MINER – A Mobile Imager of Neutrons for Emergency Responders
SL11-Backpack-NImager-PD2Ka

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1. INTRODUCTION

We have developed a mobile fast neutron imaging platform to enhance the capabilities of emergency responders in the localization and characterization of special nuclear material. This mobile imager of neutrons for emergency responders (MINER) is based on the Neutron Scatter Camera, a large segmented imaging system that was optimized for large-area search applications. Due to the reduced size and power requirements of a man-portable system, MINER has been engineered to fit a much smaller form factor, and to be operated from either a battery or AC power. We chose a design that enabled omnidirectional (4π) imaging, with only a ~twofold decrease in sensitivity compared to the much larger neutron scatter cameras. The system was designed to optimize its performance for neutron imaging and spectroscopy, but it does also function as a Compton camera for gamma imaging. This document outlines the project activities, broadly characterized as system development, laboratory measurements, and deployments, and presents sample results in these areas. Additional information can be found in the documents that reside in WebPMIS.

2. SYSTEM DESIGN

The design of a truly man-portable system requires difficult trade-offs between desired detection capabilities (sensitivity, spatial resolution, and energy resolution) and portability issues (size, weight, power consumption, and ruggedness). Using the EJ-309 liquid scintillator, reasonable neutron single-scatter efficiency led us to a 3” cell size, with a cylindrical cell geometry using a 3” PMT providing the optimum configuration.[1] The more cells the greater the overall detection efficiency, but the desire for a compact, easily transported imager assembly and compatibility with existing digitizers led us to choose a sixteen-channel system. We simulated the performance of a variety of sixteen-cell designs, starting with a two-plane configuration similar to our other scatter cameras, and then exploring sensitivity, compactness, and omnidirectional capability as we rearranged the geometry of the sixteen cells. In the end, we found that a cylindrical geometry with height-staggered cells gave us similar sensitivity to a close-packed two-plane system, but provided much better omnidirectional performance.[2]

The MINER system consists of 16 detector assemblies (assembled cell shown on the bottom right of Fig. 1). The active volume of each cell is a 3” diameter, 3” deep EJ-309 bubble-free liquid scintillator cell which incorporates an expansion chamber at the end of the cell to accommodate differential thermal expansion of the liquid and the metal cell (top right). Each cell is coupled to a 3” PMT, with high voltage supplied by a low-power, USB-controlled custom circuit mounted directly behind the voltage divider board (disassembled components shown on the left).

Fig. 1. Liquid scintillator cell components and assembly

Early imaging studies were performed with a flexible test stand that enabled us to vary the spacing of the cells. As suggested by simulations, we found that a relatively close-packed geometry was optimal for double-scatter sensitivity with an acceptable angular resolution. We subsequently designed a final ruggedized mounting system with the design shown in Fig. 2. The cells are suspended in the center of the external protective cylinder, with shock mounting provided by the round structures at the top and bottom of the assemblies.[2] The photograph on the left of Fig. 3 shows the final assembly opened up to reveal its internal structure. The photograph on the right of Fig. 3 shows the entire detection system in its normal operating configuration (completely enclosed in a 15" diameter, 36" high housing, total weight ~80 pounds), with the power conditioning module (top) and sixteen-channel digitizer (bottom) mounted on the side of MINER. Power can be supplied from AC power or a battery[3] (110 W at 10-36 VDC).[3] The only other component of the system is the laptop computer connected by the USB and Ethernet cables visible at the bottom-right of the photograph.

