Two types of homemade radiation detectors are evaluated for possible use in a fallout situation.

An Evaluation of the Kearny Fallout Meter (KFM), a Radiation Detector Constructed From Commonly Available Household Materials

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Abstract: *A radiation detector constructed of common household materials was developed at Oak Ridge National Laboratory (ORNL) by Cresson H. Kearny and has been referred to as the Kearny Fallout Meter (KFM). Developed during the height of the Cold War, the KFM was intended to place a radiation meter capable of measuring fallout from nuclear weapons in the hands of every U.S. citizen. Instructions for the construction of the meter, as well as information about radiation health effects, were developed in the form of multi-page newspaper insert. Subsequently, the sensitivity of the meter was refined by a high school teacher, Dr. Paul S. Lombardi, for use in demonstrations about radiation. The meter is currently being marketed for survivalists in light of potential radiation terrorist concerns. The KFM and Lombardi's variation of it are constructed and evaluated for this work. Calibrated tests of the response and variations in response are reported. A critique of the multi-page manual is made. In addition, the suitability of using such a detector, in terms of actual ease of construction and practical sensitivity, is discussed for its use in demonstrations and introductory classes on nuclear topics. Health Phys. 87(Supplement 2):S52–S57; 2004*

Key words: *operational topic; fallout; weapons; detector, radiation*

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INTRODUCTION

The KFM was originally conceived in 1977 for the survivors of a nuclear war (Kearny et al. 1978; Kearny 1987). In such an event, it was assumed that appropriate emergency response organizations would be unavailable in all areas and that the general population would have been unable to buy or obtain a fallout meter. Thus, the need for an accurate and dependable method of measuring changing gamma radiation dangers in one's immediate area was vital. The construction by untrained individuals may be accomplished with the provided written instructions, low cost materials, and tools found in the majority of American homes. The KFM is stated to be understandable, easily repairable, and as accurate as most civil defense fallout meters. It can be used by millions of Americans who do not have access to commercially available dose-rate meters.

The unit was developed at Oak Ridge National Laboratories (ORNL) with the stated ability to measure gamma radiation dose rates of 28.5 mGy h^{-1} (0.03 R h^{-1}) up to 0.41 Gy h^{-1} (43 R h^{-1}) with an accuracy of $\pm$25%. With the increasing threat of terrorist activity, the KFM is possibly a useful tool to aid the general population in light of a dirty bomb or small atomic weapons incident.

The KFM is based on the principles of a simple electroscope-ionization chamber. It is designed to have an air enclosure provided by a metal can. The air in the enclosure must be kept very dry, with the use of a drying agent, to make accurate measurements. Suspended on insulating threads inside the chamber are two separate 8-ply aluminum foil leaves. By placing a like charge on the two leaves, the resulting difference in the leaf separation before and after exposure is measured in millimeters (mm). A determination of the gamma radiation exposure in roentgens per hour (R h^{-1}) is made

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using a previously prepared calibration table, as shown in Table 1. The standard SI units (Gy h^{-1}) were added and have a maximum error of 7% in the conversion from exposure in air to dose to tissue (based on the ratio of the mass attenuation coefficients in tissue to air over an energy range of 0.1 keV to 10 MeV). The table was calibrated from numerous tests at ORNL and is common to the dimensions and materials specified by the directions. Each unit made is stated to maintain accurate measurements governed by this table. In addition to the KFM's use as a radiation detection meter, Dr. Paul S. Lombardi of South Davis Junior High School in Salt Lake City, Utah, introduced modifications to the KFM unit to make it more suitable for class-room demonstrations and educational uses (Baerman 2002; Oldenburg 2003). The modified version of the KFM was named the Lombardi dose rate meter (Lombardi). The Lombardi's sensitivity is much greater than that of the KFM. This allows it to be useful for demonstrating the detection of low-level radiation sources in a learning environment; however, the Lombardi version could not be calibrated for use as an accurate radiation detection unit due to its increased sensitivity.

In this paper, a critique of the KFM and Lombardi construction methods are given. Suggestions for improvements in design and directions are also made. Also, the performance of each meter in response to a gamma radiation field was tested. Comments on the practical limitations of the systems and their use in response to a terrorist attack are considered.

