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Implementation of the Fissile Mass Flow Monitor Source Verification and Confirmation

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ABSTRACT

This report presents the verification procedure for neutron sources installed in U.S. Department of Energy equipment used to measure fissile material flow. The Fissile Mass Flow Monitor (FMFM) equipment determines the ^{235}U fissile mass flow of UF_6 gas streams by using ^{252}Cf neutron sources for fission activation of the UF_6 gas and by measuring the fission products in the flow. The ^{252}Cf sources in each FMFM are typically replaced every 2 to 3 years due to their relatively short half-life (~ 2.65 years). During installation of the new FMFM sources, the source identity and neutronic characteristics provided by the manufacturer are verified with the following equipment: (1) a remote-control video television (RCTV) camera monitoring system is used to confirm the source identity, and (2) a neutron detection system (NDS) is used for source-strength confirmation. Use of the RCTV and NDS permits remote monitoring of the source replacement process and eliminates unnecessary radiation exposure. The RCTV, NDS, and the confirmation process are described in detail in this report.

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1. INTRODUCTION

This report presents the equipment and the verification process for identification and characterization of neutron sources installed in the U.S. Department of Energy (DOE) Fissile Mass Flow Monitor (FMFM) equipment used to measure the flow of fissile material in uranium-processing facilities [1, 2]. The FMFM determines the ^{235}U fissile mass flow rate of UF_6 gas streams [1]. It uses ^{252}Cf neutron sources for modulated fission activation of the UF_6 gas. The fissile mass flow rate is obtained from measurements of the fission product's delayed gammas and the ^{235}U concentration. The details of the FMFM measurement technique are described in Ref. 1.

The ^{252}Cf neutron sources in the FMFM are replaced every 2 to 3 years due to their relatively short half-life. Each ^{252}Cf source comes with a source certificate stating its unique identification (ID) number, mass, activity, neutron flux, and other characteristics. The main FMFM source specifications of interest for FMFM operation are shown below (note: ^{252}Cf mass is proportional to the neutron source strength [activity or neutron flux]):

- Capsule: Sources must be in a double-wall stainless steel capsule.
- Capsule diameter: 7 ± 0.29 mm nominal.
- Capsule length: 15 ± 0.35 mm nominal.
- Source mass: The mass of ^{252}Cf is not to exceed 4 µg (equivalent activity of ~ 79 MBq) and a tolerance of ± 8% of the nominal mass.
- Radionuclide purity: The yield of neutrons from the ^{254}Cf isotope in the source shall be less than 10% of the total neutron yield from the ^{252}Cf source at the time of certification.
- Labeling: The outer capsule of each source must be labeled with a unique identification number.

Three DOE national laboratories, Lawrence Livermore, Oak Ridge, and Sandia, collaborated to implement a source verification and confirmation methodology to provide assurance that new sources meet the FMFM source requirement and that they are consistent with the previously installed sources. Determining the precise source strength is essential to ensuring that the FMFM provides accurate measurements. The source identification by a unique ID number ensures that each source is not misplaced during the handling and verification process and that it is installed in its designated place. Prior to installation of a new ^{252}Cf source, the source's ID number is confirmed and its strength is measured to verify the source specification data. In addition, the source strength must be verified as being consistent with the strength of previously installed sources to ensure seamless FMFM measurement performance.

The personnel performing the source replacement do not have access to the sources until they arrive at the uranium-processing site. Therefore, the source identification and source-strength measurements must be performed immediately prior to source installation or replacement.

Two sets of equipment were developed to permit the source replacement personnel to remotely verify the source identity and neutronic characteristics. A remote-control video television (RCTV) camera monitoring system is used to confirm the source ID number, and a neutron detection system (NDS) is used for source-strength confirmation. The equipment is portable enough to be set up and used at the location of the FMFM. Use of the RCTV and the NDS permits remote monitoring of the source replacement process and eliminates unnecessary radiation exposure.

2. INTRODUCTION TO THE RCTV: DESCRIPTION AND MEASUREMENT CHARACTERISTICS

Lawrence Livermore National Laboratory developed the RCTV system used for the FMFM ^{252}Cf-neutron source identification and for monitoring the source installation and replacement activities. The RCTV system consists of the following components (see Fig. 1):

- TV surveillance camera: Pelco [3] Esprit series, model ES30125CBZ30N
- keyboard with joystick: Pelco, model KBD300A
- closed-circuit TV monitor: Tatung [4], model TLM-1702
- remote keyboard wiring kit (transformer):Pelco, model KBDKITX
- cable connection boxes
- cables
- tripod

Fig. 1. The RCTV system: large connection box and tripod, cables, TV monitor, and the keyboard with joystick.

