Semiconductor Materials and Radiological Technologies Laboratory

2012 Annual Report

Mechanical and Nuclear Engineering Department
Kansas State University
Manhattan, KS 66506
INTRODUCTION

During 2012, The Semiconductor Materials and Radiological Technologies (SMART) Laboratory faculty and students presented their radiation detector work at numerous conferences, including the SPIE Micro and Nanotechnology Sensors, Systems and Applications Conference in Baltimore, MD, the IEEE Symposium on Radiation Measurements and Applications (SORMA) in Oakland, CA, and the IEEE Nuclear Science Symposium in Anaheim, CA, where Kyle Nelson received third place for his presentation on Li-Foil neutron detectors. Dr. Ugorowski presented recent developments of the MSNDs at the NIST Center for Neutron Research. Many of the highlights from the research presented at these events can be found in this year’s report. Additionally, the SMART Laboratory received visits from several distinguished guests, including NRC Commissioner William Magwood, House Representative Tim Huelskamp, Navy Nuclear Propulsion Program Director Admiral Kirkland Donald, and Ecuadorian Educational Coordinator for International Relations Lola Allen. Please take time to peruse the 2012 report to learn more about our students, projects, capabilities and faculty.

The SMART Laboratory at Kansas State University (KSU) is a unique facility dedicated to the research and development of new and innovative radiation detector technologies. Established in 1997, it is one of the largest and most diverse university-based radiation detector development laboratories in the United States. A variety of radiation detectors are investigated and fabricated, which include compact low-power semiconductor neutron detectors, high-resolution room-temperature-operated semiconductor gamma-ray spectrometers, pixelated devices for gamma-ray or neutron imaging, large-area neutron detectors, and miniaturized gas-filled detectors. The SMART Lab is involved with all aspects of solid state detector development, including materials purification, crystal growth and characterization, detector modeling and design, detector fabrication, testing and characterization, electronics design and final packaging.

The SMART Lab spans over 6000 square feet of lab space divided into specialized research labs, including three crystal growth labs, a crystal segmenting and polishing lab, a 300 sq ft class-1000 clean room, a 1200 sq ft class-100 detector fabrication clean room, a detector testing and characterization lab, a materials characterization and analysis lab, a workshop and tool room, a machine shop, and an electronics shop.

The SMART Lab serves as a center for undergraduate and graduate student education as well as a facility to accommodate funded research projects from various government and industrial sponsors. The SMART Lab is conveniently located next to the KSU TRIGA Mark II Nuclear Reactor, thereby, allowing for straightforward testing of various radiation detectors. Detectors and systems designed in the SMART Lab have resulted in twelve allowed U.S. patents with several additional patents pending. SMART Lab researchers were presented R&D 100 Awards in 2005 and 2009 for innovative gamma-ray spectrometer and neutron detector designs. Students and faculty performing research in the SMART Laboratory have generated over 160 scientific papers over the period of its existence. Over the years, the SMART laboratory has benefited from numerous government and corporate sponsors, including DTRA, NSF, the DOE NEER Program and the DOE NNSA, amounting to over $16M in extramural research support.

Douglas S. McGregor, Ph.D.
Director, SMART Laboratory
Professor, Mechanical and Nuclear Engineering Department
Kansas State University, Manhattan, KS 66506
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Micro-Pocket Fission Detectors (MPFD), first developed in the KSU SMART Laboratory over ten years ago, are again being researched in the SMART Laboratory. The compact miniaturized fission chambers, being less than 3 mm diameter, have a large dynamic range and excellent radiation hardness. Further, the detectors can be designed to operate for extended periods of time (> 4 years) with as little as 1% count rate deviation in a reactor flux of $10^{14} \text{n cm}^{-2} \text{s}^{-1}$. The present effort is aimed at producing MPFDs for the Idaho National Laboratory (INL) Advanced Test Reactor (ATR). The new devices are even more compact than previous SMART Laboratory designs, offering a cylindrical shape that can be inserted in a tiny tube (Fig. 1B).

The present effort includes experiments to smooth the new insulating substrates with a combination of manual polishing and wet-etching, the development of unique shadow-masks for electron-beam evaporation, the development of compound contacts with improved adhesion and conductivity, and the development of new electrolytic solutions containing neutron reactive materials. Substantial improvement has been made with the new contact application methods, which have shown considerably higher adhesion and uniformity over prior methods (Fig. 2B).

Future work will focus on device optimization for a variety of reactor environments (including different neutron fluxes expected at the ATR at INL in comparison to the KSU TRIGA Mark II Nuclear Reactor). Future work will also include device testing at both the KSU and INL facilities. Collaborative efforts with INL will emphasize high temperature testing to evaluate the physical detector performance, characterization of gamma-ray insensitivity, and fast and thermal neutron response characterization.

Bismuth Tri-iodide (BiI$_3$) Investigations

During the 2012 fiscal year, crystal growth research pertaining to the purification and growth of Bismuth Tri-Iodide (BiI$_3$) was performed using physical vapor transport crystal growth techniques (or Physical Vapor Deposition (PVD)). Upon obtaining the 99.9999% Puratronic BiI$_3$, the material must undergo a purification process involving physical vapor transport of the source material, first with the material under static vacuum and later with the material under dynamic vacuum. This purification process is repeated twice to ensure the source material used during growth trials is of relatively high purity (Fig. 1A). Physical vapor transport of the source material is performed in a two-zone horizontal furnace, where one zone serves as the hot zone (temperature set slightly above the melting point) and the second zone as the cold zone (temperature set slightly below the melting point). The resulting material purification temperature gradient is approximately 20°C.

Once the material purification process is complete, the purified material is loaded into growth ampoules before placing the growth ampoules into the same two-zone horizontal furnaces used for material purification. A growth temperature gradient is established, which differs from that used during material purification, to govern the position of the deposited material within the growth ampoule. The establishment of the temperature gradient is accomplished experimentally by maintaining the hot zone temperature used during material purification and adjusting the cold zone temperature until the transported material is deposited in the desired region of the growth ampoule.

Upon completing limited growth trials, preliminary results indicate that only extremely thin (on the order of a couple hundred microns) crystals form, with larger samples having an overall hexagonal shape (Fig. 2A). Therefore, by following a similar procedure as was previously utilized when successfully growing prismatic HgI$_2$ crystals, the next necessary step required to successfully grow prismatic BiI$_3$ crystals is to add small amounts (1 - 2 weight %) of organics such as n-alkanes and ketones to inhibit the growth rate in certain directions while still maintaining the growth rate in all other directions.

