Development of a Characterized Radiation Field for Evaluating Sensor Performance - 8427

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ABSTRACT

Numerous efforts are funded by US agencies (DOE, DoD, DHS) for development of novel radiation sensing and measurement systems. An effort has been undertaken to develop a flexible shielding system compatible with a variety of sources (beta, X-ray, gamma, and neutron) that can be highly characterized using conventional radiation detection and measurement systems. Sources available for use in this system include americium-beryllium (AmBe), plutonium-beryllium (PuBe), strontimum-90 (Sr-90), californium-252 (Cf-252), krypton-85 (Kr-85), americium-241 (Am-241), and depleted uranium (DU). Shielding can be varied by utilization of materials that include lexan, water, oil, lead, and polyethylene. Arrangements and geometries of source(s) and shielding can produce symmetrical or asymmetrical radiation fields. The system has been developed to facilitate accurately repeatable configurations. Measurement positions are similarly capable of being accurately re-created. Stand-off measurement positions can be accurately re-established using differential global positioning system (GPS) navigation. Instruments used to characterize individual measurement locations include a variety of sodium iodide (NaI(Tl)) (3x3 inch, 4x4x16 inch, Fidler) and lithium iodide (LiI(Eu)) detectors (for use with multichannel analyzer software) and detectors for use with traditional hand held survey meters such as boron trifluoride (BF_3), helium-3 (^3He), and Geiger-Müller (GM) tubes. Also available are Global Dosimetry thermoluminescent dosimeters (TLDs), CR39 neutron chips, and film badges. Data will be presented comparing measurement techniques with shielding/source configurations. The system is demonstrated to provide a highly functional process for comparison/characterization of various detector types relative to controllable radiation types and levels. Particular attention has been paid to use of neutron sources and measurements.

INTRODUCTION

Numerous efforts by various research groups and companies have been undertaken over the past decade to develop innovative radiation detection devices, particularly for neutrons. Additionally, the availability of larger (75x75 mm) lanthanum bromide ($LaBr_3$) scintillation detectors for X- and gamma radiation represents a significant advance in the ability to detect and identify radionuclides using highly portable hand-held systems. Unfortunately, a standardized platform and suite of procedures have not been established to characterize performance of these innovative devices relative to traditional benchmarks.

The Institute for Clean Energy Technology (ICET) is part of a group of university researchers engaged in radiation detection and measurement investigations. As a part of that collaborative effort, a system for establishing a flexible and easily characterized radiation field has been developed. The purpose of the work discussed in this paper is to provide a test bed that can be used to test novel instruments in characterized radiation fields.

Figures 1A through 1D provide a general sense of the constituents employed in this flexible radiation field system. The base platform (Figure 1A) has been fabricated using 1.25 cm (1/2 inch) steel plate welded to 10 x 10 cm (4 x 4 inch) steel tubing. The center of the platform (referred to as the origin) has been drilled and tapped to accept up to four sources on individual pedestals. Series of holes have been drilled and tapped radiating from the origin on 15 degree increments. These allow positioning pointers or positioning rods that facilitate collection of measurements at highly repeatable positions. The platform can accept four eye bolts on each side (top and bottom) that can be used with slings to suspend the system from a crane.

