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R200 Spectrometer with Frisch-grid Cadmium Zinc Telluride (CZT)

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Nonproliferation and National Security Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE National Nuclear Security Administration (NNSA), Office of Nonproliferation and Verification Research and Development (NA-22)

DISCLAIMER

Title: R200 Spectrometer with Frisch-grid Cadmium Zinc Telluride (CZT)

WBS: 24.1.3.1 Nondestructive Assay Technology

Project Type: Continuing

Start Year: 2015

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PWP Amendment Log

Version #	Date Issued	Author	Summary of Changes
1.0			
1.1			

Abstract

The goal of this project is to demonstrate an engineering prototype of a gamma ray spectrometer that uses Cadmium Zinc Telluride (CZT) in a configuration comprised of an array of position-sensitive virtual Frisch grid (PSVFG) detectors and show its capability to perform functions that would be useful to the IAEA. The detectors should achieve energy resolution of 2-3% at 200 keV and <1% at > 662 keV (at temperature <30°C), thereby outperforming all hand-held instruments currently in use other than cryogenically cooled germanium. BNL is working to transfer the technology to an industrial partner so that robust, fieldable instruments can be manufactured.

Mission Relevance

STR 385, T.2: Enhance sensitivity, reliability and timeliness in sample analysis

Scope of Work

1. Overview of project including a detailed description of the technology or process to be developed.

The primary goal for this year is to demonstrate the capability of the CZT VFG technology [1] to perform essential functions needed by IAEA inspectors that provide significant advantages over currently deployed technologies [2]. In particular, the array of detector modules should operate at room temperature and show energy resolution better than 1% at 662 keV.

During FY18 BNL and FLIR evaluated two signal readout methods proposed for small CZT arrays of position-sensitive VFG.

After considering these options and taking into account previous experience and existing electronics, FLIR selected the first approach. They contracted a vendor to develop and fabricate the hybrid preamplifier board according to their specifications. This will take several months to complete, after which FLIR will assemble the prototype and will be ready to test it in October 2019.

We also conducted two field tests taking enrichment measurements of commercial UF_6 storage cylinders at Westinghouse Fuel Fabrication Facility (WFFF) using our linear array of six 5x7x25 mm^3 detectors. An anomaly was found: one cylinder seems to have a much higher count rate than the others. This is probably due to "hot spots" of daughter products that have built up in the cylinder. We also observed this in the HM-5 measurements, which were conducted at several locations around the cylinder. The low value of the derived 186-keV count rate for the CZT detector for this cylinder might be related to the higher count rate for these measurements. This needs to be further investigated.

We also investigated performance of the new 4x4 array modules, developed for the high energy gamma ray Compton camera, for spectroscopy of the low-energy gamma rays used in enrichment measurements. We were able to achieve the same energy resolution as with the linear array, <2% at 200 keV. Moreover, the efficiency of the new 4x4 array is notably higher as was expected due to its larger area. The technology of making arrays of these detectors has been proven (TRL6). They offer an economical approach to making large volume CZT detectors due to their ability to correct response non-uniformity caused by defects in standard-grade CZT crystals and should substantially reduce the overall cost of the required detectors, making the proposed instrument more affordable for the user. The detectors are hermetically sealed, and their operating temperature is maintained around 18° C using a compact Peltier cooler.

2. Description of project trajectory events, including overview of tasks, milestones, deliverables, and decision points

We plan to conduct the following activities:

Task 1 – Continue assisting FLIR in integrating and testing readout electronics based on hybrid preamplifiers and software development including enrichment estimation.

Completing integration of the prototype by FLIR will be the first milestone. FLIR's participation is an in-kind contribution from a CRADA with BNL. LLNL will complete software for the gamma analysis. BNL and SRNL will work together to agree on a feasible plan and address all necessary requirements including training and logistics. Report on FLIR prototype integration will be sent to HQ.