Micro-Pocket Fission Detectors funded by Idaho National Laboratory

RESEARCH PROJECT HIGHLIGHTS

Nate Edwards

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SMART Laboratory researchers are working to fabricate MSND devices with 4H, 3 inch diameter silicon carbide (SiC) wafers (Fig. 1C). Electroless nickel plating was initially investigated as an etchant mask, doubling as Schottky contacts. Indium-tin-oxide (ITO) is also under evaluation to perform these functions. Etching trials using various sulfur hexafluoride (SF₆) chemistries were performed on SiC wafers patterned with 25 µm features. Etch depths greater than 30 µm were achieved (Fig 2C).

It was found that Ni can be used as a protective mask for extended ICP-RIE etches and that Ni will also form a good Schottky contact on SiC. Ni was sputtered onto photoresist patterned SiC wafers, followed by a protective Au layer. The Au layer was applied to reduce surface oxidation and degradation of the Ni contact. Shown in Fig. 1C is a high resistivity SiC wafer with Ni/Au sputter-deposited Schottky contacts that serve as self-aligned etching masks. CV measurements were conducted on the planar Schottky-diode devices located in the center of the wafers. Typical leakage currents for central-located 1 cm² planar devices were <1 nA up to approximately 70 V, above which the bias voltage can cause a short to appear across the surface of the wafer and bridge to the backside contact.

The sputtering process limits metal deposition to approximately 0.5 µm; hence, additional metal must be added to the wafer to fully protect it from the aggressive plasma etching process. An electroless metal deposition apparatus was constructed to deposit a much thicker Ni layer over the Au-coated surface of the wafer. Initial tests indicate that the Ni within the electroless plating system has some adhesion difficulties when bonding to Au.

Studies are currently being conducted to characterize and calibrate the metal deposition rate of the plating system. Once acceptably thick layers of Ni can be repeatably deposited onto the SiC wafers, plasma etch tests will be conducted to test the selectivity of the etching process (i.e., how many microns of SiC can be etched for every micron of Ni before the protective mask fails). Finally, a suitable dicing recipe, tuned for hard semiconductor substrates such as SiC, will be developed to segment the SiC wafers with the SMART Laboratory dicing machine.

Fig. 1C. SiC wafer with Schottky metal (Ni/Au) patterns for different designs and sizes of MSNDs.

Fig. 2C: Plasma etching results in SiC performed with the 25 µm etchant mask pattern. Etch depths of approximately 30 µm are shown.
The microstructured semiconductor neutron detectors (MSND) have long been investigated as a means of replacing the low-efficiency thin-film coated planar devices of the previous generation. MSNDs offer two primary benefits over their thin-film counterparts. Firstly, the microstructures allow for more of the neutron reactive material, such as $^6$LiF, to be present within the same active area as shown in Fig. 1D. This change greatly increases the odds that a neutron incident on the face of the detector will be absorbed in the neutron reactive material, emitting the charged particle reaction products necessary for detecting the neutron. The second benefit that the microstructures offer is the increased probability that the charged particle reaction products will be detected by the silicon $pn$-junction diode. These benefits, enhanced by the microstructures, allow for up to a ten-fold increase in intrinsic neutron detection efficiency. In 2012, MSNDs fabricated by the SMART laboratory achieved 26.7% intrinsic thermal neutron detection efficiency with single-sided 500$\mu$m-thick, 4cm$^2$-active area devices.

Also in 2012, work continued on developing a method for etching perforations into both sides of a silicon detector, as shown in Fig. 2D. Two versions of this design are being developed; an ultra-fast design, and an ultra-high efficiency design. In the first design, trenches are interdigitated as shown in Fig. 2D and doped to form a $pin$-junction diode, thereby, forming a device with charge collection times under 100 ns. The second design replaces dual-stacking standard devices and can theoretically offer intrinsic thermal neutron detection efficiencies $>70\%$. The MSND is a versatile device that is capable of operating by itself as a compact, low-power thermal neutron detector or, if desired, the MSND can be used to populate any number of larger or specialty devices of any configuration.

**Panel Array**

The MSNDs presently produced by the SMART Laboratory have an active area of 4 cm$^2$. The MSNDs can be arrayed together and then summed to function as a single large-area device, as shown in Fig. 3D. Elements produced in 2012 consisted of sixteen 4 cm$^2$ MSNDs, which were then tiled as shown in Fig. 3D. The total active area of the array was 576 cm$^2$. Each element contains the necessary signal processing electronics to function without the need for NIM bin equipment. Presently, there is no limit on the maximum possible active area of the panel array. The panel array developed during 2012, and presented at the IEEE Nuclear Science Symposium in Anaheim, CA, operated on $\pm 8V$ power and achieved a count rate of 0.2 cts/s per ng of $^{252}$Cf at a distance of 2 meters.
Briefcase and Handheld Portable Detectors

The panel array elements were repurposed in other devices as well. Both a briefcase and handheld portable detector were developed using the same technology as the panel array, as shown in Fig. 4D. The resulting instruments were lightweight, low-power, high-efficiency portable devices operated with rechargeable battery pack systems, onboard readout displays, and Bluetooth wireless transmission (Fig. 4D). In the case of the briefcase detector, the panel array was loaded into a sturdy case along with power and signal readout electronics. The handheld detector had elements stacked one atop another in order to form a deep, densely packed detector that had a small cross-sectional area. Both devices were designed to couple with a proprietary Android phone application via Bluetooth for wireless operation.

Fig. 4D. (left) MSNDs were arrayed as with the panel array, but were sandwiched between sheets of HDPE and encased in a durable briefcase weighing ~40 lbs. (right) The panel array elements were stacked to form a densely populated low-area handheld detector weighing under 10 lbs. Included in both systems were all necessary signal processing electronics.

Domino™ Detector

Newly developed in 2012, the Domino™ (Fig. 5D) is a highly specialized electronics package (EDL-Tim Sobering), which has been designed to operate a single MSND with a low-power input and standard TTL signal output. All signal processing and transmission electronics are contained within the small and inexpensive package, allowing for discrete neutron measurements. The Dominoes™ are also designed to tile together to form a string of detectors up to a meter in length to form a 1-D array of MSNDs.

