Multi-aspect System for Measurement of Attributes of Fissile Materials and Explosives

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Abstract

One of the thrusts for exchanging technical information under the U.S.-Russia Warhead Safety and Security Exchange (WSSX) Agreement is the development of technologies to enhance the safety and security of nuclear warheads (NW) and the materials composing them. In cooperation with Sandia National Laboratories (SNL), the All-Russian Research Institute of Theoretical Physics (RFNC-VNIITF) has developed a prototype of a multi-aspect measurement system (MAMS) that is intended for determining the major attributes of NW and their component materials [presence of high explosives (HE) and the fissile materials (FM) plutonium and highly enriched uranium] in a single system. The security of sensitive data is assured during the determination of these attributes. The MAMS system has integrated a series of advanced technologies that has enabled the assessment of the major attributes of FM and HE.

This paper will describe the design of an experimental MAMS prototype and the basic technologies incorporated into the system. Results of the system testing for the measurements of FM and HE attributes will be presented. Follow-on steps in terms of technology development and the design of a more advanced prototype of the system will also be discussed.

Background

Nuclear surety is an issue of common concern for the United States and Russia. As part of ensuring nuclear safety and security, technical experts from both countries are developing methods for nuclear material control. To date, both Russia and the United States have done considerable work in the area of developing technologies that would be able to provide reliable measurements of fissile materials (FM) while protecting pertinent information from disclosure. Such systems include technical means and procedures, which secure sensitive information during the process of nuclear item measurement.

RFNC-VNIITF, along with Sandia National Laboratories (SNL), developed and tested the first prototype of the Multi-Aspect Measurement System (MAMS). This system was designed to measure attributes of systems containing plutonium (Pu), uranium, and high explosives (HE). A number of state-of-the-art radiation measurement techniques were incorporated into the first MAMS prototype to allow assessment of the following specified attributes:

- the presence of plutonium

Sandia National Laboratories is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL8500.

- the quality of the plutonium, which is based on the $^{240}Pu/^{239}Pu$ isotope ratio (exceeding the threshold value)
- the mass of plutonium (exceeding the threshold value)
- the presence of uranium
- the enrichment of uranium (exceeding the threshold value)
- the mass of highly enriched uranium (exceeding the threshold value)
- the presence of HE
- the mass of HE (exceeding the threshold value)

Efforts are currently underway to build the second MAMS prototype, which will take into account challenges and problems identified with the first prototype.

MAMS Measurement Techniques and Hardware

Selection of the radiation measurement techniques to use with MAMS was guided by the following requirements:

- A combination of the measurement techniques to be integrated into the MAMS must allow real-time measurement of specified attributes with an acceptable error.
- Measurement techniques must be based on state-of-the-art, reliable, and well-established technologies. Hardware must be commercially available.

The measurement techniques that were integrated into MAMS are listed in Table 1. The measurement system (MAMS) based on these selected techniques includes both a high-efficiency, high-resolution gamma spectrometer and a neutron detector.

The schematic diagram of the first MAMS prototype is shown in Figure 1. The MAMS includes the following components:

- a HPGe GMX50-P semiconductor gamma detector with a high efficiency of performance used in techniques that determine presence of plutonium, quality of plutonium, presence of uranium, enrichment of uranium, presence of HE, and mass of HE.
- an SRPS-2 neutron detector unit with ^{3}He neutron counters used in techniques that determine plutonium and uranium mass.
- a DSA-1000 spectrometer used for collecting spectrometry data from the detector and sending it into the processor module for processing.
- a Data Processing and Display Unit (DPDU)
- a Control panel and a Display panel