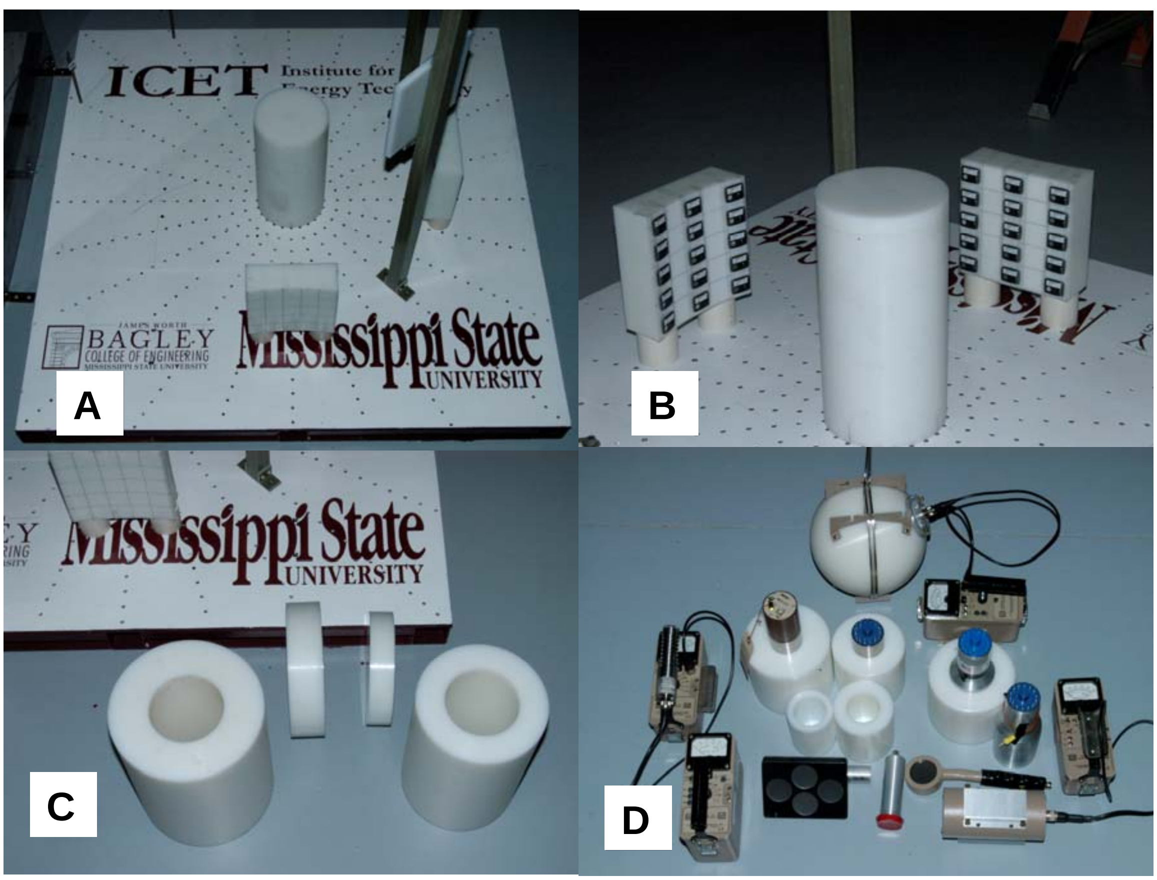

Figure 1. Pictures of elements of the radiation field system and measurement devices utilized in this study.

While the radiological specie and activity level of sources used with this system can be selected to meet the needs of testing, this paper will report on the use of two: Cs-137, and AmBe (Amercium-241 and Beryllium). A variety of shielding and moderating materials can be used to modify the radiation field. Figure 1B shows an arrangement of neutron source and cylindrical moderator with two arrays of TLD badges positioned 0.5 m from the source. It can be noted that the TLD array on the right is affixed to a high density polyethylene (HDPE) matrix that is planar and perpendicular to radiation impinging on the center badge. The left-hand array is affixed to a support with a concave cylindrical surface, radius of curvature of 0.5 m. The array is positioned so that the center TLD badge is perpendicular to the radial vector from the source. The system is capable of utilizing moderators with thicknesses varying from 42 mm to 92 mm, as can be seen in Figure 1C. Additional moderating materials can easily be added in the form of water, oil, or wax. Stainless steel or lead shielding can be used for more energetic gamma photons.

The shielding arrangement shown in Figure 1B will provide a relatively symmetrical radiation field. Combinations of shielding and moderators can also be used to produce highly asymmetrical fields. The system can be used with or without shielding or moderating materials in order to establish a field shape and intensity appropriate for evaluating detector responses.

Some measurement systems under development are intended to function from a significant stand-off distance. The system platform shown in Figure 1A is very functional for accurately positioning the volume element being evaluated for radial distances from the source of less than two meters. However, in order to facilitate repeatability of measurement configurations for techniques where the sensor is physically removed by a significant distance from the volume element being interrogated, it is essential to be able to accurately reposition the location of detector, source, and volume element being measured. This is accomplished using differential GPS equipment.

The principal driving force for developing this system is to provide a flexible and highly characterized radiation field that can serve as test bed for evaluating performance capabilities of novel detectors. This has been accomplished by a combination of infrastructure such as the hardware discussed above and by the use of an array of traditional radiation measurement devices.

Figure 1D shows a collection of standard handheld meters used by health physics professionals for surveys. This includes: He-3 and BF_3 detectors for neutrons, Geiger-Müller tubes for beta and gamma radiation, and sodium iodide detectors for gamma measurements. Figure 1D also displays a variety of scintillation detectors used in this study. These include three sizes/types of NaI(Tl) detectors: a 76x76 mm (3 x 3 inch) detector, a 102x102x406 mm (4 x 4 x 16 inch) detector, and a Fidler (Field Instrument for the Detection of Low Energy Radiation)(thin film) detector. Each of these units is used with an Ortec Digibase and Ortec Scintivision multichanel analyzer software for data collection. Additionally, a Scionix 25 mm lithium iodide (LiI(Eu)) crystal detector has been used for neutron measurements. Also seen in Figure 1D are high density polyethylene (HDPE) moderators that can be placed around the detectors.

Figure 1B displays how detectors or arrays are positioned to collect data. For measurements made 0.5 meter from the source, detectors are positioned so that the midline of the detection device is at the proper height and the face of the detector is 0.5 m from the center of the source. Adjustments are made in detector or array height using a laboratory scissor jack or other suitable elevating devices. For this paper, data were taken at 23 cm above the test platform (in the same horizontal plane as the source) and at 100 cm above the test platform. For handheld analog survey instruments, reading is allowed to stabilize for approximately one minute before being recorded.

Table 1 contains basic information about hand held survey meters and other detectors and dosimeters discussed in this study. Energy range of detectors and sensitivity information are given when provided by the manufacturer.

Table 1. Standard measurement devices used in this study to characterize radiation fields.