Table 1. Reproduction of the calibrated table to determine dose rate from the KFM leaf separation in millimeters (mm). Units of Gy h^{-1} were added. The data were obtained from numerous tests conducted at ORNL and are applicable to all KFM units constructed within the specifications of the directions (Kearny et al. 1978).[a]

Table used to find dose rates from KFM readings					
	Time interval of an exposure				
Difference in readings[b]	15 s [R h^{-1} (Gy h^{-1})]	1 min [R h^{-1} (mGy h^{-1})]	4 min [R h^{-1} (mGy h^{-1})]	15 min [R h^{-1} (mGy h^{-1})]	1 h [R h^{-1} (mGy h^{-1})]
2 mm	6.2 [0.059]	1.6 [15]	0.4 [3.8]	0.1 [0.95]	0.03 [0.29]
4 mm	12 [0.11]	3.1 [29]	0.8 [7.6]	0.2 [1.9]	0.06 [0.57]
6 mm	19 [0.18]	4.6 [44]	1.2 [11]	0.3 [2.9]	0.08 [0.76]
8 mm	26 [0.25]	6.2 [59]	1.6 [15]	0.4 [3.8]	0.10 [0.95]
10 mm	31 [0.29]	7.7 [73]	2.0 [19]	0.5 [4.8]	0.13 [1.2]
12 mm	37 [0.35]	9.2 [87]	2.3 [22]	0.6 [5.7]	0.15 [1.4]
14 mm	43 [0.41]	11 [100]	2.7 [26]	0.7 [6.7]	0.18 [1.7]

[a] The additional S.I. units added and have a maximum error of 7% in the conversion from exposure in air to dose to tissue.
[b] Difference between the reading before exposure and the reading after exposure.

MATERIALS AND METHODS

Construction overview

The instructions for building the KFM emphasize the importance of reading aloud the procedures prior to beginning the construction. The general materials needed for the construction of KFM unit include a typical metal can, standard aluminum foil, insulated wire, lightweight thread, a transparent plastic sheet, tape, a bandage, wallboard, glue, pencil, and rubber bands (Fig. 1). Several of these materials are not set rigidly and can be substituted with other available items.

Figure 1. Typical household materials used for the construction of the KFM unit. From the bottom left: tape, ruler, transparent plastic sheet, charging wire, bandage, nail, needle, broken pencil, insulating thread (polyester sewing thread and non-waxed dental floss), standard aluminum foil, scissors, drying agent (drywall and calcium sulfate), and a typical metal can (glue is not pictured).

Two KFM units were constructed for testing. The first was made by a first year engineering undergraduate and the second by a fourth year engineering undergraduate. The first unit's construction time took over 5 h to complete, and there was substantial confusion while following the instructions. The second unit's construction was facilitated knowing the errors and difficulties that were found with the first. The construction was completed in less than 3 h, substantially shorter than the time to complete the first. A modification to the KFM, the Lombardi dose rate meter, was also completed by the fourth year student with little difficulty, within 2 h.

Preparation of desiccant

The first step in the construction of the KFM was the preparation of the desiccant. This is placed at the bottom of the unit once construction is complete. It should be emphasized here that the drying agent has a major role in the proper function of the KFM unit—for a relative humidity greater than 70% the device is all but useless. This is due to uncontrollable charge dissipation caused by the moisture in the air. Two different drying agents were used. The suggested drying agent was used in the first unit, made from sheetrock or gypsum wallboard. Calcium sulfate ($CaSO_4$), a common drying agent found in chemical supply stores, was tested in the second unit.

The calcium sulfate was stored in a jar and was ready for immediate use. However, the suggested desiccant, sheetrock, was prepared according to the construction directions. The pieces used needed to be cut into approximately 2.5-cm (1-inch) cubes. These cubes were then heated in an oven at 204 °C (400 °F) for 1 h to remove any previously accumulated moisture. The time to complete this process required over 2 h and is best completed prior to the threat of any nuclear event.

