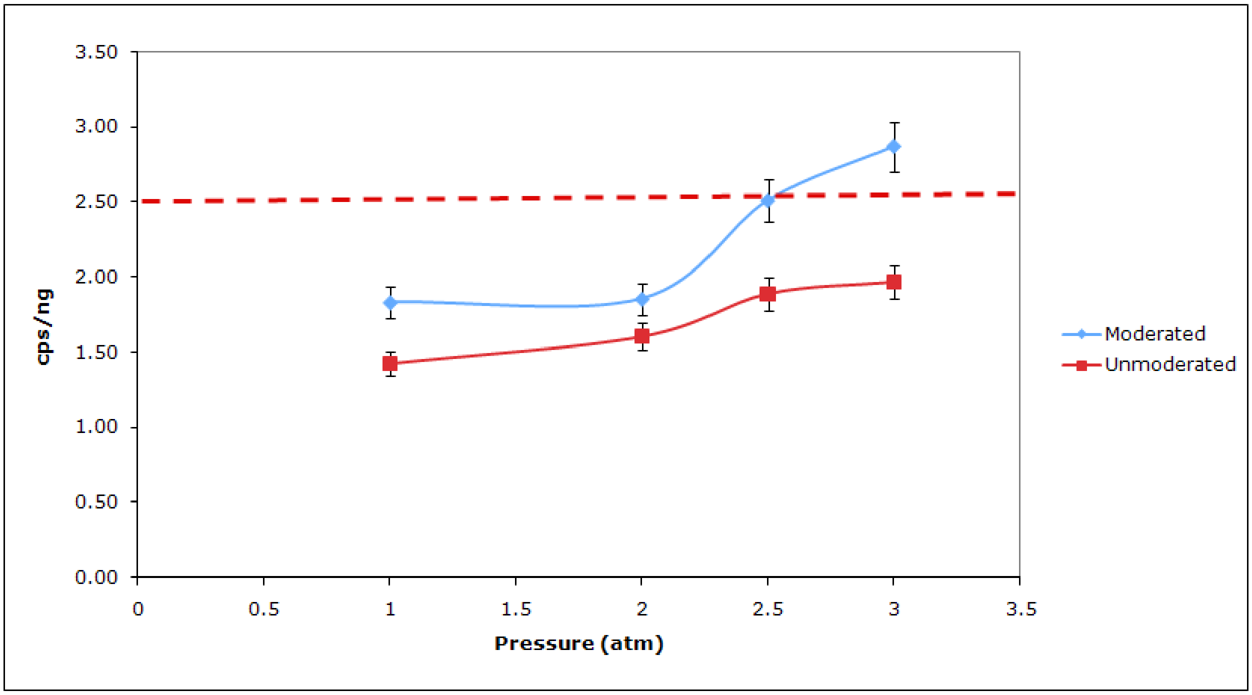

Figure 6.1. Single-Tube Efficiency Versus Partial Pressure from the First Test Campaign Tests.

6.2 Second Test Campaign

For the second through fourth test campaigns, measurements were made only for the moderated (i.e. "w/Pig") source. For the second campaign, results were obtained for four one-tube tests and one two-tube test. Table 6.2 lists the net count rates recorded at different tube pressures (with uncertainties in parentheses) and the resulting counts per second per nanogram of ^{252}Cf. The results for the one-tube values are also plotted in Figure 6.2, where the (unexpected) drop in the 304 kPa (3 atm) tube is clearly seen. This apparently anomalous result for the 304 kPa (3 atm) tube led to making the third set of measurements to verify if one of the tubes had a problem that produced this inconsistency. Figure 6.3 shows the pulse height spectra from the tubes at various pressures. These spectra are typical and indicate that the neutron signal is well separated from the baseline noise.

Table 6.2. Measurement results for second campaign.

One Tube	**Tube ID[1]**	**Partial Pressure kPa (atm)**	**cps**	**cps/ng**
	325177	101 (1.0)	74.4(5)	1.9
	325186	203 (2.0)	103.6(6)	2.6
	325183	253 (2.5)	117.3(6)	2.9
	102439	304 (3.0)	114.0(6)	2.9
Two Tubes				
Left	325180	101 (1.0)	62.4(5)	1.6
Right	325177	101 (1.0)	60.2(5)	1.5
Total		101 (1.0)	122.5(7)	3.1
	1) See Table 2.1.			