The TV camera system incorporates a high-resolution color National Television Standards Committee (NTSC) camera with motorized zoom, integrated pan-and-tilt capability, and an enclosure and receiver in one compact system. An on-screen menu can be used to program and operate the camera. Features include 360° continuous pan rotation and tilt range from +33° to –83°. Input voltage is selectable from 24, 120, or 220 V with a frequency of 50 or 60 Hz. The lens has 30× optical zoom capability, minimum aperture (f) of 1.8-360, and a minimum focus distance of 1.8 m. The system is designed to operate in the temperature range of –40° to +50°C. The full-function desktop keyboard controller can be used in a variety of applications. A barrel-type joystick provides precise pan-and-tilt control of fixed-speed and variable-speed receivers. Twisting the joystick clockwise or counterclockwise zooms the lens in or out. Keys can be used to operate the zoom and focus of the lens as well as several other aspects of operation, such as presets, patterns, auxiliaries, and sequences. The keyboard is connected to the camera in direct mode for our application. The input voltage of 12 V to the keyboard is supplied by a transformer via a small (5 × 5 cm) connection box.

The TV monitor has a 17-in. thin-film-transistor liquid crystal display (LCD) with a brightness of 430 cd/m^2 and a contrast ratio of 400:1. The monitor has resolution of 1280 × 1024 pixels and uses an NTSC or a phase-alternating-line system with autodetection. The power supply is rated for 60 W at 100–240 V with a frequency of 60/50 Hz.

There are two cable connection boxes:

- A large metal box (15.5 ×15.5 cm) is mounted beneath the TV camera base and has three connectors. One connector is for the cable that provides 220-V power, and two connectors are for the composite cable.
- A smaller, plastic box (5 × 5 cm) is mounted at the monitor/keyboard end. The other ends of the composite cable and the cable from the 220-to-12-V transformer are connected to it. The small connection box also has a connector for the cable that connects to the keyboard.

The cables consist of the following:

- 25-m composite cable—composed of two cables, one for the TV camera-to-monitor video signals and one for the control of signals from the keyboard to the TV camera
- power cable—provides 220-V power to the TV camera via the larger connection box
- 2-m power cable—provides 220-V power to the monitor
- 5-m flat cable—provides 12-V power to the keyboard from the small connection box and keyboard signals to the small connection box
- cable wired to the small connection box and the transformer.

The heavy-duty commercial tripod is able to hold the camera at heights of up to 2 m.

The system can be programmed and operated in various automated ways; however, the camera is configured in the manual direct mode for FMFM replacement. Operating the RCTV monitoring system during the FMFM source replacement in direct manual mode requires only the use of the joystick and the focus (near-far) keys.

When the camera is being set up, the location should be selected to cover the entire source-handling area. Source-handling equipment should be staged between 2 and 5 m from the camera because that range is the optimal for reading the ^{252}Cf source identification numbers, as illustrated in Fig. 2. The connection diagram of the RCTV monitoring and NDS system combination will be discussed after the NDS introduction.

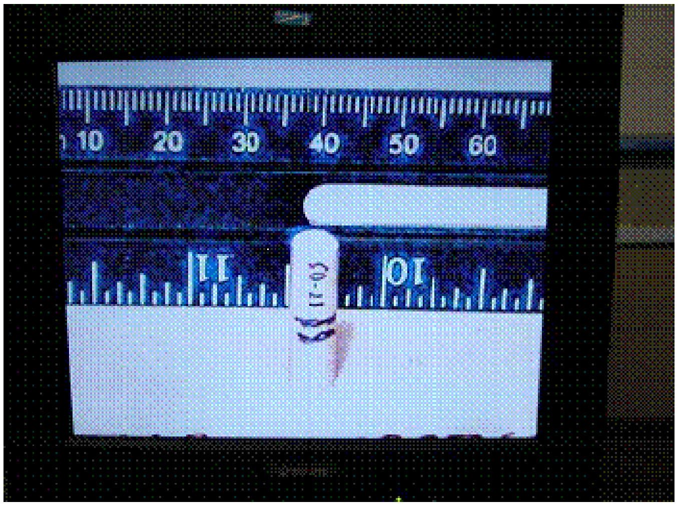

Fig. 2. Display showing the RCTV resolution and the ability to perform source identification from a distance.