Detector	Type	Range (keV)	Sensitivity
Alpha Spectra 3x3 NaI(Tl) Type 12I12/3	3x3 NaI(Tl) crystal mounted on a 3"PMT for measuring gamma radiation	15-5000	Not reported
Alpha Spectra Fidler Detector Type 20DTO63QB2/5	Gamma	10-100	Not reported
Scionix Holland LiI(Eu) 25B3/2M-Li-X	Gamma/Neutron	0.000025-4780	Not reported
Ludlum Model 12-4 Neutron Counter	^{3}He detector inside 22.9" dia. Cd loaded polyethylene sphere	0.000025 - 10000	Approximately 120 cpm/mrem/hr (AmBe neutrons)
Ludlum Model 15 Survey Meter	^{3}He proportional detector with 3"dia. Cd lined moderator for fast neutrons	0.000025 - 12000	Typically 60 cpm/mrem/hr (AmBe fast neutrons)
Ludlum Model 19 MicroR Meter	1"x1" sodium iodide (NaI)(Tl) scintillator for low level gamma survey	Not reported	Typically 175 cpm/microR/hr (^{137}Cs gamma)
Ludlum Model 44-6 Sidewall G-M Detector	30 mg/cm^{3} stainless steel wall halogen quenched G-M with rotary β window	Not reported	Typically 1200 cpm/mR/hr (^{137}Cs gamma)
Ludlum Model 44-7 End Window G-M Detector	End window (mica) halogen quenched G-M	Not reported	Typically 1200 cpm/mR/hr (^{137}Cs gamma)
Ludlum Model 44-9 Pancake G-M Detector	Pancake type halogen quenched G-M with mica window	Not reported	Typically 3300 cpm/mR/hr (^{137}Cs gamma)
Ludlum Model 44-94 Diamond Cluster Pancake G-M	4 each pancake type halogen quenched G-M with mica windows for alpha beta gamma survey	Not reported	Typically 12,000 cpm/mR/hr (^{137}Cs gamma)
Film Badge	Film dosimeter with five filter areas: Open window, Al, Cu, Pb/Sn, and Plastic for beta, X, and gamma monitoring	Photon 5 keV-3 MeV Beta (MAX) 1.71 MeV-5 Mev	LLD = 4 mrem (0.04 mSv)
TLD 760 with CR39	Beta, X, Gamma, Neutron	Beta (MAX) 0.766 MeV – 5 MeV Photon 5 keV-6MeV Neutron Thermal-6MeV (up to 20 MeV with CR39	LLD = 6 mrem (0.06 mSv)
CR39 Neutron chip	Fast neutron radiation	Neutron: 150 keV-10 MeV	LLD = 6 mrem (0.06 mSv)

ICET hopes to make the test bed discussed in this study available to other research groups wishing to test radiation detection instruments in a highly characterized radiation field. Any research groups or companies making use of ICET's radiation field test bed will be required to follow standard operating procedures for handling of sources in order to minimize exposure and ensure the security of the sources while testing is conducted. Proof of training records, as well as exposure history may be required before utilizing the facility, and persons may be required to go through a background security check prior to being allowed access. Limitations may be placed on time of use, and a test plan will be required in order to ensure testing is well thought out prior to utilizing sources. Film badges are required to be worn in testing area, and a film badge with neutron chip will be required of all persons making use of AmBe and Cf-252 sources. Other personal dosimeters may be required.

The test bed is currently set up to allow the placement of detectors on one side of a 0.5 inch Lexan shield while having the meter available for reading on the shielded side. A laboratory scissor jack allows for rapid height adjustment for various detectors in order to minimize time near the source. Testing procedures must ensure that exposures are kept as low as reasonably achievable (ALARA) and will be reviewed by the MSU Radiation Safety Officer. Additional training or other requirements may be mandated by MSU's Regulatory Compliance Office and may vary due to nature of testing.

A variety of radioactive sources is available and can be used with this system. These include: americium-beryllium (AmBe), plutonium-beryllium (PuBe), strontimum-90 (Sr-90), californium-252 (Cf-252), krypton-85 (Kr-85), americium-241 (Am-241), and depleted uranium (DU). Table 2 contains a listing of the sources available for use with this system, along with pertinent data about each.

Table 2. Sample of radioactive sources available for data collection activities.

Source	**Half Life**	**Activity**	**Emission of interest**	**Energy (keV)**
AmBe	^{241}Am 432.2 y	1 Ci	Gamma	26.3, 33.2, 59.5
			Neutron	4,160 (average energy)
Cs-137	30.2 y	20 mCi	x-ray	Barium k x-ray 661.62
Cf-252	2.65 y	100 mCi	x-ray	Cm L x-ray 42.8 and other x-rays of low energy
			Neutron	2,130 (average energy)

EXPERIMENTAL

A series of measurements has been made to characterize the radiation field for the AmBe and Cs-137 sources described in Table 2 and to serve as benchmarks against which to compare measurements made using novel detection devices. Data were collected for these two sources with detector distances from the source of 0.5 and one meter. Measurements at the 0.5 meter radial distance were made with detector heights of 23 and 100 cm above the platform.