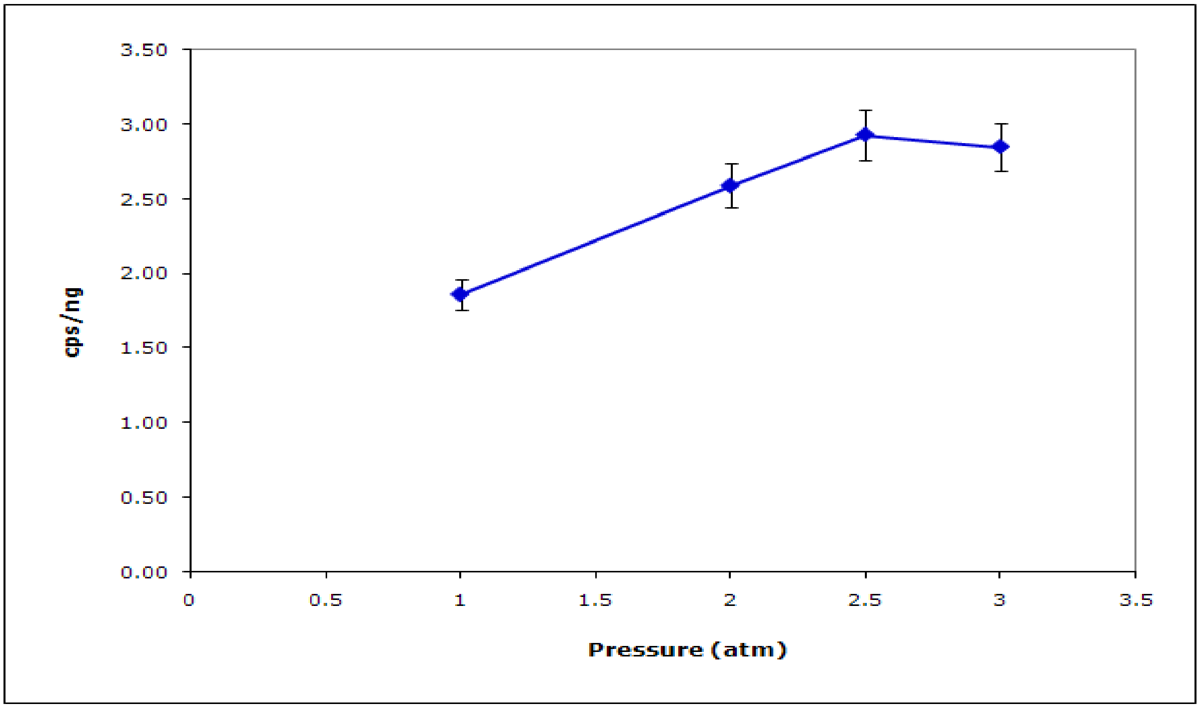

Figure 6.2. One-Tube Efficiency Versus Partial Pressure From The Second Campaign.

