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ABSTRACT

In this paper, the neutron detector system (NDS) developed for the Californium-252 (^{252}Cf) neutron source measurements of the fissile mass flow monitor (FMFM) will be presented. The FMFM measures the ^{235}U fissile mass flow of UF_6 gas streams. The FMFM uses ^{252}Cf neutron sources for fission activation of the UF_6 gas. These ^{252}Cf sources are replaced about every 2 years because they have a relatively short half-life (~2.65 years). During source replacement, the new ^{252}Cf sources are calibrated with the previously installed sources (i.e., a relative source measurement is made) to ensure proper and seamless FMFM performance. The NDS has been developed as a possible alternative for the FMFM ^{252}Cf relative source measurements. The NDS consists of a neutron detector (a commercially available high-efficiency ^{3}He proportional counter), and electronics, which are commercial NIM modules. During the measurements, the ^{252}Cf source is placed into its FMFM source plug and is then inserted into a polyethylene source-plug holder that contains the detector. The source-plug holder and the NIM bin that contains the electronics are separated and are connected by an 18-m cable. The expected measurement time is 10 s for each source. Measurement repeatability is good (< 1%), and is not sensitive (< 0.5%) to the orientation of the source plug inside the NDS polyethylene source holder. The NDS will provide reasonable measurement times due to its high detection efficiency and will reduce the radiation exposure levels to operating personnel. A detailed description of the NDS and its instrumentation as well as the performance characteristics will be presented.

1. INTRODUCTION

The neutron detector system (NDS) is specifically developed to be used for the relative ^{252}Cf neutron source measurements taken during source replacement in the fissile mass flow monitor (FMFM) [1]. The ^{252}Cf sources are replaced about every 2 years because they have a short half-life (~2.65 years). During source replacement, the new ^{252}Cf sources are calibrated with the previously installed sources (i.e., a relative source measurement is made) to ensure proper and seamless FMFM performance. As illustrated schematically in Fig. 1, the NDS consists of a neutron detector, a high-efficiency ^{3}He neutron counter (manufactured by G. E. Reuter-Stokes, model RS-P4-0806-207 [2]); the electronics, which are

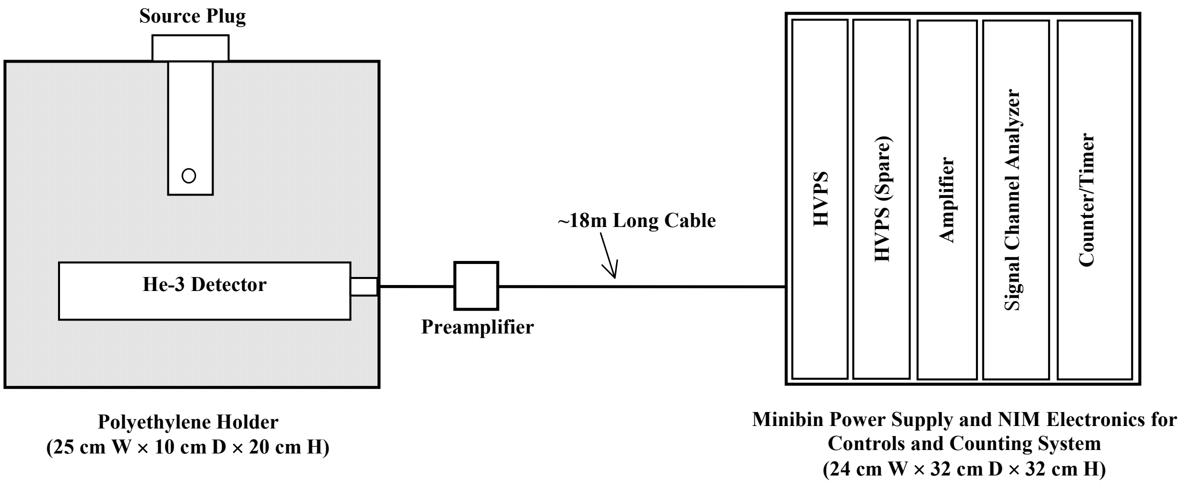

Fig. 1. Main components of the NDS are shown: the polyethylene holder, the minibin power supply and NIM electronics, the preamplifier, and the 18-m cable.