Table 3 contains data collected at a detector-to-source distance of 0.5 meter and for detector heights of 23 and 100 cm. Data contained in Table 3 are for scalar measurements that were made for devices including the full range of survey meters included in the study. Data provided for the Ludlum 3 meter equipped with a 44-6 sidewall G-M detector reflect the capabilities of this detector to make measurements with a window open or closed. Measurements made with the devices listed in Table 3 are provided in units that are common for the type detectors used and range from counts/minute to mrem/hour. Also provided in Table 3 are data for measurements made with and without a high density polyethylene (HDPE) moderator (42 mm) in place.

Table 3. Table of data collected with survey instruments and for an AmBe source with: (1) only a symmetrical stainless steel shield and with (2) both a symmetrical stainless steel shield and 42 mm high-density polyethylene moderator.

Method	**Source+Steel**		**Source+Steel+ 4.2 HDPE Moderator**	
	23cm	100cm	23cm	100cm
Ludlum 3 w/ 44-94 Square Cluster Pancake G-M Detector	11 kcpm	2.4 kcpm	11 kcpm	2.5 kcpm
Ludlum 3 w/ 44-7 End Window G-M Detector	1.0 kcpm	0.3 kcpm	1.3 kcpm	0.3 kcpm
Ludlum 3 w/ 44-6 Sidewall G-M Detector	0.7 kcpm closed 1.0 kcpm open	0.2 kcpm closed 0.3 kcpm open	0.8 kcpm closed 0.9 kcpm open	0.2 kcpm closed 0.2 kcpm open
Ludlum 3 w/ 44-9 Pancake G-M Detector	2.0 kcpm	0.5 kcpm	3.0 kcpm	0.6 kcpm
Ludlum 12-4 Neutron Counter	10 mrem/hr	2.8 mrem/hr	8 mrem/hr	2 mrem/hr
Ludlum15 Survey Meter w/ He-3 Proportional Detector	420 cpm	160 cpm	600 cpm	140 cpm
Ludlum 19 MicroR Meter	440 μR/hr	120 μR/hr	850 μR/hr	180 μR/hr

Measurements were also made for the AmBe source using multichanel analyzer compatible NaI(Tl) and LiI(Eu) scintillation detectors. These data were collected using Ortec DigiBases and Ortec Scintivision software. Data from these measurements are provided in Table 4 and in Figures 2 and 3. Table 4 contains total counts for 60-sec measurements for each of the detectors included in the study. Since each of these detectors has an asymmetrical geometry, measurements were made with the detector crystal and photomultiplier tube positioned in both the horizontal and vertical direction.

In each case the center of mass of the detector crystal was positioned at the appropriate height (either 23 or 100 cm).

LiI(Eu) detectors are commonly employed for making neutron and gamma measurements. Data were collected with LiI(Eu) detectors with 0, 1.3, 2.6, 3.8, and 5.1 cm of HDPE moderator around the detector (see Figure 2B). The 3 x 3 NaI(Tl) detector was used without additional moderating material around it.

Table 4. Data collected using scintillation detectors and multichanel analyzer software for an AmBe source with: (1) only a symmetrical stainless steel shield and with (2) both a symmetrical stainless steel shield and 42 mm high-density polyethylene moderator.

	AmBe + Steel				**AmBe + Steel + 42 mm Mod**			
	23 cm		**100cm**		**23 cm**		**100 cm**	
Detector-Moderator	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**
LiI(Eu)- 0	48,227	13,192	12,255	3,261	69,983	21,429	41,706	3,715
LiI(Eu)- 1.3 cm	43,738	14,650	10,953	3,949	60,685	26,657	14,807	4,166
LiI(Eu)- 2.6 cm	41,684	15,318	9,446	4,320	58,769	28,684	13,859	4,519
LiI(Eu)- 3.8 cm	39,457	15,791	8,282	4,563	56,469	31,287	12,108	5,136
LiI(Eu)- 5.1 cm	37,406	17,973	7,522	4,579	54,044	31,029	11,120	5,421
3x3 NaI(Tl) – 0	856,985	937,601	290,174	269,033	2,394,875	2,360,468	939,455	955,271
Fidler	1,025,976	196,939	244,988	65,528	1,218,230	342,560	603,159	945,192

Spectral data collected for the AmBe source experiments with the LiI(Eu) detectors are represented in Figures 2 and 3. Figure 2 displays spectra collected without moderator around the AmBe source and Figure 3 displays spectra collected with the 42 mm HDPE moderator in place. In each figure, the upper left spectrum was collected without an additional moderator around the scintillator crystal. The upper right spectrum was collected using a 1.3 cm moderator on the detector, the lower left spectrum with a 2.6 cm moderator on the detector, and the lower right, a 5.1 cm thick moderator on the detector.