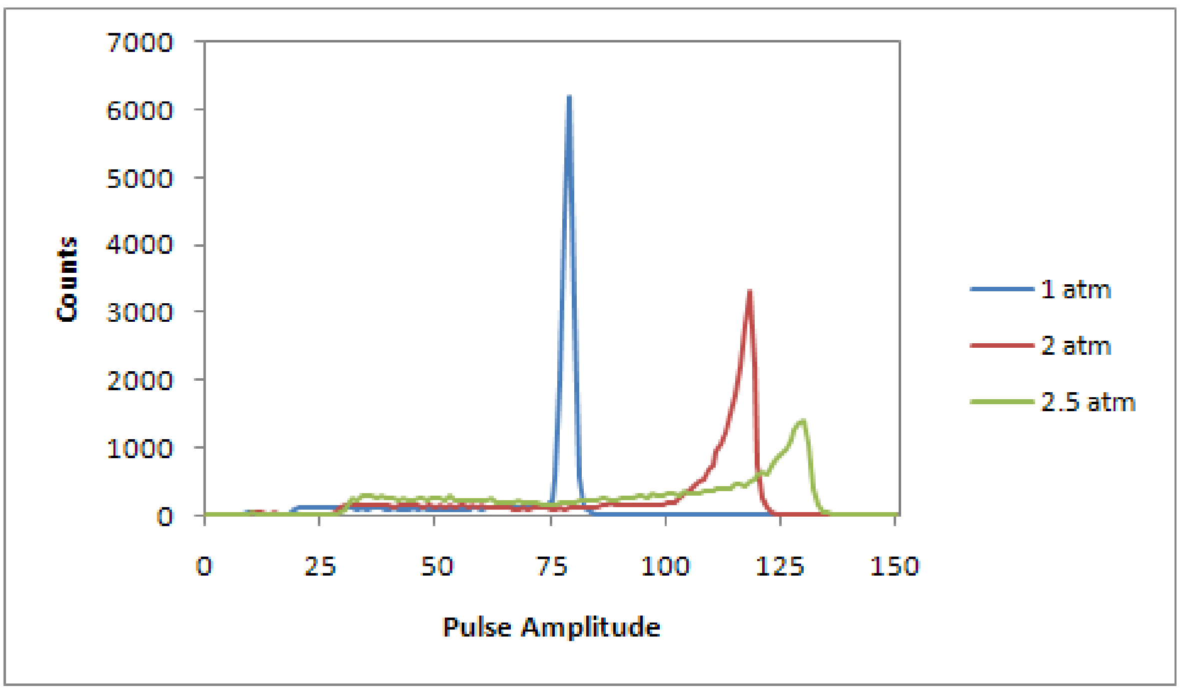

Figure 6.3. Illustrative Pulse Height Spectra for Different Pressure Tubes Measured In Second Campaign.

6.3 Third Test Campaign

The results from the third test are shown in Table 6.3 and Figure 6.4 shows the results from both the second and third tests. The net count rates recorded at different tube pressures (with uncertainties in parentheses) and the resulting counts per second per nanogram of ^{252}Cf are shown.

The values found are consistent with the previous measurements with the exception of the result from the 304-kPa tube, which for this test continued the expected upward trend. This result initiated the fourth test campaign in order to determine if one of the two 304 kPa (3 atm) tubes that were originally in the system tested was less efficient. The pulse height spectra observed for the third set of measurements with the 101, 203, and 253 kPa (1, 2, 2.5 atm) tubes were the same as the spectra observed in the second test.

Table 6.3. Measurement results for third campaign.

One Tube	Tube ID	Partial Pressure kPa (atm)	cps	cps/ng
	325177	101 (1.0)	79.1(5)	2.0
	325186	203 (2.0)	104.8(6)	2.6
	325183	253 (2.5)	113.3(6)	2.9
	102345	304 (3.0)	127.3(7)	3.2