Fig. 5D. (left and center) The Domino™ is a versatile, individually populated, MSND that houses the neutron detector and all necessary signal processing electronics. The Domino™ takes a +5V input and outputs standard +5V TTL output pulses. (far right) The Dominoes™ can be strung together to form up to 1 meter-long 1-D arrays.
The compact fast neutron energy spectrometer (Fig. 1E) is currently being developed as a lightweight, portable, handheld detector for the purpose of identifying potential special nuclear material (SMN). The spectrometer has 11 MSND devices linearly positioned within high-density polyethylene (HDPE); positioned after each MSND is a layer of cadmium. Because neutrons of interest have a distribution of energies ranging from thermal to fast, it is necessary to moderate the higher energy neutrons as they pass through the instrument to improve detection efficiency. Each successive 3cm slice of HDPE provides a portion of the necessary moderation so that neutrons reach thermal energies within the instrument and may interact with the MSND in that section. A neutron may undergo many scattering events before it is thermalized. The cadmium prevents thermalized neutrons from interacting with previous detectors. The moderator column and cadmium can be seen in Fig. 2E. Each MSND has a total active area of 4cm$^2$ and is centered vertically and horizontally within the HDPE.

The events recorded by each detector are stored in a respective detector electronic bin. During a measurement, the collected data is presented in real-time on a backlit LCD screen, thereby, allowing the user to observe the neutron count rate and the developing spectrum (Fig 4E). It is possible to either view the entire spectrum or the individual tally for each detector. At the completion of the measurement, the collected data is compared to the reference library containing common SMN response templates and a Figure-of-Merit (FOM) is calculated for each template. The reference library (Fig. 3E) was generated by modeling the spectrometer within MCNP to determine the response of each detector to a particular neutron source. The reference source with the smallest FOM value is presented as the identified source for the measurement. The user can selectively view the collected neutron spectrum, channel tally, or identified neutron source. The measurement time can also be set by the user to allow for longer collection times if the neutron flux entering the instrument is low or shorter collection times if the instrument has sufficiently high counting rates.

Positive identification of $^{252}$Cf, moderated $^{252}$Cf, and AmBe sources has been demonstrated. The overall performance of the unit can be improved by including more detectors per location, although this change would also increase the required electronics and power consumption. The entire instrument is powered by a 6V battery that is located within the main housing (Fig. 2E) and has sufficient battery life to operate continuously for over 24 hours. The overall weight of the instrument is less than 20 lbs.

Future work will focus on studying the impact of shielding materials between the neutron source and the spectrometer, and interpretation of the resultant spectrum. The minimum counting time and minimum counts per channel that are necessary for positive source identification will be determined. Also, the ability to simultaneously identify dual sources while determining the absolute contribution each source adds to the collected spectrum will be studied. The reference library will be expanded with additional simulated templates as well as experimentally gathered templates.
RESEARCH PROJECT HIGHLIGHTS
Portable Fast Neutron Energy Spectrometer
funded by the University of Missouri-Kansas City (through ONR)

In an effort led by colleague and collaborator, Prof. Tony Caruso, at the University of Missouri/Kansas City, an advanced portable neutron spectrometer has been constructed. The goal of this instrument is to enable high intrinsic neutron detection efficiency over a large spectral range (25 meV to 15 MeV) for the search and identification of bare or shielded neutron emitting sources. The identification process is made possible without unfolding by comparing the measured intensity at which neutrons reach thermal energy in a moderator in relation to a pre-computed or pre-measured library reference.

The instrument is comprised of 30 MSND arrays, each of which is made up of 108 individual 1-cm\(^2\) MSND diodes. The MSND arrays were constructed from single 5" Si(110) wafers representing the largest MSND array areas fabricated thus far by the SMART Lab, and demonstrating that there really is no limitation to the monolithic areas or shapes (hexagons in this case) that can be produced. The mask artwork and project oversight were completed by Dr. Steven Bellinger, while painstaking wire bonds (>9000) were completed in tandem by Ryan Fronk and Dr. Steven Bellinger.

The KSU electronics design lab (EDL) was responsible for the design and fabrication of the readout electronics. Special to this project was the request to place all but the preamplifiers to the outside of the moderating region to reduce the perturbation to the spectroscopic scattering process. In doing so, the electronic board sizes were 12" x 12" which helped to contribute to the 48 lb weight, including the moderator. The team is now working toward a new spectrometer that marries the best of both the compact spectrometer, an effort led by Brian Cooper, with the large hex spectrometer. Further improvements include the ability to perform crude time resolution that can be used as an additional degree of freedom to provide information proportional to the incident neutron energy.

While one intention of measuring quantities proportional to neutron energy can be applied to source identification, this class of instruments also serves as a low error means of measuring the neutron dose equivalent (an advanced portable neutron rem meter).
Many neutron detectors operate by measuring the appearance and energy of neutron reaction products, such as with the $^6\text{Li}(n,t)^4\text{He}$ reaction. The ability to measure both reaction products simultaneously affects both the detection efficiency and the gamma-ray discrimination capabilities of the detector. The gamma-ray discrimination is increased by a combined use of low Z-materials to fabricate the detector and relatively high-energy reaction products that deposit considerably more energy compared to background gamma-ray interactions. The Li Foil detector is composed of low Z materials (Li, Al, HDPE) and takes advantage of the relatively high energy $^6\text{Li}(n,t)^4\text{He}$ reaction ($Q = 4.78$ MeV). The overall detection efficiency was calculated by integrating the neutron interaction and reaction product escape probabilities and subsequently summing all cases (see Fig. 1G). The triton energy deposition is the dominating factor in pulse-height spectra, a result of the relatively long range of that reaction product in Li metal. Fortuitously, the pulse height spectrum has a salient valley between the electronic noise/background, thereby, allowing for easy discriminator selection (see Fig. 4G).

In the Li foil multi-wire proportional counter (MWPC), the ranges of the reaction products in the proportional gas at 1 atm are relatively long, being 7.25 cm and 2.5 cm for the triton and alpha particle, respectively. In order to collect all of the energy from the 2.73 MeV triton, the distance between the adjacent foils must be at least 7.25 cm. Consequently, in order to construct a five layer device, a 43.5 cm thick detector must be constructed. However, this distance is impractical and unnecessary. Higher gas pressures decrease the required distance between foils, thereby, allowing for a thinner design. The minimum amount of energy deposited in the gas volume between the slabs of Li foil must be greater than a predetermined lower level discriminator (LLD) setting, typically between 300 – 500 keV.

In construction of the Li Foil MWPC’s, the foil distance was reduced to approximately 1.6 cm. Neutron response pulse-height spectra were collected for P-10 gas (90% Ar, 10% CH₄) pressures of 1.0, 1.5, 2.0, and 2.8 atm. Overall, each prototype detector (see Figs. 2G and 3G), having only five $^6\text{Li}$ foils apiece, performed as follows:

**Li foil area:** 1250 cm²

**Li foil neutron detection efficiency:** 54%
  (theoretical Li foil efficiency: 55%)

**Gamma-ray rejection ratio:** $10^3 – 10^9$
  (required minimum gamma-ray rejection ratio: $10^6$)

**GARRn:** 1.00
  (required GARRn range: 0.9– 1.1)

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**Fig. 1G.** The calculated neutron detection efficiency as function of Li foil thickness and number of foils.