3. INTRODUCTION TO THE NDS: DESCRIPTION AND MEASUREMENT CHARACTERISTICS

Oak Ridge National Laboratory developed the NDS for measurement of the source strength of the ^{252}Cf neutron sources used in the FMFM equipment. The FMFM's determination of the ^{235}U fissile mass flow requires an accurate value for the ^{252}Cf source strength, and the FMFM calculation algorithm uses the ^{252}Cf source strength value in terms of ^{252}Cf mass [1]. The FMFM sources (total of four sources, 3 μg of ^{252}Cf or equivalent activity of ~ 59 MBq each) are replaced every 2 to 3 years due to their relatively short half-life (~ 2.65 years). Figure 3 shows the location of the sources inside the FMFM source modulator [1]. The source plugs that house the sources are shown separately on the right.

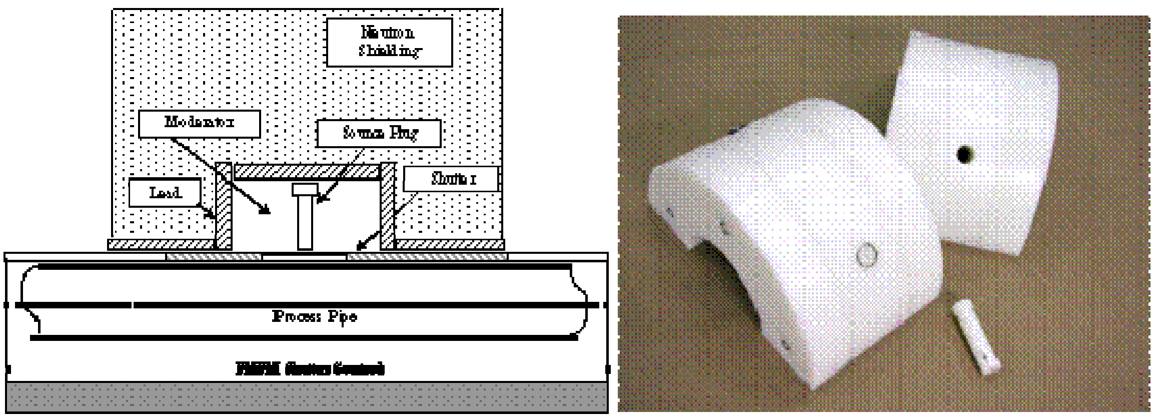

Fig. 3. Location of the FMFM sources inside the source modulator (left) and the polyethylene source plug housing the ^{252}Cf neutron source (right) prior to installation in the source moderator [1].

The NDS was developed as an alternative to the commercially available RemBall (Eberline NRD with ASP2), which measures neutron counts at 1 m from a bare source, provides relatively higher uncertainty in the source strength values, and requires longer measurement times (7 min). The NDS consists of a commercially available high-efficiency ^{3}He proportional counter [5] and the associated electronics. The electronics are commercially available NIM modules made by ORTEC [6] (see Figs. 4 and 5).

During the measurements the ^{252}Cf source is placed into its FMFM source plug and is then inserted into a polyethylene source plug holder, as shown in Fig. 6. \An additional advantage to this geometry compared with a bare-source measurement is that it reduces the exposure of the personnel. The intrinsic shielding of the NDS's polyethylene plug holder reduces the dose rate by more than a factor of 4. The radiation exposure of the monitoring personnel is further reduced during source measurements by placing the NIM counting electronics and display 20 m away and by connecting it to the detector with a cable (see Fig. 4). Thus, during the FMFM source replacements the participating personnel can safely monitor the ongoing process and collect neutron count data at a distance.