Table 1. MAMS Measurement Techniques

##	Measured Attributes	Measurement Technique	Measurement Equipment Required
1.	Presence of Plutonium	High-resolution gamma spectrometry in the 630-670 keV energy region. Recording in the Pu radiation spectrum.	Gamma spectrometer with HPGe detector
2.	^{240}Pu/^{239}Pu Isotope Ratio	High-resolution gamma spectrometry in the 630-670 keV energy region. Comparison between ^{240}Pu and ^{239}Pu line intensities.	Gamma spectrometer with HPGe detector
3.	Mass of Plutonium	Detection of neutron radiation and comparison of measured count rate versus threshold.	Sensitive neutron detector
4.	Presence of uranium	Gamma spectrometry. Finding 185.7-keV and 1001-keV peak areas and their comparison versus background.	Gamma spectrometer with HPGe detector
5.	^{235}U/^{238}U Ratio	Gamma spectrometry. Recording in the gamma spectrum of peak energy 2614 keV over background.	Gamma spectrometer with HPGe detector
6.	Mass of ^{235}U	Measurement of neutron multiplication using external neutron source. Requires pre-calibration using inert (without fissile material) mockup.	Neutron source with a yield of 10^6-10^7 n/sec. Neutron detector.
7.	Presence of HE	Neutron radiation analysis. Recording in the spectrum of gamma energies ~10.8, 10.3, and 9.8 MeV while interrogating a package with neutrons	Gamma spectrometer. Neutron source with a yield of ~ 10^7 n/sec.
8.	Mass of HE	Neutron radiation analysis. Comparison of 10.8 (10.3; 9.8)-MeV peak areas to values obtained in calibration measurements.	Gamma spectrometer. Neutron source with a yield of ~ 10^7 n/sec.

Security of Sensitive Data

The system allows operation in two modes — open and closed (private). The open mode, which is intended for testing and authenticating the system, requires an external computer to be connected to the Electronics Unit. In the closed (private) mode, measurement results are shown on the Display Panel only as yes/no statements to indicate whether the measured attributes correspond to the specified criteria.

The system is designed to provide security of sensitive data, which is achieved through the following technical solutions:

- "Sensitive" data from the detectors is processed by the DPDU processor unit. The resulting data are displayed on the external Display Panel as yes/no statements.
- The electronic and detector units are placed in protective enclosures (physical barrier) that provide mechanical and electromagnetic protection. Enclosures are also used to suppress intrinsic electromagnetic emissions of the electronic equipment.

- Electronic and detector units are equipped with tamper-indicating devices. When those devices are triggered, the detectors shut down and data residing in DSA-1000 and DPDU are erased.
- The DSA-1000 analyzer and DPDU do not have non-volatile memory in which to store the data coming from the detectors. When power is off or if the electronics unit is tampered with, all accumulated data are erased.
- The system operation can be switched to the open mode only from the control panel. This should be done with all of the administrative and technical measures in place (such as sealing the cover that protects the mode switch button) to preclude unauthorized use of this mode.