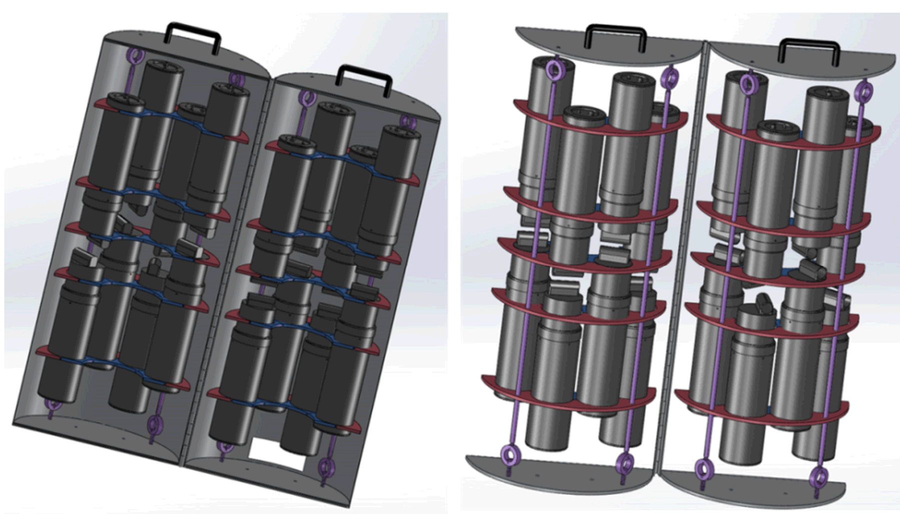

Figure 2. Mechanical design of the final MINER system

Fig. 3. Final configuration of MINER

3. LABORATORY MEASUREMENTS

Data acquisition, analysis, and real-time display are provided by a LabVIEW-based code running on a conventional laptop PC. This code acquires data in list mode, recording to disk the key pulse parameters (pulse height, window-integrated waveform measurements for PSD characterization, and timing information) on an event-by-event basis, while simultaneously providing a real-time display of neutron and gamma images and a variety of diagnostic graphics. The real-time display from a representative laboratory measurement is presented in Fig. 4 below (for a complete description, see Ref. 2). Results demonstrating the robustness of the neutron image reconstruction procedure in the presence of strong gamma fields are provided in Fig. 5.

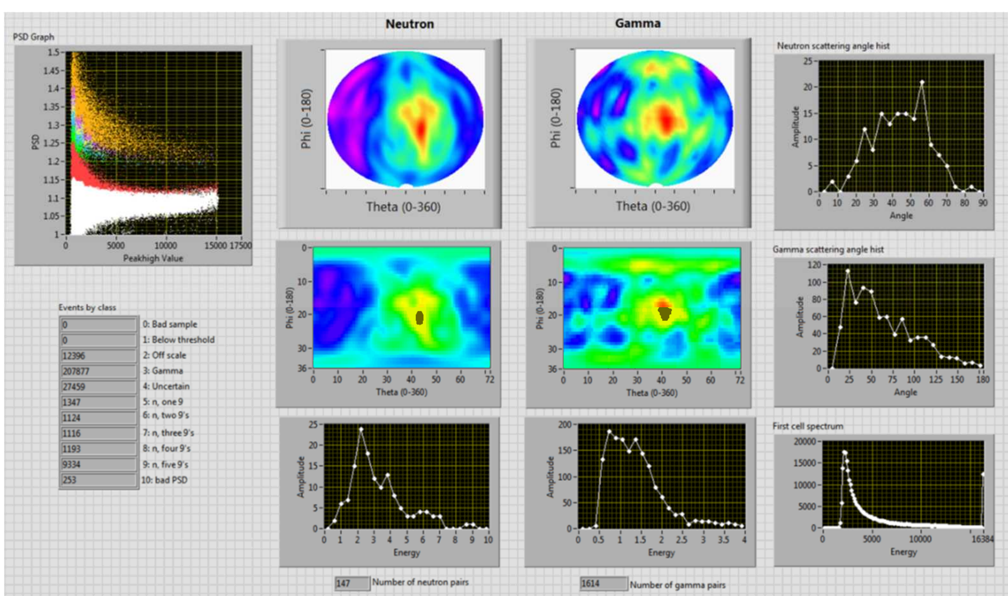

Fig. 4. Real-time display of a five-minute measurement of a ^{252}Cf source 5.3 m from the detector