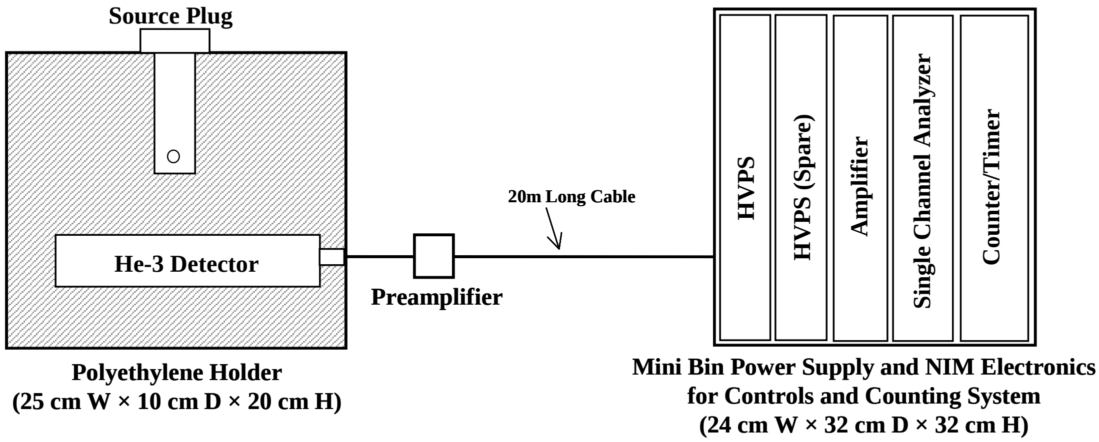

Fig. 4. Main components of the NDS: Polyethylene plug holder, mini bin power supply and NIM electronics, preamplifier, and 20-m cable. The plug holder contains a neutron detector, a high-efficiency ^{3}He neutron counter wrapped with a cadmium sheet (manufactured by G.E. Reuter-Stokes, model RS-P4-0806-207).

Fig. 5. The mini NIM bin and power supply (ORTEC 4006) and the NIM electronics. Modules shown (from left to right) are the main and the spare high-voltage power supply (ORTEC 478), dual spectroscopy amplifier (ORTEC 855), quad single-channel analyzer (ORTEC 850), and dual counter/timer (ORTEC 994).

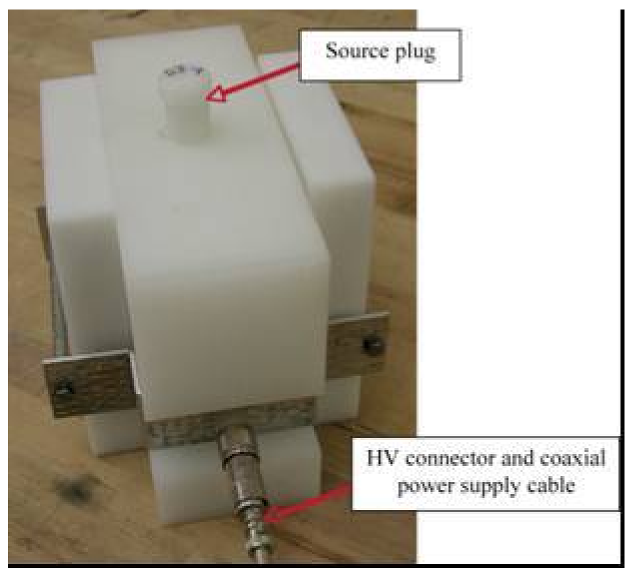

Fig. 6. Detail view of the NDS source plug holder showing the FMFM source plug and the high-voltage connector used for the detector signal and to supply high voltage to the ^{3}He counter located inside the plug holder.

3.1 NDS PERFORMANCE CHARACTERISTICS

The NDS instrument settings were determined during optimization of the NDS performance. Namely, the contributions from the low-energy X rays and from electronic noise in the signal were eliminated with the proper adjustment of the single-channel analyzer's lower-level-energy threshold. In addition, the operating parameters for the signal-shaping amplifier were selected to minimize signal pileup and to prevent saturation of the detector. The first set of NDS measurements was used to characterize the performance of the NDS and to establish the shortest measurement time without making a significant error (i.e., less than a few percent). A known ~3-μg ^{252}Cf reference source was used for a number of measurements. As shown in Fig. 7, a 10-s data acquisition time is sufficient to obtain a statistical uncertainty of less than 0.5%. Measurement repeatability is good (< 1% variation) and is not sensitive (< 0.5%) to the orientation of the source plug inside the NDS polyethylene source plug holder. The NDS source-strength (mass) calibration was performed using three ^{252}Cf sources manufactured and calibrated by Frontier Technology [7]. The resulting NDS calibration is close to linear, as shown in Fig. 8, with slight nonlinearity for the higher counts, possibly due to pileup effects. Considering these systematic errors, an assessment of the estimated NDS source strength (as mass equivalent) measurement uncertainty was performed. For a 10-s measurement of a typical 3-μg FMFM source mass (activity of ~59 MBq or about 7×10^6 neutrons/s), the evaluated uncertainty did not exceed 1.5%.