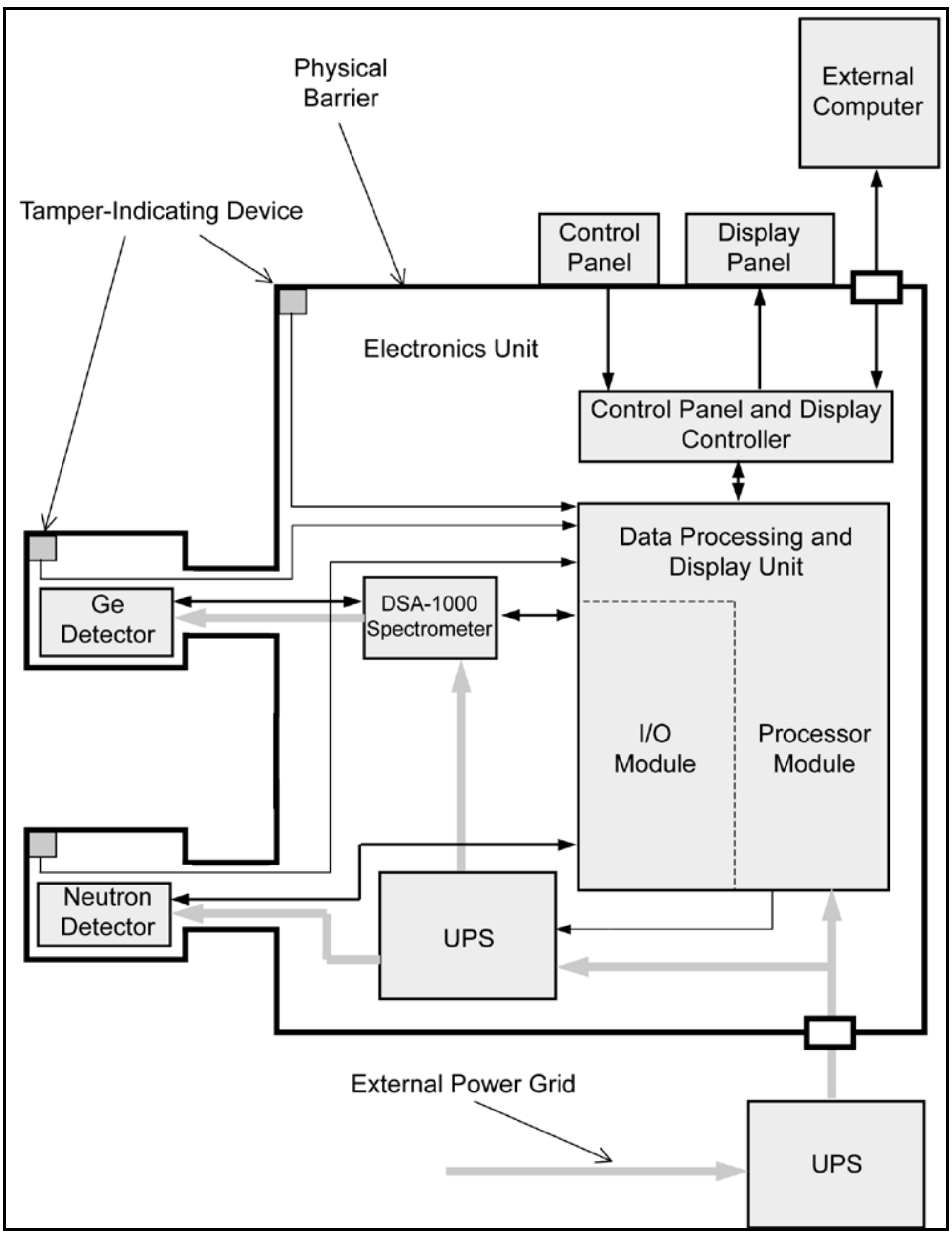

Figure 1. Schematic Diagram of MAMS

First MAMS Prototype Design

The design of the first MAMS prototype, shown in Figure 2, includes the following:

- **Measuring Bench —** All of the recording equipment is laid out on the measuring bench in a strictly defined configuration relative to the measured item. The measuring bench includes:
  - a bed for placement of containers with FM and HE that allows movement of containers relative to the detectors
  - recording equipment in protective enclosures
  - a polyethylene block with a neutron source
- **Operator's Workstation —** The operator's workstation can be biologically shielded if it is located in a room with permanent personnel presence. The workstation and the measuring bench are connected via shielded cables. The Electronics Unit, with the control and display panels and a computer, are placed on the worktable.