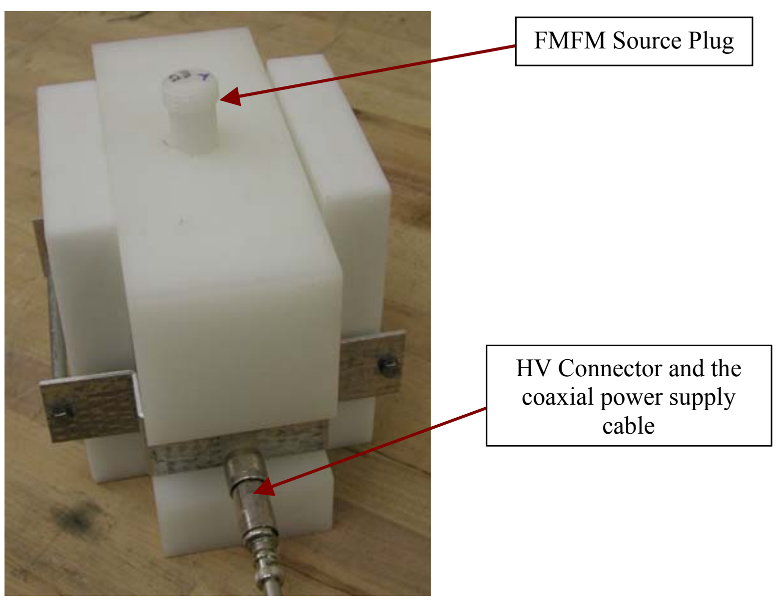

Fig. 2. Detailed view of the NDS PH showing the FMFM source plug and the high-voltage (HV) connector used for the detector's coaxial signal and power supply cable, which connects to the ^{3}He counter located inside the PH.

commercial (manufactured by ORTEC [3]); NIM instrumentation modules; a polyethylene holder (PH) that contains the ^{3}He detector wrapped with a cadmium sheet; and the FMFM source plug. The PH and the mini NIM bin that contains the modular electronics are connected by an 18-m coaxial signal and power supply cable (see Fig. 1).

Before a measurement is taken, the ^{252}Cf source is placed into its FMFM source plug. The source plug is then inserted into the source plug housing in the PH, as shown in Fig. 2. The electronics components of the NDS are housed in a minibin power supply unit (see Fig. 3). Instrumentation redundancy (i.e., a spare power supply, a dual amplifier, and a quad analyzer) is built into the NDS to minimize down time in the field due to possible component failure.