**Fig. 2G.** The moderated Li-Pack neutron detector.

**Fig. 3G.** Four Li-Pack detectors each having 54% intrinsic thermal neutron detector efficiency. Each Li-Pack has an active area of 1250 cm².

**Fig. 4G.** Neutron and gamma-ray pulse-height spectra obtained from two different neutron sources and two different gamma-ray sources. P-10 gas pressures were 1.1, 1.5, 2.0, and 2.8 atm.
RESEARCH PROJECT HIGHLIGHTS
Aerogel/Foam Detectors
funded by DTRA and ALION Science & Technology

Aerogel Detectors
Aerogel disc samples approximately 2.5 cm in diameter and thicknesses ranging from 2.0 – 6.0 mm were provided by Aerogel Technologies, LLC. Borosilicate aerogel was the first recorded sample used for neutron detection. Current practices are underway using both boron and lithium in the aerogel synthesis. Assuming these same formulas can use enriched $^6$Li and $^{10}$B, the higher neutron absorbing aerogels can absorb greater than 90 percent of incident neutrons in only 5.0 mm of material. Thus, using two slabs of 2.5 mm thick aerogel, a neutron detector with relatively high detection efficiency should be possible.

Foam Saturated Detectors
The open-celled polyurethane foam was impregnated with LiF and B$_2$O$_3$. The foam samples were cut to thicknesses of 2 – 4 mm and positioned in multi-wire proportional counters. The pulse-height spectra revealed a large wall-effect with the B$_2$O$_3$ impregnated foam, which would hinder the detection efficiency because only one reaction product was being measured per neutron absorption. The current maximum impregnation level of the LiF foam is 27.5%, but globules larger than 1.0 mm in diameter were observed, thus nano-sized LiF is currently being synthesized to reduce this problem. However, LiF impregnated foam shows the most promise because of the valley observed in the pulse-height spectra between the electronic noise and the main features of the spectra.
Solid-form neutron detectors continue to be explored as a possible replacement to present-day gas-filled $^3$He and $^{10}$BF detectors. Boron-based compounds such as BN and BAs have been investigated with marginal results. Some Li compounds such as LiI scintillators have been successful neutron detectors, but have not been explored to the extent of B-based semiconductors. A sub-branch of the III-V semiconductors, the filled tetrahedral compounds, $A^I B^{II} C^V$, known as Nowotny-Juza compounds are known for their desirable cubic crystal structure (Fig. 1I), and were originally studied for photonic applications, namely LiZnAs, LiZnAs, LiMgP, LiMgAs, LiZnN, and LiMgN.

As with many novel ternary semiconductor compounds, these materials are not commercially available. Recipes were developed in-house, which are conducted as controlled reactions performed in crucible-lined, vacuum-sealed quartz ampoules. Bulk samples were grown using a high temperature/high pressure method in a sealed tantalum ampoule (Fig. 2I). These samples were tested for resistivity characteristics, and although some samples were more desirable than others, high conductivity is a recurring problem, and is likely due to the impurity content, specifically elemental and binary impurities mixed within the desired ternary material. Inductively-coupled plasma atomic emission spectroscopy (ICP-AES) results (Galbraith Laboratories) indicate that the reacted material resulted in equal stoichiometric ratios, 1:1:1, with some indication of inconsistency within a few samples.

Purification methods of the synthesized material have shown promise thus far to remedy the purity issues, and are presently under further investigation. Samples were collected from the “purified” material, and also the remaining binaries and other elemental material, and were analyzed through ICP-AES for molar concentration. Shown in Table 1I is the collected data, where it is shown that the molar concentration of each element from the ternary, or “purified,” material is approximately equal within a standard deviation of the measured values (10% - Galbraith Laboratories, Inc), which indicates the material is compounded in the desired ternary ratio, 1:1:1. Interestingly, the material that remained after the purification did not contain any measurable amount of lithium. Although the purification yield is not yet optimized, after several purification operations enough material can be accumulated to completely load a Ta ampoule, thereby, allowing for the bulk growth of relatively large crystals for bulk semiconductor neutron detectors.

### Table 1I

<table>
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<th>Result (%)</th>
<th>Molar Concentration</th>
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<th>Result (%)</th>
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LOLA ALLEN, ECUADORAN EDUCATIONAL COORDINATOR,

Lola Allen, Ecuadoran government Coordinator for International Relations in Secretaría Nacional de Educación Superior, Ciencia, Tecnología e Innovación (SENESCOY), visited Kansas State University on Nov. 30, 2012, to finalize an international educational agreement between Ecuador and KSU. During her visit she took time to tour through the SMART Laboratory and discuss the educational value of the laboratory, the various research projects and the innovative technologies being produced in the laboratory.

ADMIRAL KIRKLAND H. DONALD

Admiral Kirkland Donald came to Kansas State University on December 8, 2012, to deliver the commencement address for graduating seniors. Adm. Donald was Commanding Officer, USS Key West (SSN 722), from October 1990 to February 1993. He served as Commander, Submarine Development Squadron 12 from August 1995 to July 1997. From June 2002 to July 2003, he was assigned as Commander, Submarine Group 8; Commander, Submarine Force 6th Fleet (CTF 69); Commander, Submarines Allied Naval Forces South; and Commander, Fleet Ballistic Missile Submarine Force (CTF 164) in Naples, Italy. Most recently, he served as Commander, Naval Submarine Forces; Commander, Submarine Force, U.S. Atlantic Fleet; Commander, Allied Submarine Command; and Commander, Task Force 84 and 144 in Norfolk, Virginia. On Nov. 2, 2012, Adm. Donald transferred his duties as Director, Naval Propulsion Program to Adm. J.M. Richardson, and was subsequently transferred to the retired list on Jan. 1, 2013.

During his visit, he took time to tour the SMART Laboratory facilities and discuss the various radiation detector projects with faculty and students. Adm. Donald toured through the new clean room fabrication laboratory, where graduate students Brian Cooper and Ryan Fronk showed him the processes used to fabricate MSNDs. He also toured through the crystal growth labs, where graduate students Nate Edwards and Ben Montag showed him the techniques used to grow Hgl₂, CdZnTe, BiI₃ and various halogen scintillators.