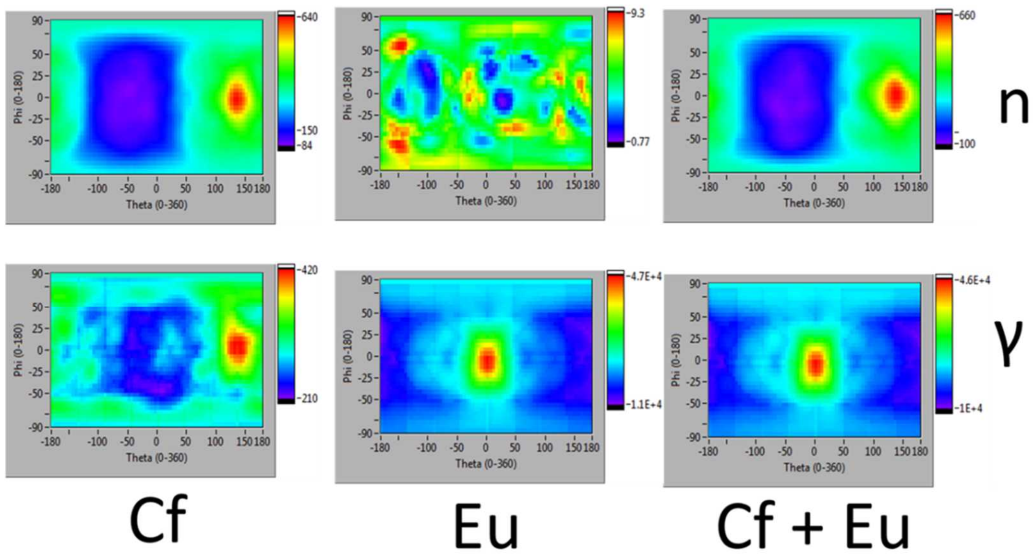

Fig. 5. Images recorded using a Cf-252 source 2 m from MINER at a relative angle of 135°, a strong Eu-152 source 1 m from MINER at a relative angle of 0°, and both sources together.

4. DEPLOYMENTS

MINER has participated in three deployments to date. These are described briefly below.

One use of an imaging neutron detector such as MINER is to detect the presence and location (or absence) of SNM located in inaccessible areas, such as behind concrete walls. We had an opportunity to detect and localize a small sample of Pu being used for an unrelated experiment at the Baker facility of the National Nuclear Security Site during June 2013.[4] This study was conducted with a 12” thick reinforced concrete wall (acting as a surrogate for a vault wall) between the hallway where MINER was set up and the Baker cell housing the small Pu sample. Neutron images recorded through the wall enabled us to detect motion of the source on the other side of the wall.

During August 2013 we had an opportunity to participate in diagnostic measurements at the INL ZPPR (Zero Power Physics Reactor) facility.[4] This gave us an opportunity to make detailed measurements of three test objects that contain a much larger quantity of plutonium (one containing pure metal, the other two containing oxides). During the course of the week, we conducted measurements of the three objects in a variety of detector configurations, and with and without various combinations of poly moderator and stainless steel shielding around the objects. Fig. 6 shows a photograph of a typical configuration. Representative neutron and gamma images of the shielded Pu sphere are shown in Fig. 7. The long dwell time available for these measurements provided an excellent opportunity to compare spectra from the samples, demonstrating our ability to distinguish Pu metal from Pu oxide. We cannot distinguish Pu metal from Cf, but AmBe (measured at Sandia) is easily distinguished from the other materials.

Fig. 6. MINER at ZPPR

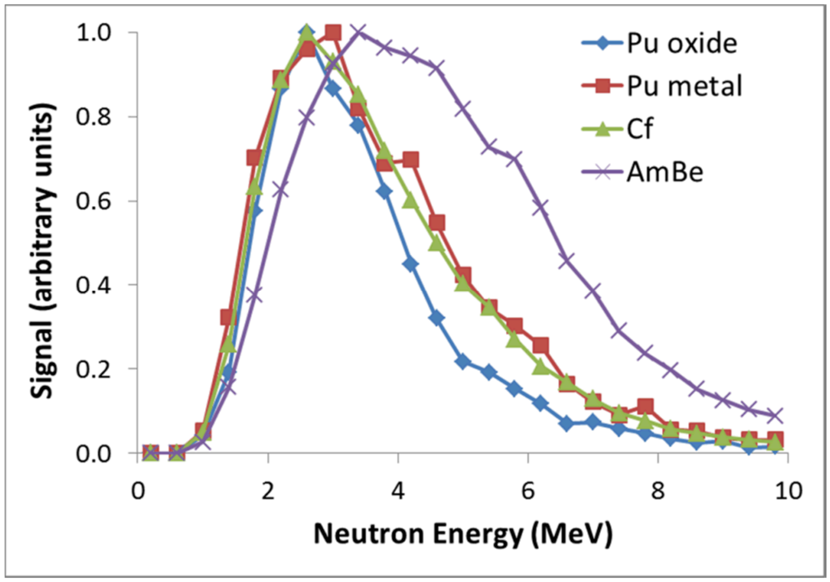

Fig. 7. Peak-normalized neutron spectra (not corrected for energy variations in the instrument response).