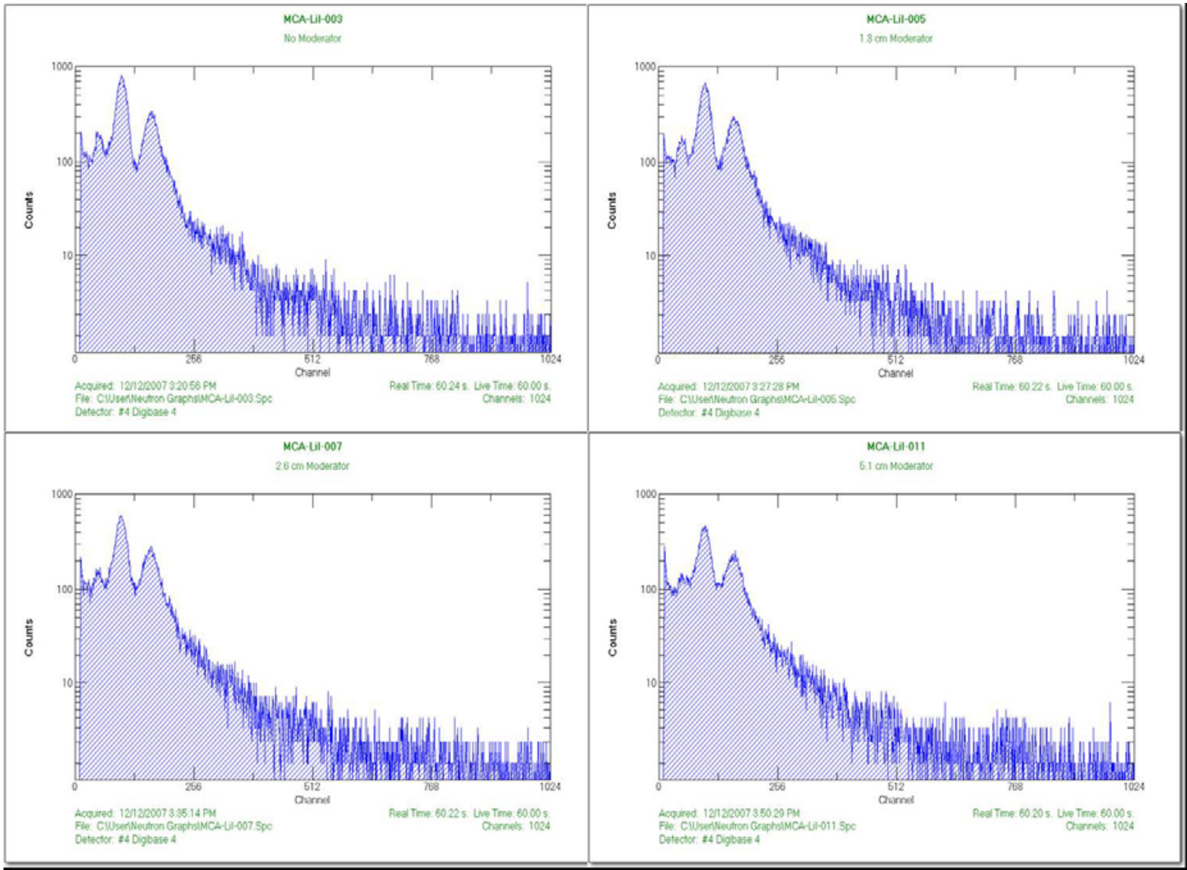

Figure 2. Spectra of measurements made with a LiI(Eu) detector for the AmBe source with only the symmetrical stainless shield in place. A high-density polyethylene moderator was not used with the source. Upper left spectrum has no detector moderator, upper right spectrum has a 1.3 cm moderator on the detector, lower left spectrum has a 2.6 cm moderator, and the lower right spectrum has a 5.1 cm moderator.