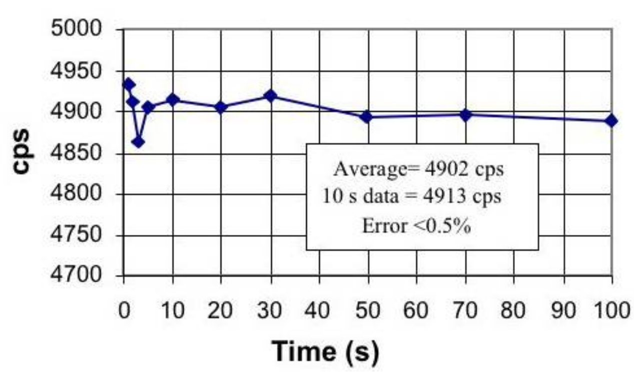

Fig. 7. NDS measurement count rate at various data collection times. A 10-s measurement time is sufficient to take the data. It yields about ≤ 0.5% uncertainty (error) from the average count.

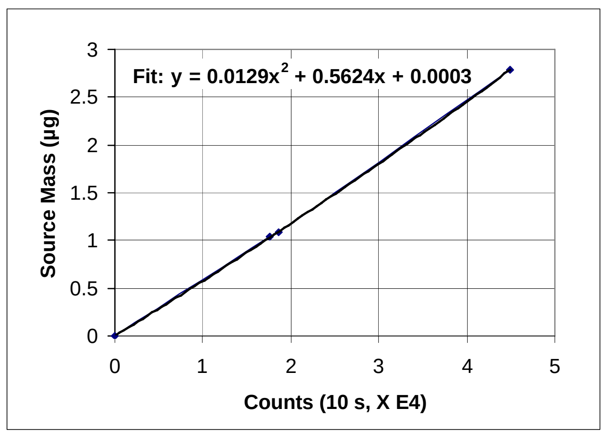

Fig. 8. NDS calibration for the source-strength measurements and the corresponding curve fit (the *y*-axis is the measured source mass strength, and *x*-axis is total counts) to the measurement data.

3.2 NDS DOSE RATE MEASUREMENTS

An assessment of the radiological environment around the NDS was made from dose rate measurements taken at various points and distances from the NDS. A typical FMFM ^{252}Cf source with a mass of about 3 μg was used. The neutron dose rates were measured with a RemBall calibrated with a ^{252}Cf source (Fig. 9). The dose rate measurement results are provided in Table 1. As shown by the results, use of the NDS provides a significant reduction in neutron dose rates compared with the dose rates associated with the use of bare sources. Thus the radiation exposure levels of operating personnel are reduced.

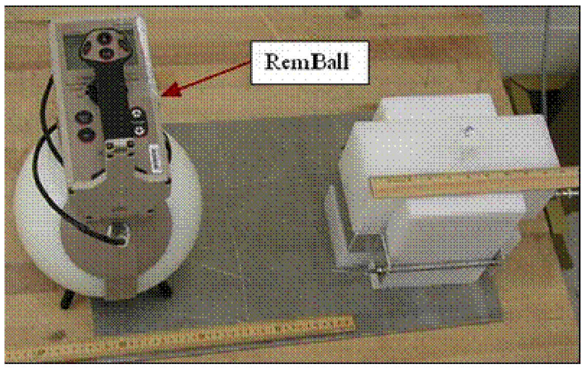

Fig. 9. Arrangement for the NDS dose-rate measurements performed with a commercially available RemBall (made by Eberline).