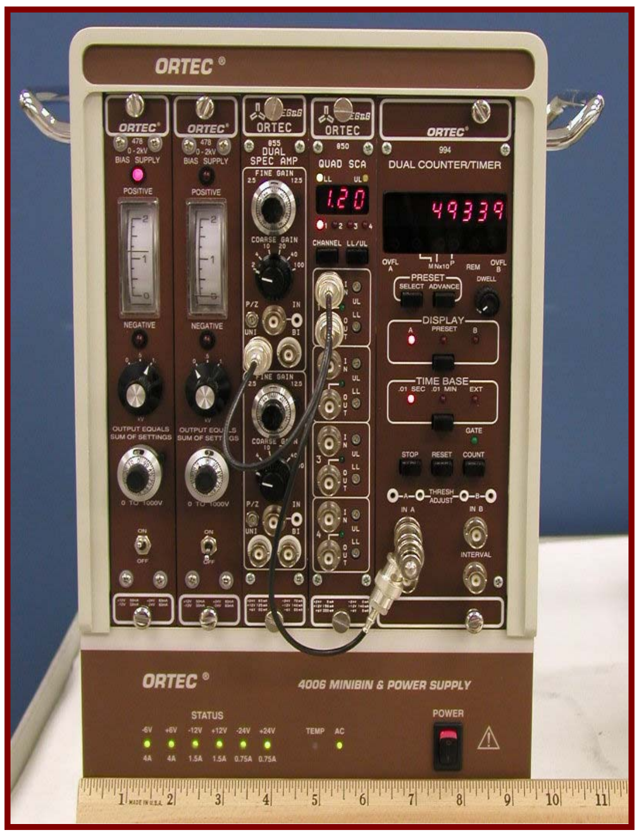

Fig. 3. The minibin and power supply (ORTEC 4006) and the NIM electronics. Shown from left to right are as follows: the main and the spare high-voltage power supplies (ORTEC 478), dual spectroscopy amplifier (ORTEC 855), the quad single channel analyzer (ORTEC 850), and the dual counter/timer (ORTEC 994) modules.

2. NIM INSTRUMENTS AND SETTINGS

The following instrument settings were determined from optimization of NDS performance. Contributions to the signal from low-energy X rays and from electronic noise were eliminated by the proper selection of a lower-level energy threshold adjustment for the single channel analyzer. In addition, operating parameters for the signal-shaping amplifier were selected to minimize signal pileup and thus to prevent saturation of the detector.

- **The ORTEC 4006** minibin contains the NIM electronics modules and provides the necessary power to them (see Fig. 3).
- **The ORTEC 478** main high-voltage power supply (HVPS) provides high voltage (HV) to the ^{3}He detector. The HV setting is +1200 V (positive).
- **The ORTEC 478** spare HVPS provides backup for the main HVPS**.**
- **The ORTEC 855** dual spectroscopy amplifier provides a proper signal waveform for the single channel analyzer (SCA). The amplifier settings are as follows:
  - coarse gain = 2.
  - fine gain = 2.5.
  - pulse-shaping time constant = 1.5 μs.
  - output pulse shape = unipolar.
- **The ORTEC 850** quad single channel analyzer (SCA) provides a logic signal to the counter whenever the input signal is higher than the lower level (LL) threshold setting. The LL threshold setting is 1.20 V (see Fig. 3).
- **The ORTEC 994** dual counter/timer measures the total counts for the preset counting time. The preset counting time (*T*) is set to 10 s.

3. NDS CABLING LAYOUT

The details of the NDS cabling layout are shown schematically in Fig. 4.