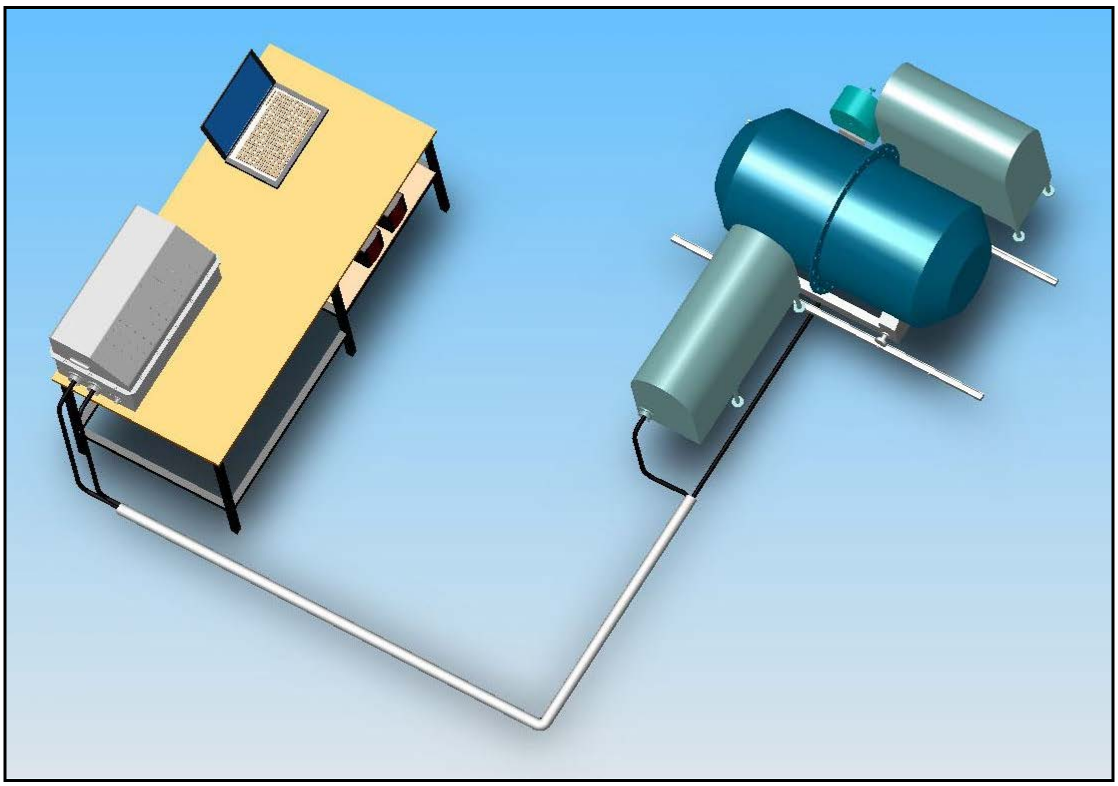

Figure 2. First MAMS Prototype Design

The control and display panels are structurally integrated with the top panel of the Electronics Unit. The physical configuration of these panels is shown in Figure 3. The top section of the figure shows the Control Panel buttons and connector for the external computer, while the bottom section shows the displays. The Control Panel maintains control of the system operations consistent with a pre-set operation algorithm. The Display Panel provides on-line indication of the system status, operation modes, measured attributes, and assessment results.

The measurement cycle is started by pressing the "Attribute Measurement" button. At the end of the cycle, the system goes back to its initial state. When the system is operated in the attribute measurement mode, the "Operation Mode" button and connector for the external computer are covered with a hinged cover plate to prevent access.

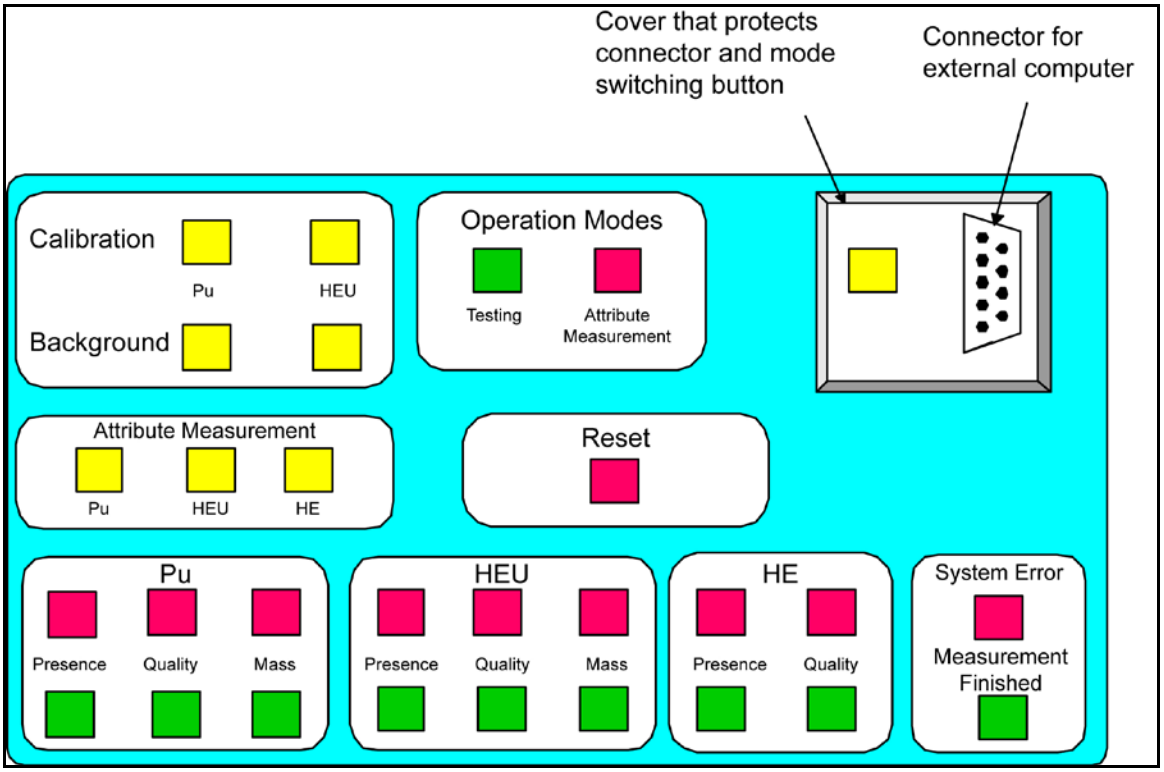

Figure 3. Physical Configuration of Control and Display Panels

Model Assembly

A Model Assembly (MA) was developed for experimental validation and testing of the system. It was used to conduct experimental research directed at optimization and refinement of the measurement techniques integrated into the multi-aspect system.