Table 1. NDS dose rate measurements taken with a typical FMFM ^{252}Cf source (~ 3 μg)

Location (m)	Bare source (mrem/h)	NDS (mrem/h)	
		Front	Side
Contact	520.6	31.4	69.6
0.3	77.1	8.85	18.75
1	9.7	1.95	2.98

4. MEASUREMENT AND OBSERVATION PROCESS

The RCTV and the NDS were successfully utilized during a recent FMFM source replacement for measurement and verification of source characteristics. In 2006, new ^{252}Cf sources were purchased to replace sources installed in 2004. The FMFM sources are ordered with a nominal ^{252}Cf mass of 3-μg (or equivalent activity of ~ 59 MBq) with a tolerance of ± 8%. The source manufacturer provides source certificates describing the neutronic characteristics and listing the unique ID number marked on each source.

The ^{252}Cf source dimensions are only 7 × 15 mm (see source specifications), and the dimensions of the source identification numbers do not exceed a few millimeters. However, the TV camera, which is 2 to 5 m from the source and set on high magnification, allows the observers to view the sources on the TV monitor to read and verify the small identification numbers (the observers and the TV monitor are about 20 m away from the source). Figure 2, taken during the testing of the RCTV with the simulated source capsule, shows the ID number; the actual source identification numbers are smaller and still verifiable. By controlling the TV camera's motorized zoom, pan, and tilt from a distance, the observers are able to monitor the entire cycle of source replacement: source-handling activities at the FMFM, source placement at the NDS measurement platform, and source placement in the storage and transport containers. Observers are able to watch all of these activities on the RCTV monitor. A typical layout of the NDS and RCTV equipment is shown in Fig. 10.

The source replacement process begins with the removal of the old sources (mounted in the source plugs) from the FMFM equipment (see Fig. 3). The source plug containing the old source is installed in the NDS polyethylene source holder for a count measurement (see Fig. 4). The current count rate is compared with the count rate at the time of purchase, corrected for decay (see Fig. 11). The source-handling process is monitored from a distance with the RCTV system. After the measurement, the old source is removed from the source plug and its ID number is verified. The old source is then placed in a storage container for transport. A new source is then removed from a storage container, the source ID number is verified against source certificate data, and the source is mounted in the source plug. The source, mounted in the plug, is placed into the NDS. The 10-s count is obtained and is used to verify that the measured source activity is consistent with the source certificate data. The source plug, containing ^{252}Cf source, is then installed in the FMFM equipment.