Fig. 1J. (from left) Dr. Phil Ugorowski, Continuing Education Dean Sue Maes, Ed. Coordinator Lola Allen and Prof. Douglas McGregor.

Fig. 2J. Dean Sue Maes, Lola Allen, Prof. Douglas McGregor and Dr. Phil Ugorowski touring the SMART Laboratory clean room facility.

Fig. 1K. (front row) Prof. Douglas McGregor, Adm. Kirkland Donald, Ryan Fronk, Justin Clark; (back row) Michael Reichenberger, Brian Cooper, Dr. Phil Ugorowski, Dr. Steven Bellinger, and Zachary Schular.

Fig. 2K. (from left) Nate Edwards and Adm. Kirkland Donald look on as Ben Montag explains the operation of the multi-zone horizontal Stockbarger crystal growth furnace.
**RIBBON CUTTING CEREMONY/ REP. HUELSKAMP**

The new class 100 clean room inauguration was held on October 15, 2012. After opening comments from the Mechanical and Nuclear Engineering Department Head, Don Fenton, Congressional Representative Tim Huelskamp (Kansas District 1) made statements to a crowd of over 50 in attendance regarding the importance of the SMART Laboratory detector research. Just this last year, the national census resulted in Manhattan, Kansas being relocated from Kansas District 2 into District 1, making Rep. Huelskamp our new congressman. We were honored that Rep. Huelskamp took time to tour the SMART Laboratory on this important occasion.

Rep. Huelskamp recognized the importance of supporting Kansas businesses, and was glad to learn that a new start up business, RDT, Inc. (opposite page) was commercializing detectors developed in the SMART Laboratory. After some discussions and refreshments, Rep. Huelskamp performed the official ribbon cutting of the 1200 sq. ft. class 100 clean room, along with Dr. Phil Ugorowski and Prof. Douglas McGregor. Rep. Huelskamp then “suited up” and went through the clean room. Graduate students Brian Cooper and Ryan Fronk explained the processes used to fabricate various radiation detectors, including those processes used to make the high-efficiency MSNDs (pages 6-7). Also in attendance were Associate Dean Gary Clark, Associate Vice-President for Research Jim Guikema, and the Director of Governmental Relations Sue Peterson. The event was covered by the local news team at WIBW. Located in the basement of Ward Hall, the construction of the new class 100 clean room was made possible through a generous grant from the Defense Threat Reduction Agency (DTRA), totaling nearly $2.7M. KSU also contributed approximately $400k to the construction project. The new laboratory has already allowed for tremendous improvement in processing yields and detector performance.

**NRC COMMISSIONER WILLIAM D. MAGWOOD**

Nuclear Regulatory Commissioner William Magwood came to Kansas State University in 2012, to tour the KSU TRIGA Mark II nuclear reactor and the SMART Laboratory, and afterwards give an invited talk for the MNE Department seminar series. The Honorable William D. Magwood, IV was sworn in as a Commissioner of the U.S. Nuclear Regulatory Commission (NRC) on April 1, 2010, to an initial term ending on June 30, 2010, and a reappointment term ending June 30, 2015. Mr. Magwood has a distinguished career in the nuclear field and in public service. He was the longest-serving head of the United States' civilian nuclear technology program, serving two Presidents and five Secretaries of Energy.

Comm. Magwood served seven years as the Director of Nuclear Energy with the U.S. Department of Energy (DOE), where he was the senior nuclear technology official in the United States Government. He oversaw the restoration of the Federal nuclear technology program and led the creation of "Nuclear Power 2010," "Generation IV," and other innovative initiatives—including successful efforts that helped reverse the decline in American nuclear technology education.

Comm. Magwood toured through the SMART Laboratory where students and faculty explained the various processes used to fabricate radiation detectors, including purification and crystal growth processes, chemical fabrication processes, and detector fabrication processes. Mr. Magwood showed great interest in the detectors being developed in the SMART Laboratory, especially the compact microstructured semiconductor neutron detectors (MSNDs). Various new applications of developing detector technologies were discussed during his visit.

Comm. Magwood discussed the future of nuclear power in the USA and the regulatory process in place for licensing new reactor plants. Also discussed were political issues regarding the Yucca Mountain Nuclear Waste Repository.
IEEE NSS - ANAHEIM, CA

Two students from Kansas State University, Brian Cooper and Kyle Nelson, attended the IEEE Nuclear Science Symposium in Anaheim, California, Oct. 29—Nov. 3, 2012, to present their research work on innovative radiation detection technologies. The symposium is internationally attended by over 1000 engineers and scientists participating in the field of radiation detector development and radiation measurements. The SMART Lab group and collaborators had six presentations. Kyle Nelson gave a poster presentation on the modeling and expected efficiencies of Li-foil neutron detectors and an oral presentation on the construction and performance of Li-foil detectors (p.10). Kyle Nelson received the third place award for his presentation on the Li foil detectors. Brian Cooper gave an oral presentation on the performance of the fast neutron spectrometer (p.8) and he gave a poster presentation on the construction and performance of compact arrays of MSNDs (pgs. 6-7). Collaborator Prof. Caruso from the Univ. Missouri/Kansas City gave oral and poster presentations on the portable neutron spectrometer (p.9). Additionally, Prof. Douglas McGregor and Prof. Tony Caruso occupied a booth for Radiation Detection Technologies, Inc., a company started by Dr. Steven Bellinger, president, to commercialize the microstructured semiconductor neutron detectors. Bellinger, Caruso and McGregor are co-owners in the operation.

RADIATION DETECTION TECHNOLOGIES

Radiation Detection Technologies, Inc. (RDT) was established because of a gap in the radiation detection industry in both the US and the rest of the world. This gap is particularly noticeable because of the lack of a transition of many new and novel technologies reported in literature to the commercial sector. These novel technologies are mostly practiced in the academic arena, with major commercial companies in industry using old or outdated technology and retreating from offering broad product lines, seeking instead to focus on general industrial products. While many fundamental university research projects terminate with an academic publication, RDT has bridged the gap and transitioned KSU grown technology to deliver sensors to the Department of Energy, Department of Defense, and private industry partners.