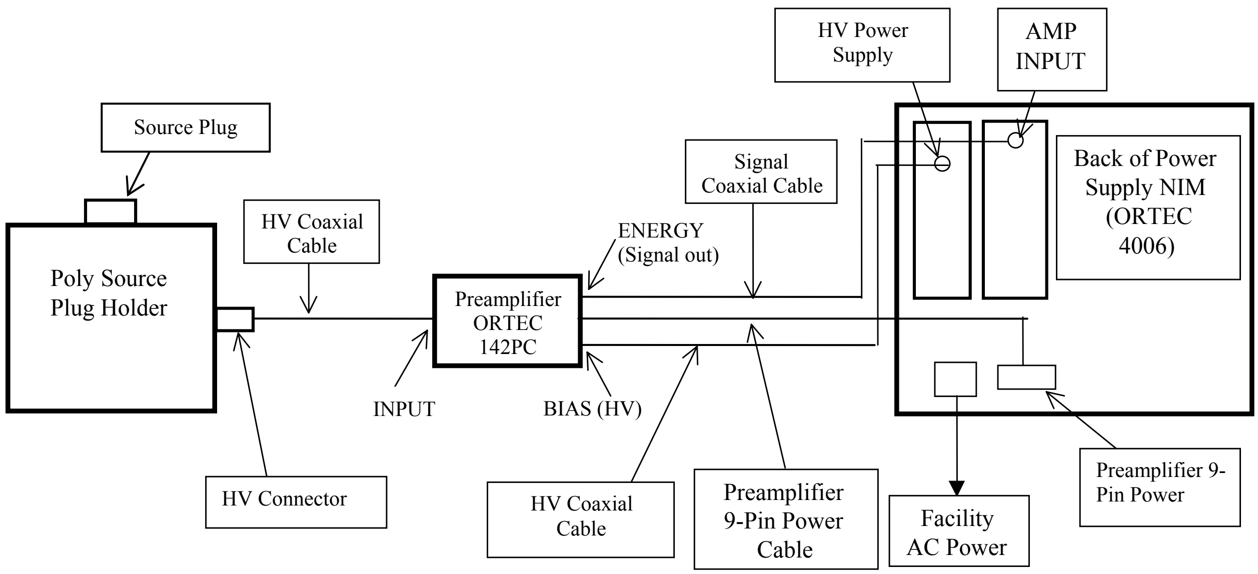

Fig. 4. Details of the NDS cabling layout. The cables are already attached to the ORTEC 142PC preamplifier as shown.

4. NDS POWER REQUIREMENT AND OPERATIONAL STEPS

The NDS operates with 110/220 VAC (a voltage selection switch is located on the back of the minibin). The maximum line power is 60 VA. The NDS operational steps are as follows:

1. Turn on the NDS power using the minibin power switch (see Fig. 3).
2. Apply 1200 V (positive) to the detector from the HVPS (see Fig. 3).
3. Set the preset time for data collection to $T = 10$ s on the ORTEC 994 counter/timer (see Fig. 3).
4. Allow about 30 min of warming time for the NDS before the start of measurements.

5. NDS PERFORMANCE CHARACTERIZATION

A ^{252}Cf source (~3 μg), manufactured by Frontier Technology Corp., [4] placed into an FMFM source plug is used for a number of measurements to characterize NDS performance. The first one is to establish shortest measurement time without making a significant error (i.e., less than a few percent). Figure 5 illustrates various data collection times (from 1 to 100 s) vs the corresponding counts per second (cps). As shown in the figure, a 10-s measurement time yields an approximate error of less than ~0.5% from an average count. A typical 10-s measurement has good repeatability (< 1%), and is not sensitive (≤ 0.5%) to the orientation of the source plug inside the NDS polyethylene source holder (see Fig. 2).

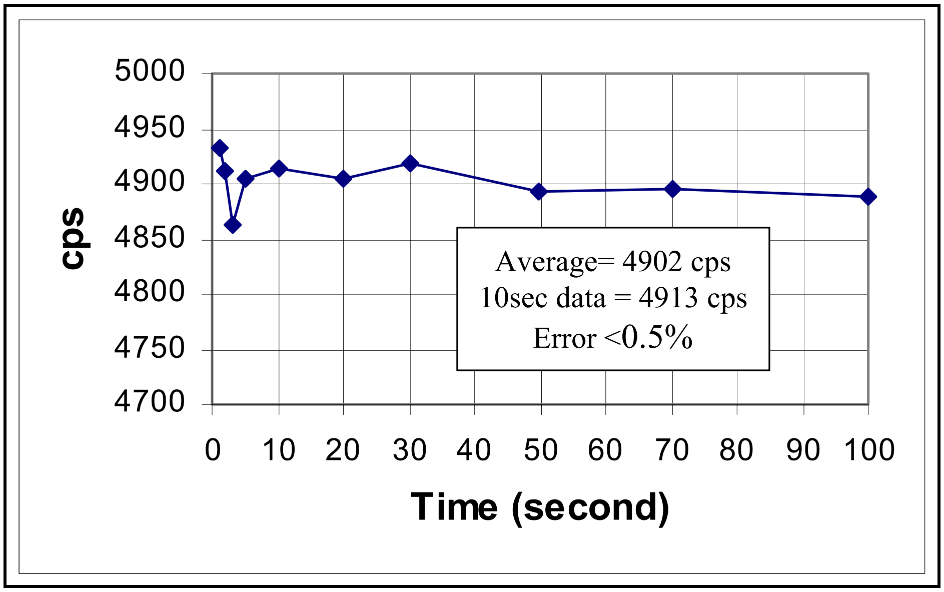

Fig. 5. NDS measurement counts (cps) at various data collection times.