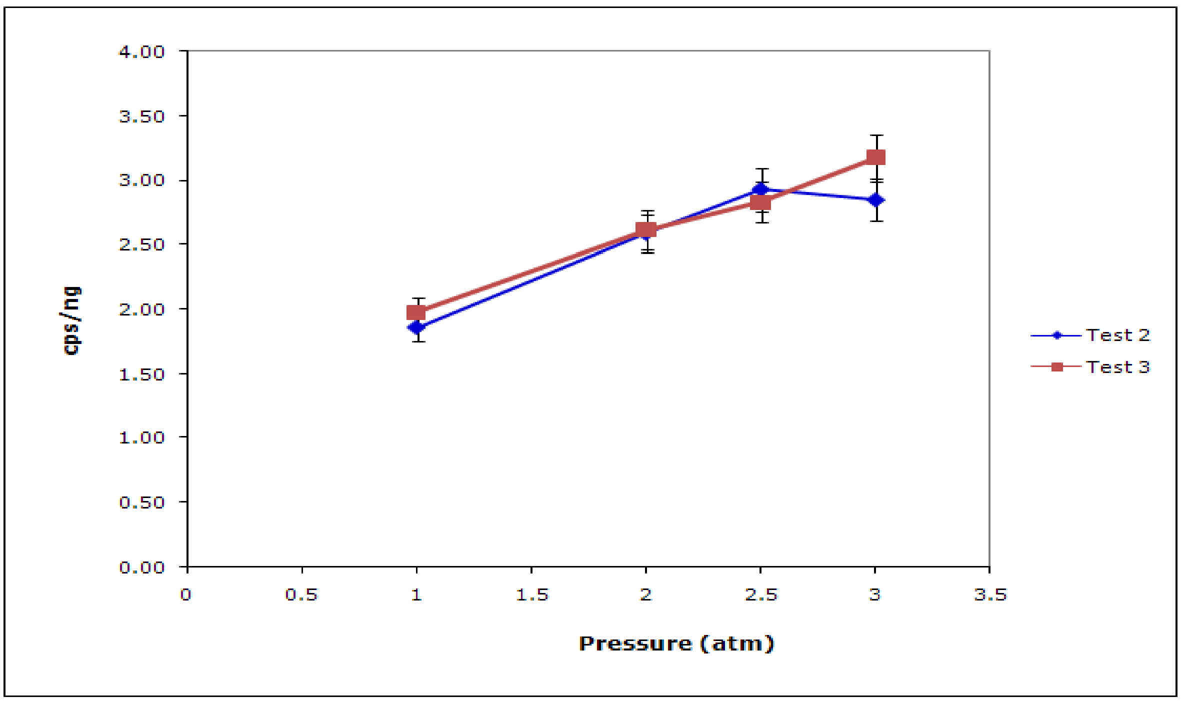

Figure 6.4. One-Tube Efficiency Versus Partial Pressure From Second And Third Campaigns

6.4 Fourth Test Campaign

The main purpose of the fourth test was to test the consistency between the two 304 kPa (3 atm) tubes. Tube A had serial number 102439 and Tube B had serial number 102345. The results of the measurements are given in Table 6.4 and plotted in Figure 6.5. The net count rates recorded at different

^{3}He partial pressures (with uncertainties in parentheses) and the resulting counts per second per nanogram of ^{252}Cf are shown.

Table 6.4. Measurement results for Fourth Campaign

One Tube	Tube ID	Partial Pressure kPa (atm)	cps	cps/ng
	325177	101 (1.0)	77.0(5)	1.92
	325186	203 (2.0)	105.2(6)	2.63
	325183	253 (2.5)	117.8(6)	2.95
	102439	304 (3.0) A	113.0(6)	2.83
	102345	304 (3.0) B	123.0(7)	3.08

It can be seen that the absolute efficiencies for tubes A and B differ significantly, which explains the differences seen in earlier measurements. The measurements for all pressures agree across the four sets of measurements when the two different "3 atm" tubes are understood to be different in efficiency. The most likely explanation is that tube A currently has a lower pressure than the 304 kPa (3 atm) stated by the vendor, and is actually about 243 kPa (2.4 atm), though there may be some other explanation. The vendor states that they were filled identically, so there may be a slow leak in tube A.