Construction of the KFM ionization chamber

The ionization chamber can be made using a soup, soda, or a standard 267 mL (8 ounce) can. The specified dimensions for the chamber have a height of 73.025 mm (2 ⅞ inches) and diameter of 65.0875 mm (2 9⁄16 inches). For the two units being tested, soda cans were used and cut to within ±2 mm of the specified height. The diameter of the cans was 63 ± 1 mm. The process of cutting the can was best accomplished with scissors rather then the suggested process of puncturing the can with a pocket knife. A precaution must be made in handling sharp edges of the can to avoid injury. The cut edge can be dulled using sand paper or a file.

Next, two separate 8-ply leaves were created from a 15.24 × 15.24 cm^2 (6 × 6 in^2) sheet of standard aluminum foil. These were then suspended by dry, clean insulating threads inside of the ionization chamber. Two types of insulting thread were used: a polyester sewing thread and non-waxed dental floss. The remaining instructions allowed no substitution in materials and were followed as written. The completed KFM units are shown in Fig. 2.

Construction of the Lombardi dose rate meter

The modifications to the KFM unit to produce the Lombardi dose rate meter were relatively simple. The major adaptation was the use of 1-ply aluminum foil leaves in place of the 8-ply leaves on the KFM. Next, the drying agent is removed from the system. Finally, the bottom of the ionization chamber was cut off in order to place low-level sources in close proximity to the suspended leaves.

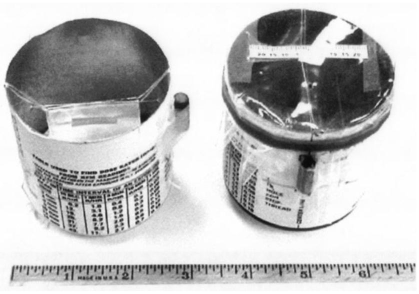

Figure 2. Completed KFM units. (left) Construction of the first unit, completed by first year engineering undergraduate, took over 5 h to complete. (right) The second unit, completed by a fourth year engineering undergraduate, required nearly 3 h using the experience and knowledge of the first.

Charging and testing

After the construction was completed, two methods for charging the units were suggested. The first method used a hard plastic ruler rubbed on dry paper, and the second involved the unrolling of a roll of clear adhesive tape. The user then places the stored electrostatic charge near the insulated charging wire, which extends from just above the suspended leaves to outside of the plastic cover on the can. An additional method was used that involved rubbing a balloon on short hair or wool and then placing the balloon near the insulated charging wire to transfer the charge.

Using measurements of the KFM unit requires a watch with a second hand, a flashlight (for optimal reading or night measurements), a pencil, and paper or notebook. To explore the use of the KFM and Lombardi units, tests were conducted on the stability of each unit to maintain an electrostatic charge. This was accomplished by charging the unit and letting it remain undisturbed for an hour or more in a normal background.

Several tests were also completed to investigate the reliability of the KFM using a ^{137}Cs irradiator. These results were compared to the expected dose rates, given by Table 1, to determine if the two KFM units constructed here abided by this table or if individual calibrations are required for these devices.

RESULTS

Charging difficulties

The charging of the KFM was found to be a tedious and barely effective process. The tape-rolling method charged the device very inefficiently. It took several trials to separate the leaves approximately 5 mm. This separation was unacceptable for testing, and the method was abandoned since it was unable to demonstrate any appreciable charge-generating abilities. The paper rubbing method was useful in generating some charge, but more than ten consecutive charges were needed before the aluminum foil leaves were sufficiently separated. The most effective method of generating charge came from rubbing a balloon on short hair or clothing, but this still required many consecutive attempts. The largest charge separation obtained was 12 ± 1 mm in a relative humidity lower than 30%. Typically, the separation was measured as 10 ± 1 mm.

During several of these tests, the relative humidity in the environment was typically 50% or higher. All of the charging methods failed to produce any electrostatic charge on the KFM, particularly when the humidity was 70% or higher. Thus, the use of the KFM in a humid environment is a large problem and has remained unresolved. As a result, the testing of the units was severally limited.