The NDS performance is then characterized for the relative source measurements using three ^{252}Cf sources that were manufactured and calibrated (~2.9%) by Frontier Technology. Table 1 summarizes the source masses and their corresponding averaged 10-s counts (background corrected) obtained from the source plug orientation along with the source location inside the source plug, and using different plugs from the same set of plugs. No statistical difference was observed when measurements were made using different plugs from the same set. Since the NDS is used to measure the relative source mass, Table 1 is arranged to provide the three possible source mass ratios and the corresponding count ratios, as is also displayed in Fig. 6. The NDS responds almost linearly for the source count ratio $x \leq 2$ (see Fig. 6); however the apparent slight nonlinearity for the higher values of the count ratio is due to the system dead time (~15 μs).

Table 1. NDS ^{252}Cf calibration sources and the corresponding counts and their ratios

Source ORNL ID	Source mass[a] (μg)	Count ID	Averaged counts[b] (10 s)	Source mass ratio (y)		Count ratio (x)	
S3 (5023)	1.039	C3	17,612	S2/S3	1.043	C2/C3	1.057
S2 (5021)	1.084	C2	18,618	S1/S2	2.567	C1/C2	2.409
S1 (5234)	2.783	C1	44,856	S1/S3	2.679	C1/C3	2.547

[a]Sources are manufactured and calibrated (2.9%) by the Frontier Technology Corp.
[b]Average counts obtained from the source plug orientation, the source location in the plug, and different plugs.

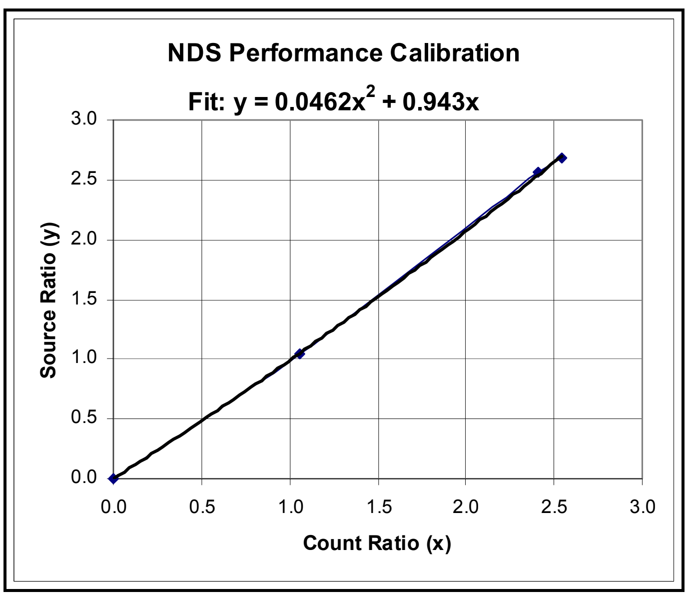

Fig. 6. NDS performance calibration for the relative source strength measurements and the corresponding curve fitted to the measurement data.

The assessment of the NDS relative source measurement error was also performed, and the results are summarized in Table 2. For this study, the maximum and minimum errors obtained from the single measurement performed out of the ten repeated measurements (i.e., the maximum deviation from the average value) were used to assess the most expected error on the measurement of the relative source ratio. A typical expected source mass ratio would be $y = 1.5$ to 2 when the FMFM sources are replaced with the fresh ones. According to Table 2, that leads to an expected error of about 6%. The FMFM source manufacturer provides the source mass (strength) with 8% uncertainty, and thus the error on the expected source mass ratio becomes about 11%, which is large enough to be easily distinguished from the NDS relative source measurements.