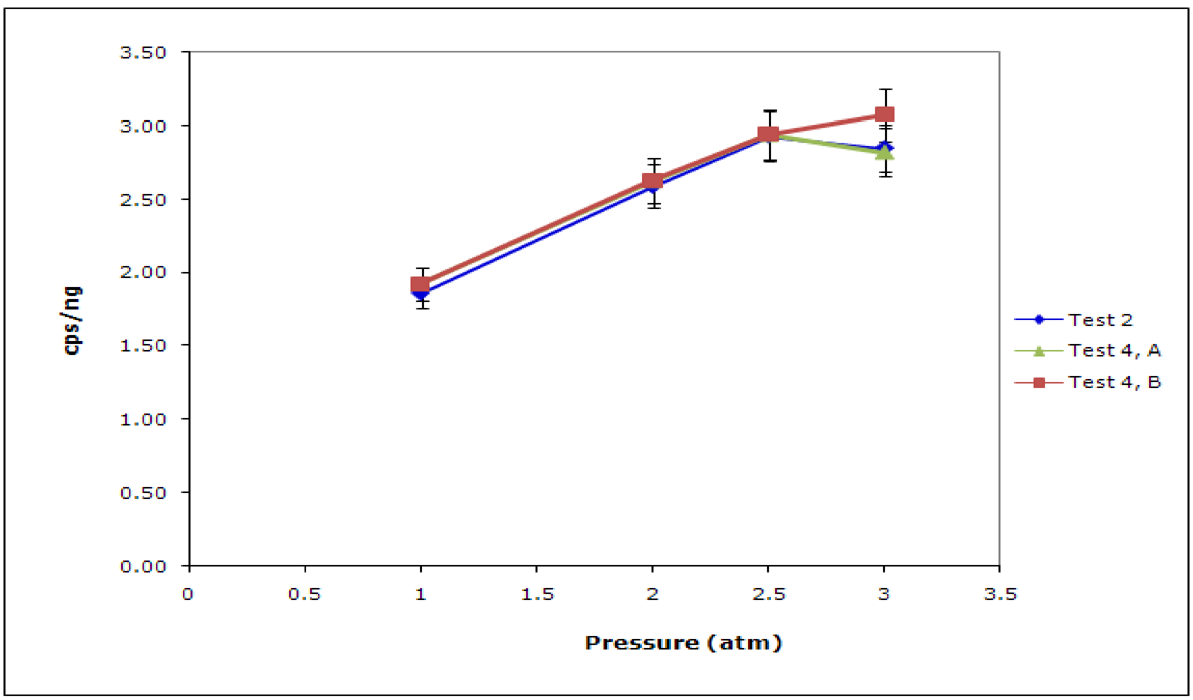

Figure 6.5. Efficiency Versus Partial Pressure from Second and Fourth Campaign.

6.5 Experimental and Modeling Comparison

Because the experimental data described in this report were taken over four different test campaigns, and because some of those data were considered less reliable than others; the first step in comparing those results to the model predictions was to collect all the measured values into one chart. These are shown in the top chart of Figure 6.6, where except for the 3(A) value from Table 6.4, the total set of measured values listed in this report are displayed. The only un-moderated ("w/o Pig") values were recorded during Test I. Note that there were only three measurements made for a two-tube configuration, two values at

304 kPa in first test campaign and one value at 101 kPa in the second campaign. Apparent from Figure 6.6 are the obviously anomalous (i.e., "less reliable") values reported for the 203 kPa (2 atm) tube used in Test I and the 304 kPa (3 atm) tube in Test II. Repeat measurements were made to correct the problems seen in Test I, and the efficiency problem with one 304-kPa ^{3}He tube was identified. Without further justification, those data are omitted from the following comparison.

The bottom graph of Figure 6.6 is used to compare the set of measured data to the results from model calculations. For the moderated, one-tube results considered, this comparison was made by first determining the average values from that set of data, and then fitting the predicted logarithmic function to determine how well that particular functional form described the data. That fit is shown by the thick solid line, and can be seen to describe the data extremely well. As for the absolute values, however, the thick dashed line shows the logarithmic function plotted with the model fitted parameters (after multiplying by 2300 n/s/ng), and is seen to under-estimate the averaged measured values by 7% to 9%.

A similar analysis was performed for the three un-moderated, one-tube values taken during Test I. The thin solid line shows the logarithmic parameters obtained by fitting those data, and the thin dashed-line is the curve produced with the corresponding "w/o Pig" model fitted values. Opposite to the "w/Pig" comparisons, the model prediction for this case tends to have a slightly different shape and overestimate the observed cps/ng values.

A fit to the two two-tube "w/Pig" values was not made because one ("3A") of the two 304 kPa (3 atm) tubes used for the two-tube measurements in Test I was found (in Test-IV) to be performing slightly under its partner ("3B"), and thus suspected of having a pressure slightly less than the vendor's designation. Nevertheless, those two two-tube points are compared to the corresponding model predicted logarithmic curve shown by the long-dashed lines in Figure 6.6. Note from that comparison, the two-tube 101 kPa (1 atm) measurement is slightly above the predicted value, a behavior consistent with the one-tube comparison. On the other hand, the two-tube 304 kPa (3 atm) value is slightly below the model prediction, which is inconsistent the one-tube behavior, and again a result of tube "3A" being less than "3B" in its individual performance.

The above differences are reasonable for MCNP *ab initio* calculations, since such models typically overestimate performance rather than underestimate it because there is no loss of efficiency from electronics included in the model calculations. Because the difference in the modeled and experimental results is probably not due solely to the uncertainty in the source strength, as shown by measurements with several sources, further investigation is needed to explain the small difference between the model predictions and the measured values.