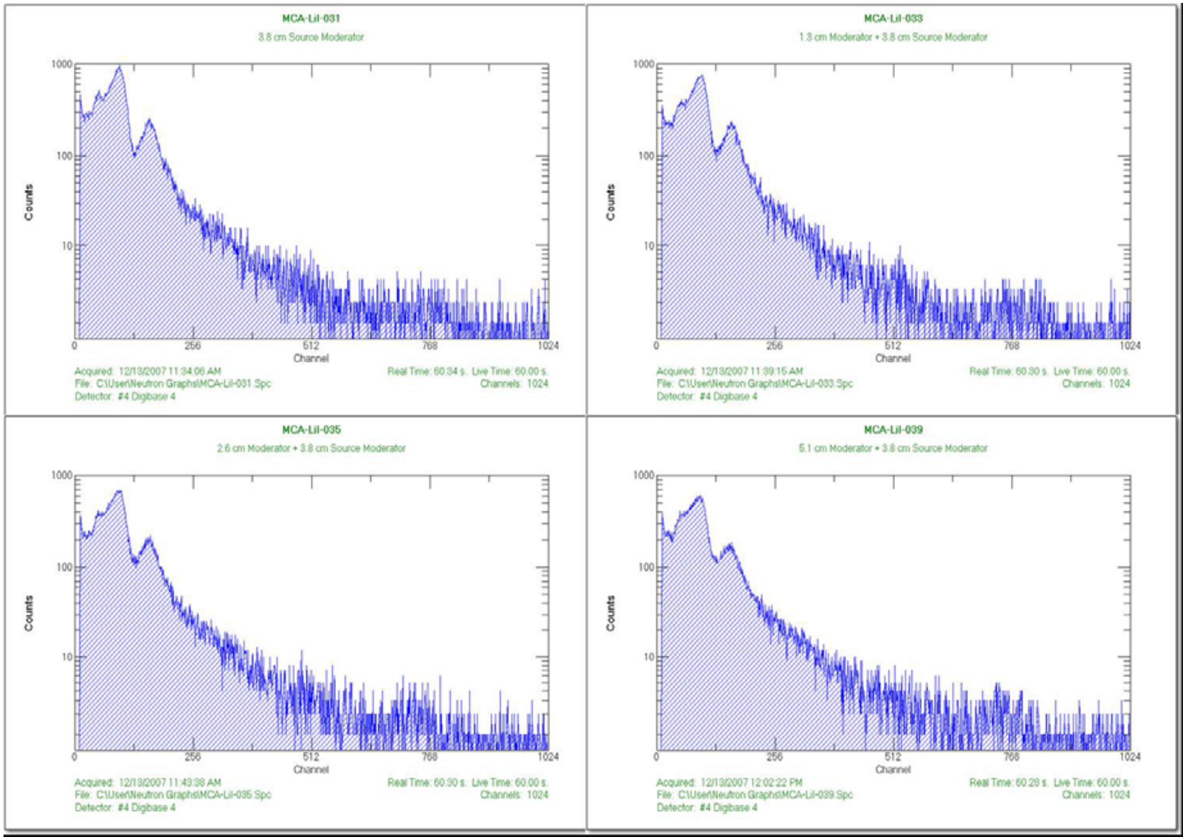

Figure 3. Spectra of measurements made with a LiI(Eu) detector for the AmBe source with both the symmetrical stainless shield and a 4.2 cm high-density polyethylene moderator in place. Upper left spectrum has no detector moderator, upper right spectrum has a 1.3 cm moderator on the detector, lower left spectrum has a 2.6 cm moderator, and the lower right spectrum has a 5.1 cm moderator.

Figure 1B shows two arrays of TLD badges positioned at 0.5 meter from the AmBe source. The support units upon which the badges are affixed are made of high density polyethylene (HDPE) with the dimensions of 28.5 x 28.5 x 10 cm. The face of each support unit has been divided into a 5 x 5 array of cells each measuring 57 x 57 mm. Supports have been constructed with planar and curved surfaces. The curved surface supports were constructed with concave cylindrical surfaces having a radius of curvature of 0.5 and 1.0 m. Additional supports have been fabricated with spherically concave surfaces having a radius of curvature of 0.5 and 1.0 m.

Data were collected with TLD badges positioned in the first, third, and fifth columns of the 5 x 5 array, as can be seen in Figure 1B. All badges were exposed simultaneously for a 36 h period. Tables 5 and 6 contain data collected using TLD badges that were positioned 0.5 m from the source with the center TLD badge of the 5 x 5 array positioned in the horizontal plane containing the AmBe source. Table 5 displays results from exposure of the TLD badges positioned on the planar support, and Table 6 displays data collected on the curved cylindrical surface.

The AmBe source used in this experiment had a total activity of 1Ci with gamma energies of 26.3, 33.2, and 59.5 keV. Neutron energies range from 477 to over 14,000 keV.

Data reported for each TLD badge in Tables 5 and 6 consist of two values. The first number represents deep, eye, and shallow doses, while the second value represents the neutron dose. As shown in Figure 1B, Tables 5 and 6 display values for cell locations in a 5x5 array. The difference in the first and second values represents the photon dose. It is clear from the small difference in values represented in the cells of Table 5 (all values provided in mrem) that the gamma ray energies of the AmBe source photons are not high enough for the photons to penetrate the steel shielding and 42 mm HDPE moderator in great enough numbers to represent a large dose for the TLD badges. The National Voluntary Laboratory Accreditation Program (NVLAP) calls for this type measurement to have bias plus standard deviation to be less than 0.4. Additionally, Global Dosimetry states that their measurement uncertainty is less than twenty percent. While all measurements for deep, eye, and shallow doses are greater than the neutron dose component, these differences are within the range of measurement error. Therefore, it is safe to say that measurements made for this experimental configuration have a minor component of gamma radiation, and evaluation of neutron measurement devices can be made without a confounding influence of high gamma doses.

Table 5. Neutron radiation exposure for flat surface using TLD badges with CR-39 chips at 0.5 m from source. Table displays values for cell locations in a 5x5 array as shown in Figure 1B. First number in series denotes deep, eye, and shallow doses. Second number denotes neutron component of dose. Dose equivalent reported in mrem.

250 233		273 254		261 245
277 259		278 258		270 253
278 260		*		281 264
263 245		283 264		263 246
243 225		264 245		255 238

* Data missing, faulty dosimeter.

Table 6. Neutron radiation exposure for 0.5 m cylindrical curved radius surface using TLD badges with CR-39 chips at 0.5 m from source. Table displays values for cell locations in a 5x5 array as shown in Figure 1B. First number in series denotes deep, eye, and shallow doses. Second number denotes neutron component of dose. Dose equivalent reported in mrem.