Test results

The first testing of the KFM and Lombardi Meter included sensitivity in a natural background. The approximate exposure in air due to background was measured in the location of the tests as 1.8×10^{-9} C kg^{-1} h^{-1} (7 μR h^{-1}). The lowest measurable dose rate reading of the KFM is given as 28.5 mGy h^{-1} (0.03 R h^{-1}), and thus background would not be measurable for this instrument. This ensures that negligible charge is being lost due to background radiation and that the losses originate from mechanical or insulating problems.

The first sets of measurements were made with a relative humidity of approximately 50% and no source exposure. The instructions state the loss of separation between the leaves of the KFM should be 1 mm or less within approximately 3 h. Initially, the KFM units were not able to maintain a substantial charge separation and had lost 2 mm in less than 2 h (Fig. 3). These measurements suggest that the dose rate obtained using these units will not be accurate for longer exposure times due to charge leakage. After switching the insulating thread to the non-waxed dental floss and adding fresh drying agent, the units maintained the stipulated charge separation for nearly 2 h. Note that this entire process took well over 5 h to complete.

For the Lombardi Meter, the loss of charge within 3 h was much larger. It was extremely sensitive and had lost much of its charge within an hour (Fig. 4). Also, for the lowest radiation exposure of the irradiator available, this detector also lost its charge within seconds for an exposure of approximately 4.8 mGy h^{-1} (0.5 R h^{-1}). With this information, it is not suitable as a radiation detection meter. However, this device can be useful to introduce and demonstrate ideas and concepts of ionizing radiation to younger students.

Irradiation test results obtained in Michigan in the spring were limited due to the nearly impossible nature of charging the units in a generally humid environment. Also, tests were conducted several weeks after the preparation of the wallboard drying agent in the first unit. It was found that it had become ineffective in this time and was replaced with calcium sulfate for the irradiation testing.

After waiting several days, testing results were obtained for the KFM at a relative humidity of approximately 40% or lower. Using a ^{137}Cs irradiator at several exposure levels, the difference in leaf separation was obtained. Unfortunately, the Lombardi unit's leaves would discharge within seconds at the lowest level of the irradiation source, as mentioned previously, and was not tested here.

The instructions warn the maker not to use separation measurements that are less than 2 mm and measurements where the overall leaf separation falls below a 5 mm difference. Since the typical separation before exposure was only 10 mm, several test sets where the separation fell below 5 mm were ignored. After this the remaining test results were minimal. As shown in Table 2, two exposures tests were ob-

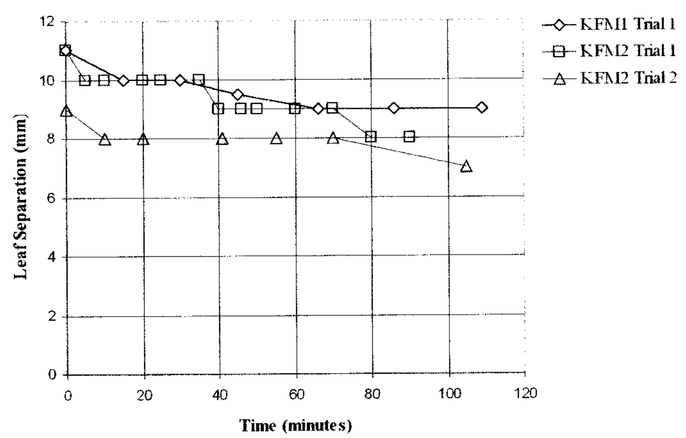

Figure 3. Tests on two KFM units without exposure and conducted at a humidity of approximately 50%. These measurements show the loss of charge due to humidity and insulating problems. According to the original publication of the KFM directions, the unit should lose no more than 1 mm over 3 h.