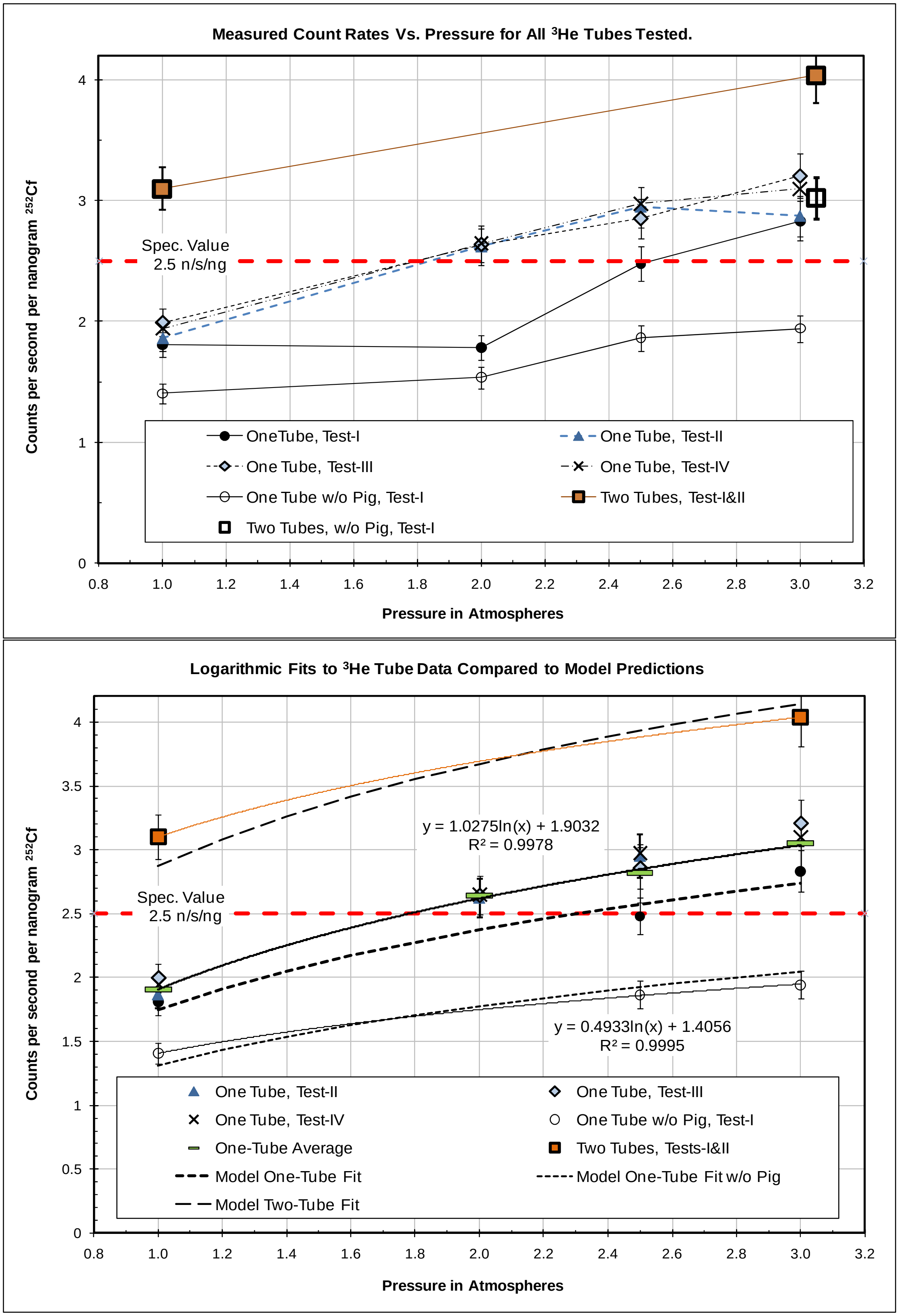

Figure 6.6. Data From All Tests (Top). Data Compared To Model As Function Of Partial Pressure (Bottom).

7 Conclusions

Measurements and model results have been presented for various pressure ^3He proportional counters.

The experimental measurements on ^3He tubes at various partial pressures show agreement with the trend predicted with a MCNP model. For the case of the shielded source, the measured absolute efficiency values are larger than those predicted with the model. Results show that the averaged measured efficiency is ~10% higher than the MCNP model predictions. Uncertainty in the source strength alone does not explain this difference, and other causes for this discrepancy are being explored. Considering the variations in the measured values about their average, the differences between the model predictions and average measured values are not large enough to change the main conclusion derived from the model results. Thus, it is advised that no reduction in ^3He pressure be considered for the SAIC system. However, the option of using two 101 kPa (1 atm) tubes to replace one 304 kPa (3 atm) tube is validated.

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