RDT is commercializing technologies developed in two labs at Kansas State University: the Semiconductor Materials and Radiological Technologies (SMART) Laboratory, which has pioneered research into detector materials and novel semiconductor processing to produce low-cost, high-efficiency radiation detectors, and the Electronics Design Laboratory (EDL), which has developed the sensor electronics needed to customize the radiation detectors for defense, homeland security and health physics applications. The focus of RDT has been to commercialize innovative radiation detection technologies that have been laboratory proven. RDT leases the class-100 semiconductor processing clean room from the KSU SMART Lab as a production and custom services test bed manufacturing facility for many of the microstructure semiconductor neutron detector (MSND)-based products it offers. As such, RDT provides the neutron detector market with new methods to cost effectively detect neutrons, as well as system integration with current and future commercially available radiation detection systems developed at the KSU SMART Lab and EDL.
STUDENT SUPPORT

Learning is given free reign in a fast-paced research environment. Students work independently on manageable portions of projects, but ultimately contribute to a larger team effort. Placement of students on projects is based on their interests and skills. From the drawing board to construction, testing and operation, students learn every aspect of what it means to be an engineer.

The KSU SMART Lab management structure is arranged to teach the students how to manage projects, coordinate activities and become responsible for project goals and deadlines. Both Ph.D. and M.S. graduate students interview undergraduate candidates that apply for research positions, and make the initial decisions regarding who will be considered for employment. The graduate students supervise those undergraduates who work for them, and make recommendations for raises and continued employment to the lab director. The graduate students are directly supervised by their respective graduate advisors. This management method encourages graduate and undergraduate students to take responsibility for their projects. Ph.D. students also participate in the proposal writing and submission process to prepare them for a successful career. The overall system prepares undergraduate and graduate students to manage and oversee engineering projects upon leaving the university environment. Students from varied backgrounds work in the SMART Lab, including nuclear engineering, mechanical engineering, electrical engineering, chemical engineering, computer engineering, chemistry, material science and physics.

The SMART Lab is operated almost entirely by student research assistants, totaling 23 combined graduate and undergraduate student researchers in 2012. Funding support for these enthusiastic young scientists is a solid investment for the future of nuclear science and technology in the United States.

PhD Students

Doctoral students in the SMART Laboratory are capable of conducting independent research on projects. They learn to design and build equipment, draw scientific conclusions through experimental methods and critical analysis, publish and present research results, write successful proposals, and mentor less experienced students. In 2012, funding from various agencies and companies supported seven Ph.D. students in the SMART Laboratory.

MS Students

Master degree students in the SMART Laboratory conduct research in collaboration with senior Ph.D. students and faculty. They learn to design and build equipment, conduct research, publish and present research results. M.S. students in the SMART Laboratory are required to write a thesis detailing their research work and results. In 2012, funding from various agencies and companies supported three M.S. students in the SMART Laboratory.
STUDENT SUPPORT

Undergraduate Students
The Mechanical and Nuclear Engineering Department at Kansas State University offers a B.S. in Mechanical Engineering with a Nuclear Option. Undergraduate students from several different university departments play important roles in the SMART Lab research structure. They participate in research projects at all levels, including materials purification and crystal growth, detector fabrication, detector testing and characterization, electronics and packaging. Each undergraduate works closely with a graduate student on a funded research project. They gain valuable experience that helps them acquire positions in industry or gain admittance into graduate school. In 2012, funding from various agencies and companies supported thirteen undergraduate students in the SMART Laboratory.

GRADUATED!

Graduating in 2012 was Martin Ohmes, who worked on some of the first generation of micro-pocket fission detectors, as described in his dissertation, “Deployment of a Three Dimensional Array of Micro-Pocket Fission Detector Triads (MPFD3) for Real-Time in-Core Neutron Flux Measurements in the Kansas State University TRIGA Mark II Nuclear Reactor”. At the time of his graduation, Dr. Ohmes had seven scientific publications relating to the MPFD work and one patent pending.

Over 90 undergraduate and graduate students have worked on research projects and have benefited from financial support in the SMART Laboratory.
DOUGLAS S. MCGREGOR  
Professor of Nuclear Engineering  
Director, SMART Laboratory  
B.S. Electrical Engineering, Texas A&M University (1985)  
M.S. Electrical Engineering, Texas A&M University (1989)  
M.S. Nuclear Engineering, University of Michigan (1992)  
Ph.D. Nuclear Engineering, University of Michigan (1993)  

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RESEARCH: Research topics include design, development, and deployment of radiation detectors and detection systems, semiconductor and scintillator materials development, nuclear measurements of various ionizing and non-ionizing radiation, semiconductor device physics, semiconductor device design, and semiconductor device fabrication.

Born in Dallas, Texas in 1957, Prof. Douglas S. McGregor studied solid state physics, semiconductor device design, and radiation detection and measurement at Texas A&M University (TAMU) and the University Of Michigan (UM), receiving his B.S. (1986) and M.S. (1989) in Electrical Engineering from TAMU, and his M.S. (1992) and Ph.D. (1993) in Nuclear Engineering from UM. In 1997 he worked at UM as an Assistant Research Scientist until 2002, when he accepted an associate professor position at Kansas State University (KSU). He has also worked at Los Alamos, Sandia, and Lawrence Livermore National Laboratories on temporary assignments. Prof. McGregor has over 30 years of experience in the fields of semiconductor device theory and fabrication, radiation detection & measurement, and radiation detector design, fabrication and characterization, and teaches radiation detection & detector design at the undergraduate and graduate levels. He conducts design, fabrication and characterization of radiation detectors and systems at KSU and is the director of the Semiconductor Materials and Radiological Technologies (SMART) Laboratory. Prof. McGregor is skilled at fabricating devices from numerous semiconductors and is recognized as an expert on semiconductor radiation detector design, fabrication and characterization. He holds records for room-temperature gamma-ray spectrometers and solid state thermal neutron detectors, has introduced novel concepts for neutron detection devices and single polarity sensitive radiation detectors, was a co-recipient of a 2005 R&D 100 award for a novel gamma ray spectrometer design and again in 2009 for novel microstructured semiconductor neutron detectors. He has consulted for numerous private and government agencies. Prof. McGregor has authored or co-authored over 170 research publications on radiation detectors, 5 radiation detection book chapters, and has 13 US patents on various detector designs with several more US patents pending on radiation detector designs.

J. KENNETH SHULTIS  
Professor of Nuclear Engineering  
Nuclear Engineering Program Director  
B.A.Sc. Engineering Physics, University of Toronto (1964)  
M.S. Nuclear Science and Engineering, University of Michigan (1965)  
Ph.D. Nuclear Science and Engineering, University of Michigan (1968)  

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RESEARCH: Monte Carlo detector analysis, inverse problems, remote sensing, transport theory and radiative transfer, risk analysis, radiation protection and shielding, numerical analysis, radiological assessment, and utility power analysis.