257 239		277 260		276 260
284 264		275 256		285 266
277 255		300 279		311 292
288 267		286 266		284 265
290 269		274 254		279 261

The TLD badges used for data collection reported in Tables 5 and 6 were obtained from Global Dosimetry and also contained their CR-39 chips. Additional data were collected with the planar support positioned 0.5 m from the source (measured horizontally) and at a height of 77 cm above the horizontal plane containing the source. Data were collected with TLD badges occupying positions in rows one, three, and five of columns one, three, and five of the 5 x 5 array. Results of exposures of the TLD badges with the support material perpendicular to the plane of the platform are displayed in Table 7. Table 8 contains data collected using loose CR-39 neutron chips in equivalent positions to the array of TLD's. The support was tilted so that the center cell of column three would be perpendicular to the radial vector from the source.

Table 7. Neutron radiation exposure for flat surface using TLD badges with CR-39 chips. Horizontal distance: 0.5 m from source. Vertical distance: 1 meter from test bed surface. First number in series denotes deep, eye, and shallow doses. Second number denotes neutron component of dose. Dose equivalent in mrem.

*		*		*
*		*		*
39 34		34 29		31 26

* Lower than minimum reportable dose.

Table 8. Fast neutron radiation exposure for flat surface for CR-39 neutron chips. Horizontal distance 0.5 m from source. Vertical distance 1 meter from test bed surface. Grid perpendicular to the radial vector from the source. Dose equivalent in mrem.

67		69		71
51		41		46
34		39		33

Data have also been collected for a 20 mCi Cs-137 source. Table 9 contains measurement results obtained using standard handheld survey meters for this source. All measurements were made in a manner analogous to those employed with the AmBe source. Data were collected at a detector-to-source distance of 0.5 m and for detector heights of 23 and 100 cm.

Table 9. Table of scalar data data collected with survey instruments for a Cs-137 source with a symmetrical stainless steel shield.

Method	**Source+Steel**	
	23cm	**100cm**
Ludlum 3 w/ 44-7 End Window G-M Detector	14 kcpm	4 kcpm
Ludlum 3 w/ 44-6 Sidewall G-M Detector	8 mrem/hr closed 8 mrem/hr open	2.5 mrem/hr closed 2.5 mrem/hr open
Ludlum 3 w/ 44-9 Pancake G-M Detector	40 kcpm	6 kcpm
Ludlum 12-4 Neutron Counter	Background	Background
Ludlum15 Survey Meter w/ He-3 Proportional Detector	Background	Background
Ludlum 19 MicroR Meter	> 5000 μR/hr	3000 μR/hr

Tables 10 and 11 contain data taken at various positions in two different planes. The first plane (Table 10) was level with the source and the second plane (Table 11) was 77 cm above the source. The idea was to get enough data to map cross sections of the radiation field generated by the AmBe source. The results of this mapping are displayed in Figure 4.

Table 10. Data from rem ball measurements taken at various points in the plane of the source.

Measurements in Plane of Source (z=0 cm)		
Radius (cm)	**Azimuth (deg)**	**mrem/hr**
50	0	10
50	45	10
50	90	10
50	135	10
50	180	10
50	225	10
50	270	10
50	315	10
100	45	4
100	135	4
100	225	4
100	315	4

Table 11. Data from rem ball measurements taken at various points in the plane 77 cm above the source.

Measurements above Plane of Source (z=77 cm)		
Radius (cm)	**Azimuth (deg)**	**mrem/hr**
50	0	4
50	45	4
50	90	4
50	135	4
50	180	4
50	225	4
50	270	4
50	315	4
100	45	2
100	135	2
100	225	2
100	315	2