Task 2 – Modifying software to accommodate a new data file format

We completed upgrade a new firmware for QAC to address the problem with "dropped" events discovered during the last-year measurements at WFFF. The new firmware is based on using fast (1 GB) internet connection and will allows us to handle rates up to a 10 kHz without skipping data. It will also provide the event counts as they trigger the system and before writing data on a hard drive. This will ensure that the detector dead time is measured correctly. We need to modify the data processing and spectra plotting software to accommodate the new ASIC firmware, including the new data format.

Task 3 – Carry out a field test at WFFF using FLIR prototype

The measurements will be conducted at Westinghouse Fuel Fabrication Facility using the prototype CZT arrays. BNL will travel to SRNL. The measurements will need to be coordinated with the facility as shipping/receiving schedules allow. One cylinder will be measured at multiple points and angles to determine the technology requirements to evaluate the effect of high-count rates on detector dead times and accuracy of the U-235 enrichment estimates. Preliminary report on the field test results and enrichment evaluations will be sent HQ.

Task 4 – Data analysis and FLIR instrument performance evaluation

Based on the field tests data we will evaluate the performance of the FLIR instrument. The final report will be delivered to HQ.

Task 5: Testing a prototype of a 2x2 array of big (8x8x35 or 10x10x35 mm3) CZT detectors.

This an optional task with a goal to demonstrate performance of a 2x2 array made up of the novel large-volume Redlen crystals (8x8x35 or 10x10x35 mm^3). The digitized waveforms approach will be used to process the signals generated in the array. Such arrays with simple designs and small-number-readout-channel electronics are very attractive for handheld instruments with increased efficiency and sensitivity to high-energy gamma rays up to several MeV. If budget permits, we will use the IDEAS ASIC for digitizing the signals.

Pertinent references

1. L. A. Ocampo Giraldo; A. E. Bolotnikov; G. S. Camarda; S. Cheng; G. De Geronimo; A. McGilloway; J. Fried; D. Hodges; A. Hossain; K. Ünlü; M. Petryk; V. Vidal; E. Vernon; G. Yang; R. B. James, "Arrays of Position-Sensitive Virtual Frisch-Grid CdZnTe Detectors: Results From a 4x4 Array Prototype", IEEE Transactions on Nuclear Science, Year: 2017, Volume: 64, Issue: 10, Pages: 2698 – 2705
2. A.R. Lebrun, et al., "Gamma Emission Tomography for the Inspection of Spent Nuclear Fuel," Proc. IEEE Nuc. Sci. Sym. and Med. Im. Conf., Atlanta, GA, 10/21-10/28, 2017.

Associated Work

Project Title	Funding Agency	Years funded
24.1.3.1.1 – Frisch Grid CZT Spectrometer	NNSA (NA-241)	2015-2018
Array of Frisch-grid CZT Detectors	NNSA (NA-22)	2016-2018
Development of a Drift-bar CZT Calorimeter with Good Energy Resolution for Gamma-ray Spectroscopy	NASA	2016-2019