Prof. J. Kenneth Shultis, born in Toronto, Canada in 1941, graduated from the University of Toronto (UT) with a B.A.Sc. degree in Engineering Physics (1964). He gained his M.S. (1965) and Ph.D. (1968) degrees in Nuclear Science and Engineering from the University of Michigan (UM). After a postdoctoral year at the Mathematics Institute of the University of Groningen, the Netherlands, he joined the Nuclear Engineering faculty at Kansas State University in 1969 where he presently holds the Black and Veatch Distinguished Professorship. He teaches and conducts research in neutron and radiation transport, radiation shielding, reactor physics, numerical analysis, particle combustion, remote sensing, and utility energy and economic analyses. He is a Fellow of the American Nuclear Society, and has received many awards for his teaching and research. Prof. Shultis is the author or co-author of six textbooks on Monte Carlo analysis, radiation shielding, radiological assessment, and nuclear science and technology, and he has an additional three independent book chapters on nuclear engineering and shielding. He has written over 220 research papers and reports, and served as a consultant to many private and governmental organizations. He was a co-recipient of an R&D 100 award in 2009 for novel microstructured semiconductor neutron detectors, and he is a co-inventor on one US patent on the devices. Prof. Shultis is presently performing research in radiation shielding and in analyses of the designs and applications of the many novel radiation detectors presently being fabricated at KSU’s SMART Laboratory, a facility unique among US universities. Prof. Shultis’s radiation shielding research has been used to design safe storage facilities for spent nuclear fuel and for designing new classes of electron accelerators for producing painted products without the need for paint solvents which often result in environmental pollution.
Prof. William L. Dunn received a B.S. degree in Electrical Engineering from the University of Notre Dame in 1968 and M.S. and Ph.D. degrees in Nuclear Engineering from North Carolina State University (NCSU) in 1970 and 1974, respectively. He then worked for Carolina Power & Light Company before returning for a few years to the Nuclear Engineering Department at NCSU, where he oversaw applications of the 1-MW PULSTAR research reactor and served on the faculty. Prof. Dunn then entered into a long career in contract research, beginning with a three-year stint at Research Triangle Institute and then moving to Applied Research Associates, Incorporated. In 1988 he founded Quantum Research Services, Inc., a small-business contract research firm in Durham, North Carolina. He spent 14 years as President of Quantum before joining the Kansas State University (KSU) faculty in the summer of 2002 as an associate professor in the Department of Mechanical and Nuclear Engineering. In 2003, Prof. Dunn established the Radiation Measurement Applications Laboratory at KSU, where research is conducted on standoff bomb detection, radiation dosimetry, detector characterization, and other radiation applications. He has spent over 40 years working in the field of radiation measurement applications and has significant experience in radio-gauging, radio-tracing, quantitative analysis, and imaging through radiography and X-ray scanning. He has three allowed patents and over 105 technical publications. He recently co-authored a book on Monte Carlo methods. He also conducts detector characterization and develops response functions and algorithms.

Dr. Philip Ugorowski earned his B.A. degrees in Physics and Mathematics from Kalamazoo College in 1983. He received a Research Masters’ in Experimental Nuclear Physics from Michigan State University in 1987, working on the development of a real-time light nuclear fragment discriminator for the National Superconducting Cyclotron Lab. He then became involved in physics education, teaching physics and mathematics, and developing exhibits and demonstrations for Impression 5 Hands-On Science Museum in Lansing, Michigan. He returned to university studies, receiving a Ph.D. in Experimental Nuclear Physics from Western Michigan University in 2002. His postdoctoral research at Youngstown State University centered on the development of a portable nuclear calorimetry array, built specifically to test claims of X-ray induced decay of nuclear isomers. In 2007, Dr. Ugorowski joined the SMART Lab, and is presently involved with the testing and characterization of new scintillator detectors and neutron detectors developed at SMART Lab.

Dr. Steven L. Bellinger earned his B.S. degrees (2006) in Mechanical Engineering and Mathematics, and his Ph.D. (2011) in Nuclear Engineering from Kansas State University. For his doctoral research, he designed and built semiconductor microstructured neutron detectors. These detectors yielded over 42% intrinsic thermal neutron detection efficiency for 1 cm² devices, for which Dr. Bellinger was a co-recipient of an R&D 100 Award in 2009. At graduation, Dr. Bellinger had 26 published papers in archival journals and conference records, along with two allowed patents and two patents pending. Dr. Bellinger’s dissertation, “Advanced Microstructured Semiconductor Neutron Detectors: Design, Fabrication and Performance,” describes the processes used to design and fabricate microstructured semiconductor neutron detectors, the most compact and rugged high-efficiency thermal neutron detectors to date. Dr. Bellinger is presently working half-time as a graduate fellow in the SMART Laboratory. He has also started his own company, Radiation Detection Technologies, Inc., producing high efficiency neutron detectors, located in the Manhattan, KS area.
PUBLICATIONS/METRICS - 2012

**Refereed Publications:**

**Refereed Publications in Press:**

**Conference Proceedings:**

**Patents Filed:**
CURRENT PROJECTS

- Micro-Pocket Fission Detectors, funded by Idaho National Laboratory - $310,435
  Development of miniaturized gas-filled detectors designed to operate in the core of high-temperature nuclear reactors.

- He-3 Replacement Technology, funded by DTRA - $1,180,903
  New gas-filled devices using alternative neutron reactive materials will be designed, built and tested.

- Large Area MSND Panel Arrays, funded by DTRA - $1,204,709
  Large panel arrays of self-biased microstructured semiconductor neutron detectors (MSND) are under construction.

- MSND Neutron Spectrometer, ONR subcontract through U. Missouri/Kansas City - $359,168
  MSND wafer arrays stacked within HDPE are operated to yield energy information to identify neutron sources.