Table 2. Estimate of the NDS relative source measurement error

Details of Error Analysis	Error on count (%)	Error on count ratio (%)	Count ratio, x	Source mass ratio, y	Error on source ratio (fit) (%)
Possible source of measurement errors	4.0	5.7	0.2	0.19	5.76
Type of error:			0.4	0.38	5.81
(1) 10-s measurements (error: 0.5%)			0.6	0.58	5.86
(2) Plug orientation + different plugs, from max and min of single measurements (error: 4.0%)			0.8	0.78	5.92
Error analysis					
(A) Fit to NDS response (see Fig. 6)			1	0.99	5.97
$y = 0.0462x^2 + 0.943x$			1.2	1.20	6.02
Note: y = source mass ratio, x = count ratio			1.4	1.41	6.07
			1.6	1.63	6.12
(B) Error on fit			1.8	1.85	6.16
$dy/y = (dy/dx)\cdot(dx/y) = (dy/dx)\cdot(x/y)\cdot(dx/x)$			2	2.07	6.21
Count ratio: $x = c_1/c_2$			2.2	2.30	6.26
			2.4	2.53	6.30
(C) Error on count ratio			2.6	2.76	6.35
$(dx/x)^2 = 2\cdot(dc/c)^2$			2.8	3.00	6.39
$(dc/c)^2 = (\text{10-s measurements})^2 + (\text{orientation + max and min})^2$			3	3.24	6.43

6. NDS DOSE RATE MEASUREMENTS

The NDS dose rate measurements were also performed using a typical FMFM ^{252}Cf-source (having a strength of about 3 μg) at various locations and distances from the NDS, as given in Table 3, together with the measurement results. The measurement arrangement is shown in Fig. 7. The neutron dose rate was measured with a commercially available RemBall (Eberline ASP2), which is calibrated with a ^{252}Cf source. A MicroRem (BICRON) is used for the gamma-ray dose rate measurements. As shown in Table 3, the NDS provides a significant reduction in the californium source dose rates compared with the bare-source dose rates. Therefore, it reduces the radiation exposure levels to operating personnel.

Table 3. NDS dose rate measurements taken with a typical FMFM ^{252}Cf source (~3 μg)

Location (m)	Bare source (mrem/h)	NDS front (mrem/h)	NDS side (mrem/h)
Contact	520.6	31.4	69.6
0.3	77.1	8.85	18.751
1	9.7	1.95	2.98

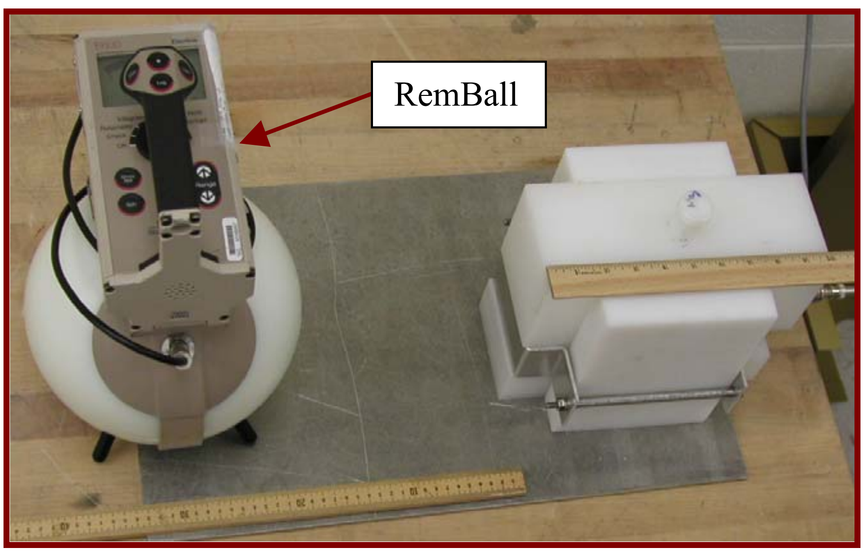

Fig. 7. Arrangement for the NDS dose rate measurements performed with a commercially available RemBall (made by Eberline).