Technology Readiness Level

Technology Readiness Level Table

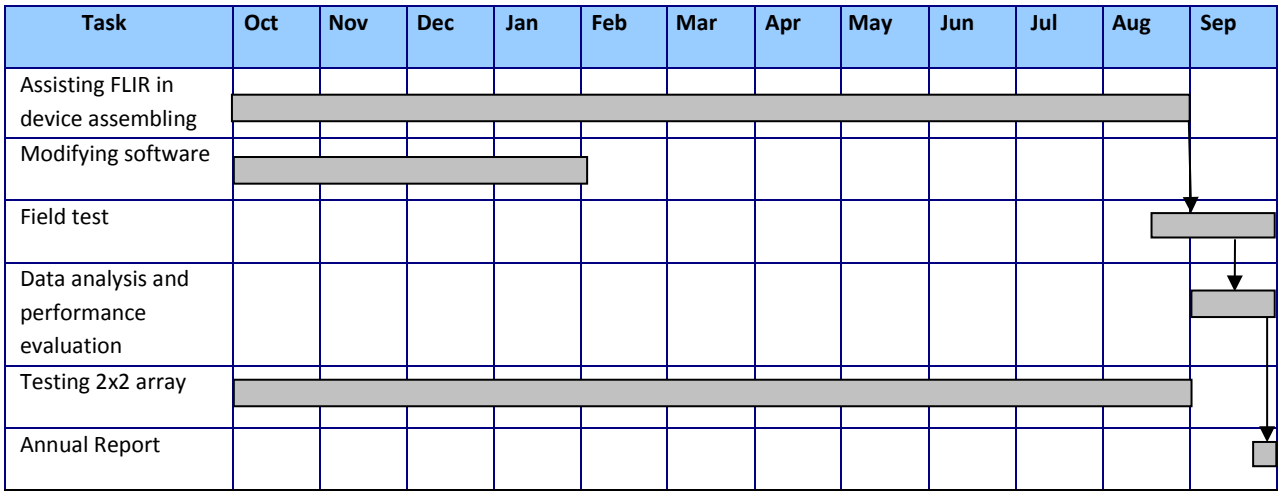
Start TRL	End TRL	Component(s)	Notes
6	7	Instrument Upgrade	Prototype arrays have been bench tested in the laboratory and used in field measurements at other sites during FY19.
6	8	Software	The software has been tested in the laboratory and in the field measurements at other sites.

Summary Table

Task No.	Event Type	Event Title	Responsible Lab	Event Date	Actual Date
1: Continue assisting FLIR	Milestone	Complete instrument prototype integration by FLIR	FLIR/BNL/LLNL	Aug 15 2020	
1	Deliverable	Report on FLIR prototype integration	BNL	Aug 15 2020	
2: Modify software	Milestone	Demonstrate modified software	BNL	Aug 15 2020	
2	Deliverable	Report on FLIR prototype integration	BNL	Aug 15 2020	
2: Field test	Field Test	Field measurements at WFFF	SRNL/BNL/LLNL/FLIR	Sep 15 2020	
2	Deliverable	Field test plan	BNL/SRNL/FLIR/LLNL	Aug 15 2020	
4: Data analysis and performance evaluation	Milestone	Acquired data from the field test	SRNL/BNL	Sep 20 2020	
4	Deliverable	Preliminary report on the test results	BNL/SRNL/LLNL	Sep 25 2020	
5: Testing 2x2 array of big CZT crystals	Milestone	Complete array testing	BNL	Aug 15 2020	
5	Deliverable	Report on test results	BNL	Aug 15 2020	
Annual Report	Deliverable	End of year report with field test results of the instrument prototype	BNL/SRNL/LLNL	Sep 30 2020	

Quarterly Reports will be due on January 10, April 10, July 10, and October 10.

Gantt Chart (FY20)



Joule Metric

A completed detector will be shipped to the IAEA (Q1FY21)

Funding by Task

Project Budget Table

Task	BNL Funding ($K)	SRNL Funding ($K)	LLNL Funding ($K)	Total ($K)
1: Continue assisting FLIR	$21	$0	$20	$67
2: Modifying software	$30			$30
3: Field test	$30	$20	$20	$70
4: Data analysis and performance evaluation	$25	$0	$25	$50
5: Testing 2x2 array	$50			$50
TOTAL	$176	$20	$65	$241

Helium-3 Allocation

N/A

Project Risks and Mitigation Plan

Risk	Level [H/M/L]	Mitigation
FLIR scheduler could be delayed due to the company management decision and development team's involvement in other projects.	L	Continuously monitoring FLIR progress. Provide technical help and in fabrication of needed hardware components (e.g., instrument enclosure, power supplies, developing a data analysis code) if necessary.

Anticipated Future Needs and Activities

Year	New Funding ($K)	Anticipated Future Tasks
FY21	230	Upgrading instrument, stability testing

Mortgage Table

Conferences and Workshops

Conference or Workshop Attendance	Budget Allocation ($K)
None	