SPONSORS

The research success that SMART Laboratory students and faculty enjoy would not be possible without funding support. The following institutions and companies have sponsored SMART Laboratory research:

- Alion Science and Technology Corporation
- Argonne National Laboratories (ANL)
- Brookhaven National Laboratory (BNL)
- Defense Threat Reduction Agency (DTRA)
- DTRA Basic Research Program
- Department of Energy (DOE)—Nuclear Engineering Education Research (NEER) Program
- DOE—Nuclear Energy Research Initiative (NERI) Program
- DOE—Innovations in Nuclear Infrastructure and Education (INIE) Program
- DOE—National Nuclear Security Administration (NNSA)
- Idaho National Laboratory
- Instrumentation Associates—DOE SBIR
- Lawrence Livermore National Laboratory (LLNL)
- Lockheed Martin Missiles and Fire Control
- National Science Foundation (NSF)
- Radiation Safety Engineering—DOE SBIR
- Radiation Detection Technologies, Inc.—DOE SBIR
- Sandia National Laboratories (SNL)
- Spire Corporation—DOE SBIR
- University of Missouri in Kansas City (UMKC) — Office of Naval Research contract

EQUIPMENT DONATIONS

Much of the equipment used in the SMART Laboratory was made available by generous donations from several different institutions and private companies. The following institutions and companies donated equipment to the SMART Laboratory:

- Cornell University
- IBM Corporation
- Knolls Atomic Power Laboratory
- Land, Sea and Sky/Texas Nautical Repair
- Lawrence Livermore National Laboratory (LLNL)
- MOXTEK, Inc.
- Northrop Grumman
- Renaissance Instruments
- Texas Nuclear (TN) Technologies
- Sandia National Laboratories (SNL)
- Science Applications International Corporation (SAIC)
- University of Illinois
- University of Michigan
**FACILITIES**

The **SMART Laboratory** was built by students and faculty working together, and the student body is the driving force in the laboratory. The SMART Lab workforce averages over 30 students per year. Students learn to be engineers in theory and practice, and actually operate and run the lab. Master and Ph.D. students learn to couple theory with practical hands-on research in all aspects of radiation detector design, fabrication and characterization to deliver the next generation of radiation detectors for a wide spectrum of applications.

The SMART Laboratory has an assortment of semiconductor processing equipment, including:

### Slicing and Polishing Equipment:
- linear drive diamond cutting wheel
- two precision diamond wire saws
- wafer dicing saw
- dual-wheel grinder
- two precision lapping systems
- two chemo-mechanical polishing systems
- wafer scriber

### Vacuum Deposition Equipment:
- six-pocket e-beam evaporator
- dual-filament evaporator
- three-target sputtering system
- parylene coating system
- carbon sputter system
- ICP-LPC System

### Semiconductor Device Processing Equipment:
- vacuum rapid thermal annealing (VRTA)
- three mask aligners
- six microscopes
- six triple-zone 4” diffusion and oxidation furnaces
- four automated triple-zone 6” diffusion and oxidation furnaces
- clean room ovens
- computer controlled inert gas processing oven
- wirebonder
- surface mount system
- two photoresist spinners
- two wafer spin washers

### Dry Etching Equipment:
- inductively-coupled-plasma RIE system
- two plasma ashers
- ion mill

### Characterization and Analysis Equipment:
- scanning electron microscope
- Auger electron spectroscopy microscope
- four-point probe
- IV/CV analysis system
- ellipsometer
- probe station
- profilometer
- Compton scatter coincidence system
- photoluminescence spectrometer
- neutron diffractometer
- Bruker D2 CRYSO X-ray diffraction system
- Bruker D8 DISCOVER X-ray diffraction system

### Materials Preparation Equipment and Growth Furnaces:
- two ultra-pure glove boxes
- high-temperature argon glove box
- carbon coating furnace
- five-port ampoule sealing station
- two high-pressure vertical Bridgman furnaces
- two low pressure vertical Stockbarger furnaces
- one horizontal/vertical Stockbarger furnace
- one horizontal Stockbarger furnace
- two vapor distillation/zone melt furnaces
- two 24-zone electro-dynamic gradient freeze furnaces
- forty horizontal vapor growth HgI₂ furnaces
- ten vertical vapor growth HgI₂ furnaces
- SiC high temperature furnace
- one zone-refining furnace
- LPE furnace

The SMART Lab has a 300 sq ft class-1000 clean room for materials preparation and detector fabrication training. A second larger 1200 sq ft class-100 clean room is used for advanced detector fabrication. Detectors are built from start to finish in readily deployable packages. The SMART Lab is equipped with radiation sources and NIM electronics to test and characterize radiation detectors. The facility is available to students and faculty for research and development of devices requiring standard equipment for VLSI processing and device fabrication.
**SUPPORTING LABORATORIES AND FACILITIES**

**THE KANSAS STATE UNIVERSITY TRIGA MARK II NUCLEAR REACTOR FACILITY**, licensed for 1.25 MW operation, has four 20-cm diameter beam tubes extending from the graphite reflector. These tubes provide well-collimated neutron beams for experimental investigations. Three of the tubes are radial and provide a mixed field of gamma-rays and neutrons, and one is tangential to provide a thermalized neutron beam with a low gamma-ray contribution. Lab Director: Dr. Jeffrey Geuther. [www.mne.ksu.edu/research/centers/reactor](http://www.mne.ksu.edu/research/centers/reactor)

**THE ELECTRONICS DESIGN LABORATORY** provides full-time electrical and electronics engineering support for research and teaching through development of advanced instrumentation, data acquisition systems, sensors, and other high-end electronics. The EDL assists with integrating electronics technology and aids in electronics technology transfer to users by providing ongoing technical support. Services include custom electronics and instrumentation design and development; analog and digital system modeling and analysis; programmable logic and embedded system development; consulting for grounding, shielding, and electronics noise problems; schematic capture; multi-layer printed wiring board (PWB) design with in-house prototype PWB fabrication; electronics prototyping and packaging; circuit and system debugging and testing; thermal testing; software development. Lab Director: Tim Sobering [www.k-state.edu/ksuedl/](http://www.k-state.edu/ksuedl/)

**THE RADIATION DETECTION INSTRUCTIONAL LABORATORY** provides fundamental and advanced instruction on the design and use of various radiation detectors and spectrometers. There are four complete workstations in the RDIL for radiation detector studies and radiation measurements, each having the nuclear detection equipment necessary to perform radiation measurements with gas-filled and gas-flow detectors, scintillation detectors, and semiconductor diode detectors. Students can perform gamma-ray counting and spectroscopy, charged particle counting, and fast and thermal neutron counting. [www.mne.ksu.edu/research/laboratories/radiation-detection-instructional-laboratory](http://www.mne.ksu.edu/research/laboratories/radiation-detection-instructional-laboratory)

**THE TATE NEUTRON ACTIVATION ANALYSIS LABORATORY** is used to perform qualitative and quantitative analyses of samples by the use of gamma-ray and x-ray spectroscopy. The laboratory is used extensively in connection with the TRIGA Mark II Nuclear Reactor Facility to perform neutron activation analysis on a wide variety of samples. The principal radiation detectors in use are four different high-purity germanium (HPGe) detectors for gamma-ray and x-ray measurements. The energy distributions of the x rays and gamma rays are accumulated and displayed by multi-channel analyzers (MCA).
For more information about the Semiconductor Materials and Radiological Technologies (SMART) Laboratory, visit:

www.mne.ksu.edu/research/centers/SMARTlab

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