MINER also participated in a weeklong detection scenario conducted in downtown Chicago during May 2014 as part of an evaluation of detection-system performance in an urban high-rise environment.[5] For this study, the detectors were located on the twelfth floor of one building, with the radionuclide sources located 28 m away on the thirteenth floor of a building across the street. Measurements were performed with Cf and AmBe neutron sources, bare and with various amounts of HDPE (high-density polyethylene) shielding. Fast-neutron "images" derived using MINER measurements were able to localize the neutron sources for all but the most heavily-shielded scenario (6" HDPE surrounding the source). A sample result is shown in Fig. 8. Spectra derived for bare AmBe and Cf sources located across the street demonstrated our ability to distinguish these sources from each other at a distance.

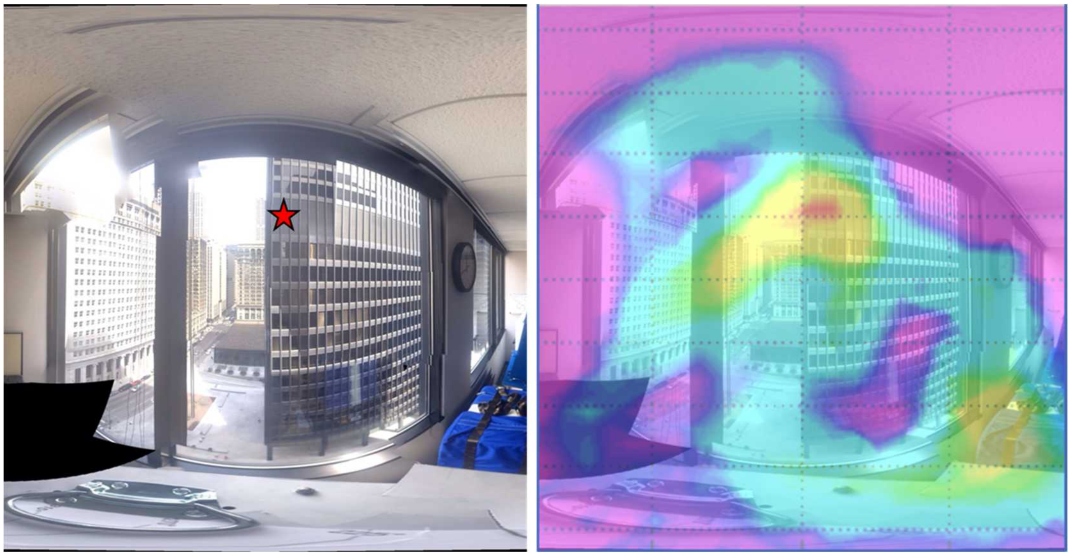

Fig. 8. Left – wide-angle view from the top of MINER, with the red star indicating the location of the radionuclide sources. Right - Hypothesis-test 180°x180° image for the bare Cf source (30 minute acquisition time); red "hot spot" demonstrates source localization.

5. REFERENCES (DOCUMENTS AVAILABLE IN WEBPMIS)

1. MINER Cell Performance (SL11-Backpack-NImager-PD03_Report_on_Cell_Performance.docx)
2. Design and Laboratory Characterization of the Mobile Imager of Neutrons for Emergency Responders (MINER) System, (MINER_design_and_lab_characterization_report.docx)
3. Battery Operation of MINER (Mobile Imager of Neutrons for Emergency Responders) (Battery_Operation_of_MINER.docx)
4. Field Measurements with MINER (Mobile Imager of Neutrons for Emergency Responders) (OUO_-_Field_Measurements_with_MINER.docx)
5. High-Rise-to-High-Rise Fast Neutron Measurements by MINER (Mobile Imager of Neutrons for Emergency Responders) (SAND2014-15861R_MINER_measurements_during_Chicago_deployment.docx)

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