7. DATA COLLECTION

Before measurement, the ^{252}Cf source is placed into its FMFM source plug. The source plug is then inserted into the PH, as shown in Fig. 8. The data are then collected by pushing the STOP, RESET, and COUNT buttons on the ORTEC 994 counter/timer module (See Fig. 3). The NDS has no memory; therefore, each measurement result needs to be recorded manually before starting a new measurement.

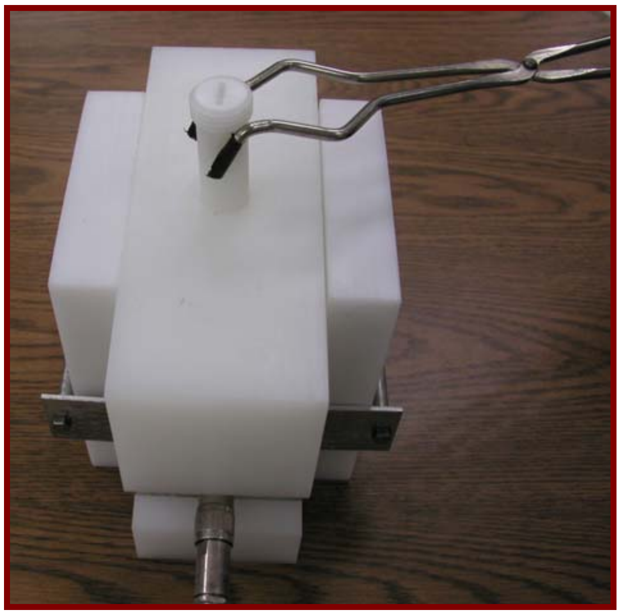

Fig. 8. Placement of the FMFM source plug, which contains the ^{252}Cf source, into the NDS for measurements.

8. NDS RELATIVE SOURCE MEASUREMENT METHODOLOGY

The NDS is designed to provide the relative source mass (strength) [y = (new source)/(reference source)] from the relative source count ratio [x = (new source counts)/(reference source counts)] and the NDS calibration response characteristics. For typical FMFM sources, the expected relative source mass (strength) ratio is y = 1.5–2, depending upon the age of the source being replaced. The NDS measurement steps are as follows.

1. Measure the NDS counts (background corrected) from the reference source and the new sources inserted into the FMFM source plugs (see Fig. 8), one at a time, and determine the relative source count ratio, *x*.
2. Determine the corresponding relative source mass (strength) from the NDS calibration response characteristic. (See Fig. 6, $y = 0.0462 \cdot x^2 + 0.943 \cdot x$).
3. Multiply the relative source mass (strength), *y,* by the known reference source mass (strength) to obtain the new source mass (strength).

9. CONCLUSION

The NDS has been developed as an alternative measurement technique for the FMFM source measurements and will provide a reasonably short measurement time (10 s) with good measurement accuracy (~6%), due to its high detection efficiency. It also significantly reduces the radiation exposure levels to operating personnel.

REFERENCES

1. J. March-Leuba, J. K. Mattingly, J. A. Mullens, et al., *38th Annual INMM Meeting*, Phoenix, Arizona, July 20, 1997.

2. G.E. Reuter-Stokes, 8499 Darrow Road, Twinsburg, OH 44087.

3. ORTEC, 801 South Illinois Ave., Oak Ridge, TN 37831.

4. Frontier Technology Corporation, 1641 Burnett Drive, Xenia, OH 45385.

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