The MA design allows several units made of uranium, plutonium, simulated HE, and combinations thereof to be mounted in the assembly at the same time. Parts of critical assemblies that have data published in the open literature were used as fissile materials. The MA has a multipurpose design that accommodates all of the tested radiation measurement technologies. Figure 4 illustrates both the design of the MA and a variety of its possible modifications.

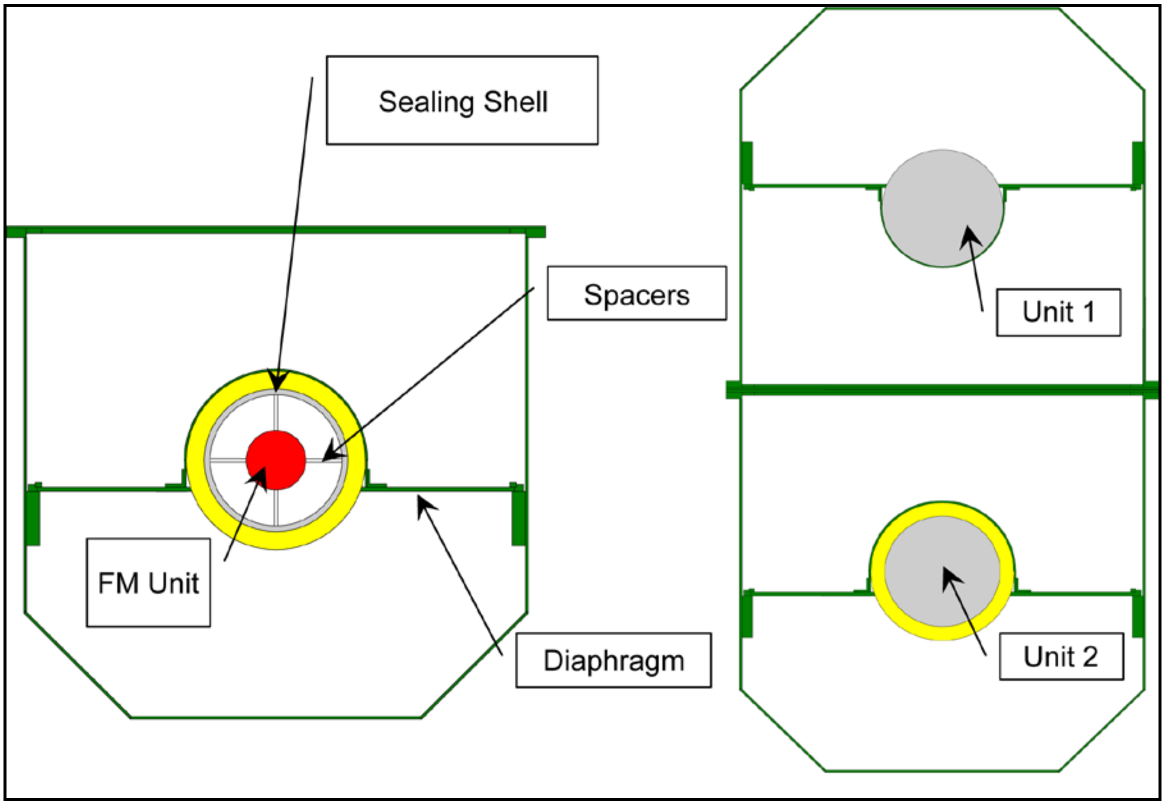

Figure 4. Various Assembly Options

MAMS Testing

MAMS was tested with the MA that consisted of units of varying configurations containing highly enriched uranium (HEU), plutonium, and simulated HE. Figure 5 shows photographs of the measurement process. As demonstrated by the test results, it was quite easy to assess the presence and quality of plutonium in the units. Measurements of plutonium mass, which was based on the neutron detector count rate, provided satisfactory results when calibration was performed. For the MA, calibration was carried out by placing samples of Pu with a known mass into the assembly.

The presence of HEU in the MA can be clearly determined through the presence of 2614-MeV energy lines in the recorded spectrum. Enrichment of uranium is measured with required accuracy if it is not shielded by a layer of high-Z material that completely absorbs relatively soft gamma radiation from uranium. Measurement of the uranium mass by measuring the external multiplication factor requires a series of preliminary calibrations using mockups with a similar composition, in which the enriched uranium parts are replaced with similar parts made of non-enriched uranium. Also, it is required to optimize the measurement geometry to improve the effect/background ratio.