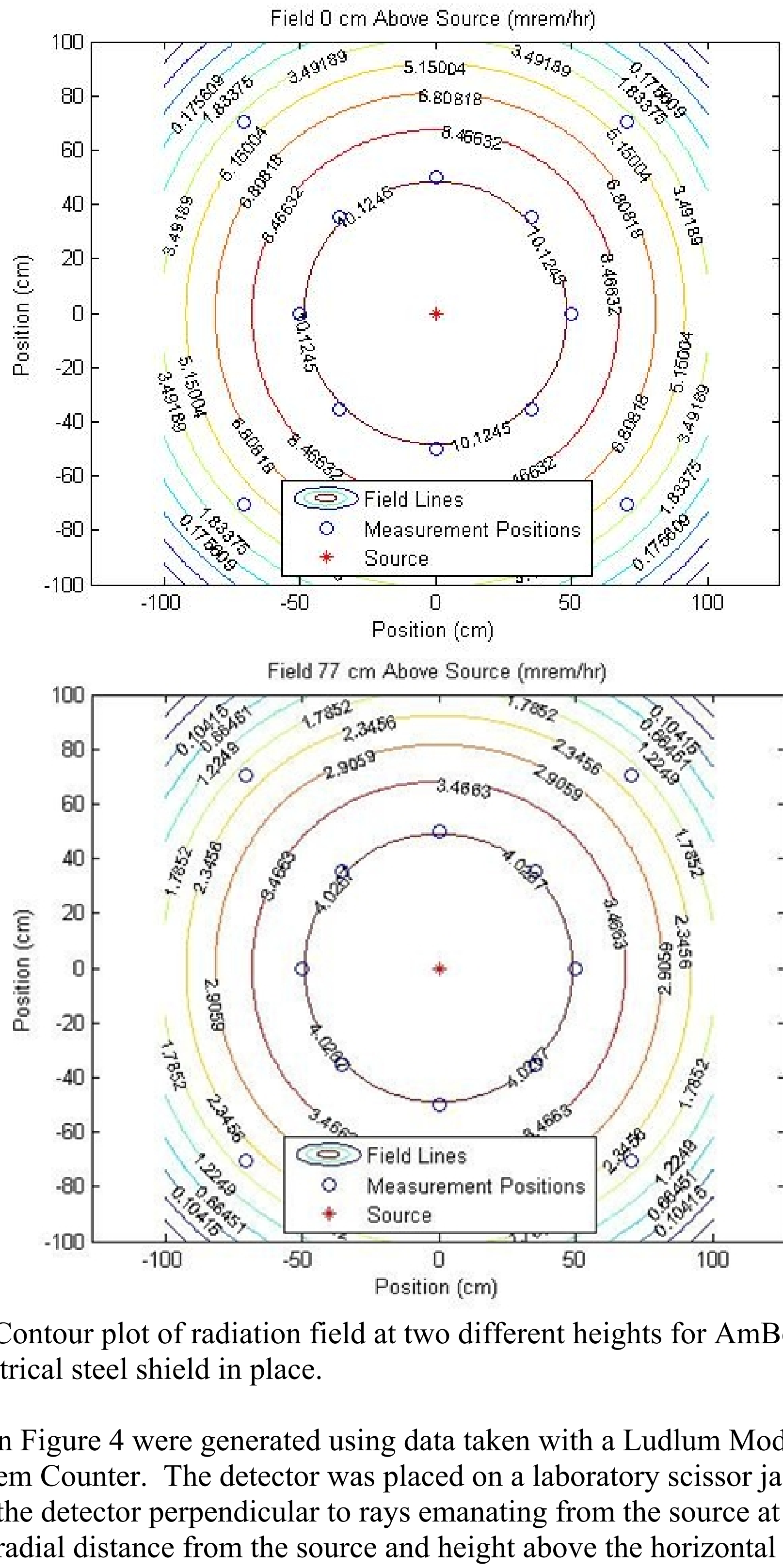

Figure 4. Contour plot of radiation field at two different heights for AmBe source with the symmetrical steel shield in place.

The plots in Figure 4 were generated using data taken with a Ludlum Model 12-4 Neutron Rem Counter. The detector was placed on a laboratory scissor jack with the surface of the detector perpendicular to rays emanating from the source at the various positions (radial distance from the source and height above the horizontal plane including the source) indicated on the plots. This process was performed for the horizontal plane containing the source (top plot) and the horizontal plane 77 cm above the source (bottom plot). The measurements were read directly from the analog display in units of mrem/hr and stored in a data file for analysis.

The file was read into a MATLAB algorithm. The contour plotting functions all required the data to be in the form of a 2-D array. Each cell in the array represented a position on a surface. The value of the cell gave the height of the surface at that point. In other words, the values in the array were the values of a surface $f(x,y)$while the indices of the array acted as the variables x and y. The array was generated by interpolating between the data points via the function *griddata*. *Griddata* took the raw data and created the contour grid Z. Along with the surface array, the contour plot required the domain and range to be in the form of arrays with identical dimensions. These arrays were generated by the function *meshgrid*. For the X array, all of the rows were identical copies of the original input x, and for the Y array all of the columns were copies of the input y. These three arrays (X, Y, and Z) were then fed into the contour function to produce the plots.

As expected, values of the contours for the horizontal plane 77 cm above the source (bottom graph) are lower than those in the top graph. One interesting feature is that the data does not seem to display an inverse square dependence. In the plane of the source, the values at the closest data points (0.5 m from the center) in the top graph are roughly 10 mrem/hr. The values at the second distance (1 m from the center) are roughly 4 mrem/hr. For an inverse square law, doubling the distance from the source should reduce the measurements by a factor of four to 2.5 mrem/hr.

The rem ball data contained in Tables 10 and 11 represent values that might be generated by routine health physics surveys. These data have been used to produce the contour plots of Figure 4. Inspection of the data contained in Tables 10 and 11 show relatively small values for the measurements, and it should be noted that a significant amount of approximation is required in recording that data due to temporal variability of the signal intensity.

CONCLUSIONS

The system reported in this paper has demonstrated capabilities for use as a reference/highly characterized radiation field for evaluating performance of novel detectors. It offers flexibility with regard to radiation flux (beta, X-ray, gamma, and neutron) by changing isotopes and activity levels of sources. Additionally, the radiation field can be further modified using shielding and moderating materials. Further, the radiation field can be established in either a very symmetrical or highly asymmetrical manner.

New or innovative detection devices can be evaluated by conducting measurements at specific points in space or by attempting to map the radiation field as an unknown entity. A full suite of traditional measurement devices are on-hand and can be employed to characterize the radiation field in manners applicable to health physicists, environmental remediation professionals, and security interests.

The system provides a mechanism for conducting highly repeatable measurements. Inclusion of differential GPS capabilities allows for expanding the ability to accurately recreate measurements with stand-off distances significantly greater than the dimensions of the test bed platform.