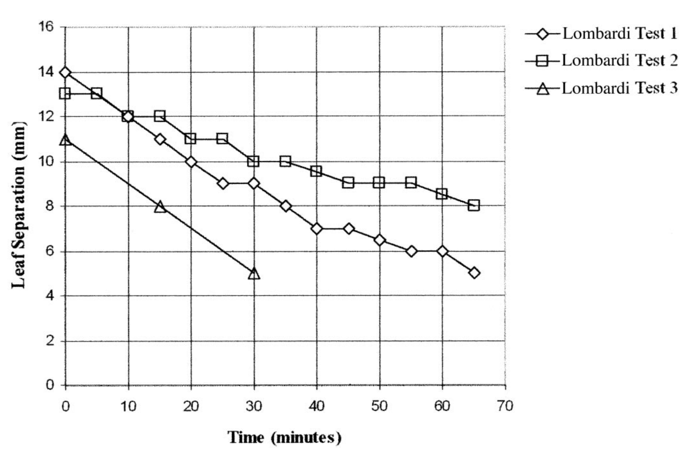

Figure 4. Tests on the Lombardi meter without exposure and conducted at a humidity of approximately 50%. These measurements indicate the meter is much more sensitive to a loss of charge due to humidity and insulating problems than the KFM.

Table 2. Irradiation test results on the two KFM units using a ^{137}Cs source with a relative humidity of less than 40%.

KFM unit tested	Leaf separation difference (mm)	Exposure time	Actual dose rate from irradiator [mGy h^{-1} (R h^{-1})]	Expected dose rate from Table 1 [mGy h^{-1} (R h^{-1})]	Percent difference
1	5±1	1 h	0.76 [0.08]	0.67 [0.07]	12%
2	4±1	60 s	38 [4.0]	29 [3.1]	23%

tained and reflect the limited results. Here the accuracy is within the stated ±25%; however, these results were obtained after several failed attempts over many days. The difficulties in the use of the KFM due to humidity, inability to charge, and not obtaining large enough leaf separation attributed to the failed testing attempts.

DISCUSSION

Critique of the KFM construction

Upon completing the construction of the KFM and Lombardi version, the major topics that demonstrated possible sources of confusion in the directions were considered. Possible revisions and additional comments for improvement are explained here. First, the importance of reading the instruction sections aloud before beginning construction was crucial and was made very clear in the directions. The initial recitation can prepare the participants for the visualization of the components to be made. However, along with reading the instructions aloud, it is suggested that the individual also draw the construction process on paper. This precaution would eliminate visualization difficulties. Also, more accurate representations of the drawings could be made to accompany the instructions.

Next, the major sections of the written instructions and diagrams are often long, redundant, and perhaps give too much detail to the maker. While the diagram shown in Fig. 5 is detailed and descriptive, it may give the maker too much information at one time and result in confusion. It would be advantageous to include a step-by-step pictorial reference guide of the construction process. For example, the instructions can display the progress of the individual components throughout the process in sequential pictures. For the sake of the KFM, the construction would be drastically simplified if these diagrams were presented.

During further construction, it is noted that some components must not to be touched by human fingers, as this would interfere with the electrical properties of the KFM. In the construction of the aluminum foil leaves and the installation of the insulating threads, for instance, it would be valuable to separate components into clean and not-clean categories. The removal of the charge from the sewing suspension threads were most likely due to touching of this component. Some of the warnings about this phenomenon came too late, after the instructions for the assembly of these parts were required. The separation of components into two categories would reduce the risk of unit contamination and would expedite the construction process.

Substitution of various materials

The material of utmost importance within the unit is the drying agent. If this component does not keep the air inside the enclosure very dry, measurements will have large errors and the unit will be nearly impossible to charge. The recommended drying agent, wallboard, was only effective for a small number of weeks. After this, the unit became difficult to charge and the drying agent was found all but useless. A more effective drying agent was the calcium sulfate, though this material may not be commonly found in a household. If the wallboard is the only material available, the instructions should emphasize the need for making several batches and storing these in an air tight jar for future use.

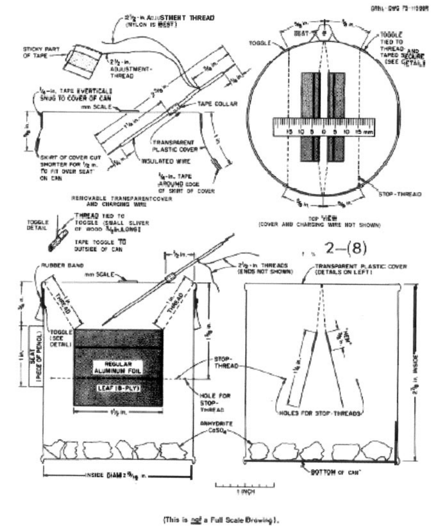

Figure 5. Detailed cross sections of the ionization chamber of KFM to be used during the construction process (Kearny et al. 1978).