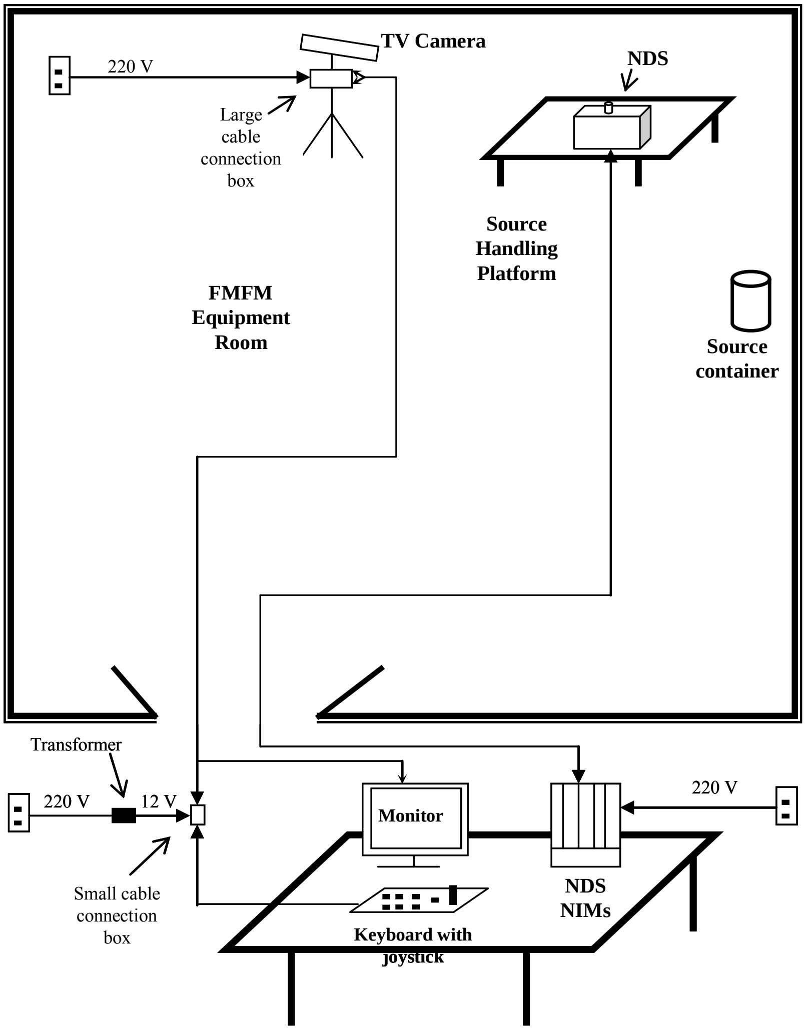

Fig. 10. Typical arrangement of the RCTV system and the NDS for the FMFM source verification and confirmation measurements.

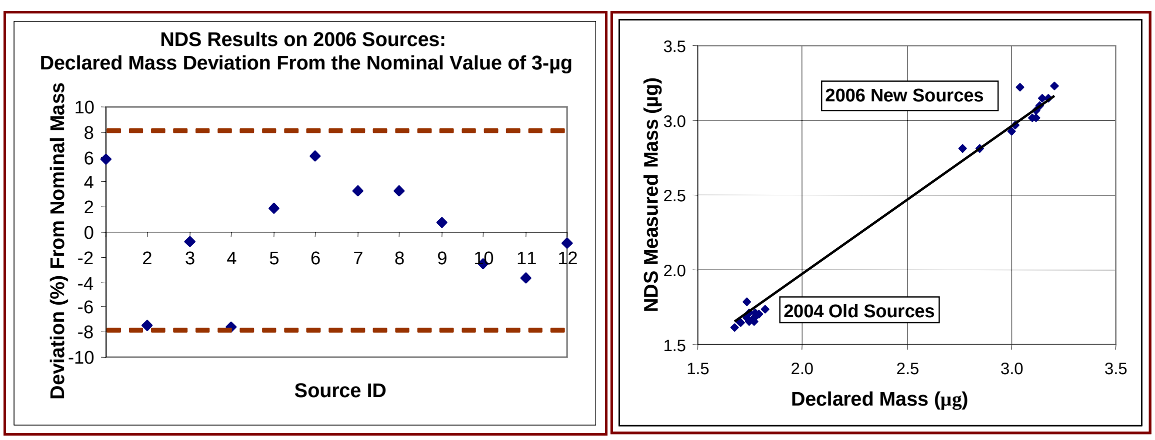

Fig. 11. NDS source mass strength measurements results of the FMFM sources (new and old). The new sources (2006) are within the source specifications (declared mass values) and are consistent with the old ones (2004). The source manufacturer provides ^{252}Cf sources for the FMFM (nominal mass: 3-µg each) with ±8% tolerance.

5. RESULTS AND CONCLUSION

Results of the NDS source strength measurements are presented in Fig. 11. The measurement results, derived from the NDS neutron count data, indicate that the masses for the new sources were in agreement with the masses listed on the source certificates (declared mass values) with ± 8% tolerance from the nominal mass of 3 μg (left chart in Fig. 11). Comparison to the measurement data for the older (2004) sources indicates that the data for the old sources agree with the previous measurements, when corrected for decay, and that they are consistent with the measured neutron count rates (masses) for both old and new sources (see right chart in Fig. 11). The NDS provided a reasonably short measurement time (10 s) with a good uncertainty (~ 1.5%) due to high detector efficiency. As a result, the NDS measurement system has proven to be a more efficient measurement instrument than the RemBall for the FMFM source strength measurements. The RCTV provides a unique capability to remotely verify the source identification numbers during the source installation and to ensure that the sources are installed in the desired locations, which was not possible otherwise because of the high radiation levels. The use of the RCTV and NDS combination provides an inexpensive, independent verification that the sources provided by the manufacturer meet the source specifications. This is important to ensure accurate FMFM system calibration and proper FMFM measurement data between source replacements. Most importantly, source verification utilizing the RCTV and the NDS reduces the radiation exposure levels of operating personnel compared with handling bare sources and conducting measurements with the RemBall at 1 m.

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[5] G.E. Reuter-Stokes, 8499 Darrow Road, Twinsburg, OH 44087.

[6] ORTEC, 801 South Illinois Ave., Oak Ridge, TN 37831.

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