Unit assembled inside the MA

MA is placed on the Measuring Bench

Measuring Bench with Recording Equipment and MA installed

Electronics unit of MAMS system

Figure 5. Measurement Process

Measurements with units containing simulated HE demonstrated that the neutron-radiation method determined the presence of more than 1 kg of HE in the units. However, this type of assessment required a considerable amount of time (for the 1-kg HE mass, the required measurement time was ~ 2 hours). HE mass can be measured only after calibration is performed. During the tests, calibration was carried out by placing simulated HE of varying mass into the MA and plotting the corresponding calibration curves.

Potential Enhancement of Multi-Aspect Measurement System

Several proposals for future enhancement of the MAMS were generated once the tests of the first MAMS prototype were complete.

The test results demonstrated that the biggest challenge was to determine uranium mass and HE mass. In addition, it was technically inconvenient to use the isotope neutron source. Therefore, a neutron generator (d, d) is now being considered for the second MAMS prototype. An ING-07D neutron generator was recently purchased that can be operated in a continuous mode and provide a neutron yield of ~10^7 n/sec.

Another new component is a polyethylene chamber into which all of the measured objects will be placed. In our estimation, the use of such a chamber will significantly reduce the time of measurements. It is also proposed to measure uranium mass by recording delayed neutrons that are generated by uranium fission.

The proposed schematic configuration for measuring the attributes of plutonium, HEU, and HE is shown in Figure 6.

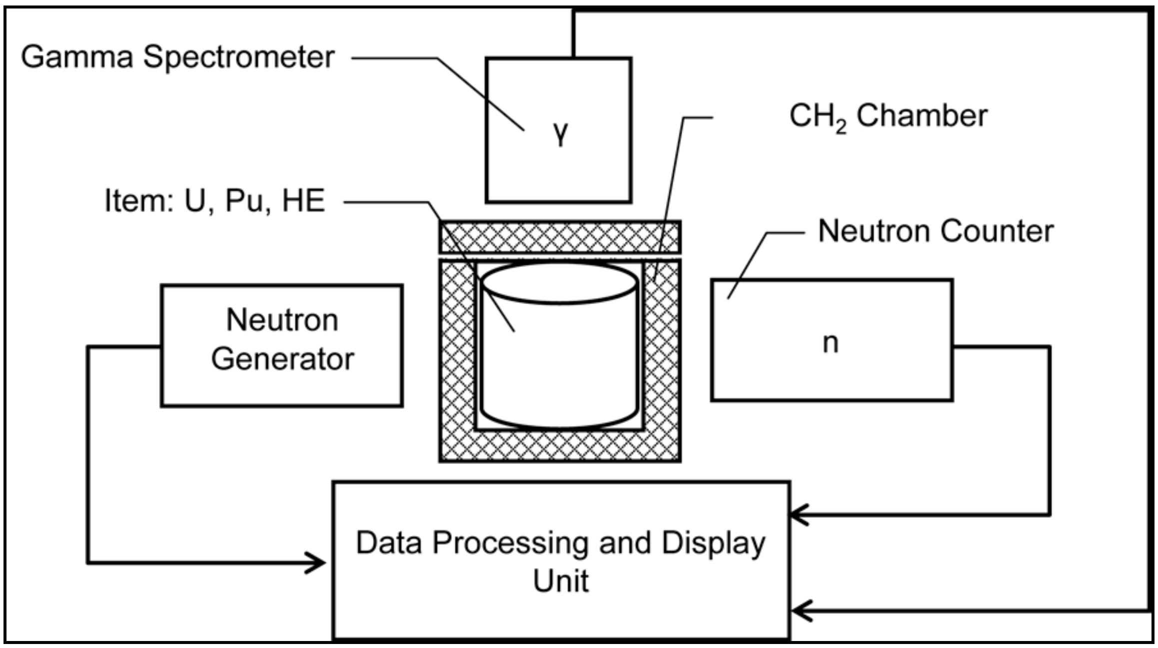

Figure 6. Proposed Schematic Layout of Second MAMS Prototype

Conclusions

Work on the system for measuring FM and HE attributes brought forth the following results:

- The first MAMS prototype was developed.
- The MA was developed and used to support a large number of experiments on finding the specified FM and HE attributes.
- Challenges and problems with measuring certain FM attributes were identified.
- Proposals on further improvement of the MAMS prototype were formulated.