The insulating thread used to hang the aluminum foil leaves was also found to have caused a major loss of charge. The polyester sewing thread was replaced with the non-waxed dental floss in the second unit after several attempts failed to generate charge. This helped to fix the charging problem.

General difficulties

Along with the major sources of confusion already discussed, several smaller details in the construction and use of the KFM resulted in major obstacles. The effects of these problems are considered for the KFM and their impact on the accuracy and sensitivity of the unit. These are listed in Table 3

Table 3. General problems and solutions with the use of the KFM that should be emphasized to the maker.

Problem	Solution
Exact measurements of the leaf separation are difficult to read	As suggested in the directions, a flashlight increases the visibility of the lower edges of the leaves. Also, coloring the lower edge of the aluminum foil leafs with a marker facilitated the measurements.
Disturbing the unit while taking measurements causes major errors in the dose rate estimate	Extreme care must be taken to not disturb the device at all; if the unit is dropped or even bumped slightly, the leaves swing wildly and discharge fully or partially. To negate this, a holding device should be included in the directions that the unit can be set into to help make it less touchy.
It is difficult to obtain a leaf separation of more than 10 mm	Rounding the edges of the aluminum foil leaves helps guard against discharge and allows the leaves to separate more.
KFM does not charge near some materials	Placing the unit near metal objects may cause the charge to dissipate. To correct for this, set the unit on a cardboard or other insulating surface and remove other possible sources of charge loss.
Measurements less than 5 mm should not be used	This statement should be emphasized to the maker since the units tested here only separated a maximum of 12 mm. This severely restricted the possible dose rates that are measurable according to Table 1 and causes the choice of exposure time to become very important. This statement only appears once in the directions.
Sheetrock is not an effective drying agent	A much more effective and longer lived drying agent is calcium sulfate ($CaSO_4$). If the suggested material, wallboard, is the only drying agent available, be sure to make numerous batches and store in an air tight jar for future use.

with possible solutions. These items are seldom, if at all, mentioned in the instructions and should be given a greater emphasis to the maker since they can seriously hinder the resulting measurements.

CONCLUSION

The KFM was stated to be understandable, easily repairable, and as accurate as most civil defense fallout meters. However, the assembly instructions are at times hard to understand and often redundant. To avoid this, the addition of several sequential diagrams of the construction process is suggested. The units are easily repairable and limited test results suggest the accuracy is within ±25%.

However, the inability to charge the KFM unit in a humid environment was extremely troublesome. On several attempts, both units constructed failed to appreciate enough electrostatic charge to separate the foil leaves using the optimal materials. Obtaining a substantial charge separation was difficult in a relative humidity of 50% and was impossible in a relative humidity of 70% or greater. This factor was never solved completely and was a hindering factor in irradiation testing. It remains a major obstacle in the usefulness of the KFM unit.

The Lombardi dose rate meter, a modified version of the KFM, has a very similar construction process. The major differences include using 1-ply aluminum foil leaves, removing the drying agent, and cutting the bottom of the ionization chamber off. These alterations increase the sensitivity of the unit drastically, thus disabling accurate and reliable measurements of radiation dose rates. However, for educational practices and demonstrations, this unit is ideal. With the proper preparation, the introduction of radiation interactions and detection concepts can be coupled with the construction of the Lombardi dose rate meter.

Under current circumstances, the use of the KFM as a radiation dose rate meter is possible, however not recommended. The original plans for its use in a total nuclear war intended that the whole nation would be enveloped in a crisis. However, the incapacitation of a large area of the nation is unlikely. Communication with the area, with the arrival of radiation detector-equipped first responders, is likely to be established long before the KFM can prove its usefulness. If the KFM was suggested for use by the average American family, it can possibly cause more alarm and concern by generating unforeseen errors in construction and an inability to charge in a humid environment.

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