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The Polaris-H imaging spectrometer

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ABSTRACT

Recently, H3D has designed and introduced a gamma-ray imaging spectrometer system named Polaris-H. Polaris-H was designed to perform gamma spectroscopy and imaging throughout nuclear power plants. It integrates a 3D-position-sensitive pixelated CZT detector (20 mm × 20 mm × 15 mm), associated readout electronics, an embedded computer, a 5-h battery, and an optical camera in a portable water-proof enclosure. The total mass is about 4 kg, and the system startup time is 2 min. Additionally, it has a connection for a tablet, which displays a gamma-ray spectrum and isotope-specific images of the gamma-ray distribution in all directions in real time. List-mode data is saved to an external USB memory stick. Based on pixelated depth-sensing technology, spectroscopy is routinely better than 1.1% FWHM at 662 keV, and imaging efficiency at 662 keV varies less than a factor of two for all directions, except through the battery. Measurements have been performed in contaminated environments, in high radiation fields, and in cramped quarters.

1. Introduction

Three-dimensional-position-sensitive CdZnTe (CZT) detectors were first proposed over a decade ago [1]. In these detectors, electron clouds produced by gamma-ray interactions in a CZT crystal drift in an applied electric field, inducing a signal on the planar cathode and on one of the 1.72-mm-pitch pixels on the anode surface (part of an array of 11-by-11 pixels). The lateral position of the interaction is determined by the anode pixel that sees the signal. The interaction depth is determined by drift time of the electron cloud and/or the ratio of the cathode to the anode signal amplitude. As long as interactions occur under different pixels, multiple interaction positions – and the energy deposited at each – can be recorded simultaneously [2]. This 3D position sensitivity allows calibration on a voxel-by-voxel basis (producing energy resolution often below 1% FWHM at 662 keV) [3] and localization of gamma-ray interactions in the crystal (permitting Compton imaging) [4]. Since the original proposal of this technology, progress has been made on materials, detector mounting, readout, event reconstruction, calibration, and imaging. These improvements have made the technology suitable for use commercially in the field.

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In this paper, we describe the design of Polaris-H—its hardware and software configuration, and some of the requirements which drove this design. We then report energy resolution and efficiency of Polaris-H and show an example measurement that reflects some of its capabilities. Finally, we conclude with other applications and possible future improvements to Polaris-H.

2. Design achievements

Polaris-H was designed specifically for measurements in nuclear power plants, which drove design decisions. The instrument is portable, so it can be moved about the plant easily, including into cramped areas like crawl spaces and manholes. This drove the decision for using only a single detector crystal and tight packing of components into the box, with tradeoffs in lower efficiency and thermal performance. The system also operates in contaminated environments. Therefore, as much as possible, it is made of material that does not absorb contamination, and all surfaces that are open to the air are easy to clean or replace. From the point of view of a user operating it in high-dose areas, it is simple and fast to operate, with features to help the user limit time in the area and operate remotely whenever possible. All portions of the system have secure attachment points, so they may be used in areas with Foreign Material Exclusion (FME).

The system offers spectroscopy and imaging performance sufficient to make detailed measurements to elucidate reactor performance and uncover potential problems. In the spectroscopic domain, Polaris-H can to distinguish important lines found at nuclear plants, such as the lines at 810 keV, 818 keV, and 834 keV from Co-58, Ag-110 m, and Mn-54, respectively. The 1674 keV line from Co-58 and the 1691 keV line from Sb-124 are also separable. Because of significant continuum from scattered gamma rays at nuclear power plants, good energy resolution decreases the background and continuum counts underneath full-energy peaks. Similarly, reduced counts under a peak leads to improved imaging performance by reducing the number of counts from the continuum.

3. Hardware

At the core of Polaris-H is the CZT crystal and readout ASIC, as described in other reports [5], operated at 30 °C. The CZT is mounted on a read-out board carrying an FPGA and supporting electronics for the ASIC. The FPGA controls biasing of the crystal to a predetermined voltage between 1000 V and 3000 V within 90 s. Also in the enclosure is a high-voltage and power board that converts the incoming DC power from the battery or power plug into the necessary voltages for the FPGA, ASIC, and cathode bias and provides un-interrupted power switching between wall and battery power.

After reaching the FPGA, the data is converted into useful information for the user. Raw event data could be transferred to a mobile device or base station for real-time analysis, but for ease of implementation, Polaris-H uses an embedded ARM-processor which applies the calibration to the raw data, makes a spectrum, does spectral detection and ID, makes an image for each detected (or requested) isotope that is overlaid on the real-time optical image, and serves a real-time interactive web page. The results are viewed with a tablet display that connects to the system or over an internet network connected to Polaris-H. Having an embedded computer also allows Polaris-H to save data to a USB flash drive connected to the system and to run with no tablet nor computer connected.

In order to more easily interpret the radiation image, it is matched to an optical image to know which objects are in the hottest direction(s). An almost-2π fish-eye camera is mounted in the enclosure, only 4 cm from the detector to minimize parallax. These images are captured by the computer and used as an underlay for the radiation image.

The enclosure also contains a 100-W h lithium-ion battery. It charges whenever the unit is attached to wall power and will last 4 to 5 h, depending on use conditions.

The enclosure itself is constructed from an aluminum block. It holds all the components described above in a water-resistant box for ease of decontamination. All seals are IP65 or better. In addition, most outside surfaces are smooth to reduce particulate contamination attachment. For heat dissipation, heat-generating components are mounted to a center aluminum bulkhead which distributes heat onto fins on the top and bottom surfaces of the enclosure. A small fan blows over those smooth fins, through a shroud that helps to direct air. This fan can be removed or replaced if it becomes contaminated. A CAD drawing of the enclosure is shown in Fig. 1. Also on the enclosure is an indicator LED, which can provide system status to the user (starting up, normal operation, error, etc.) without needing to attach the tablet display.

Not including the tablet display, Polaris-H is 4.07 kg and 21 cm × 19 cm × 13 cm. Fig. 2 shows a picture of the outside of an enclosure, with important features labeled.

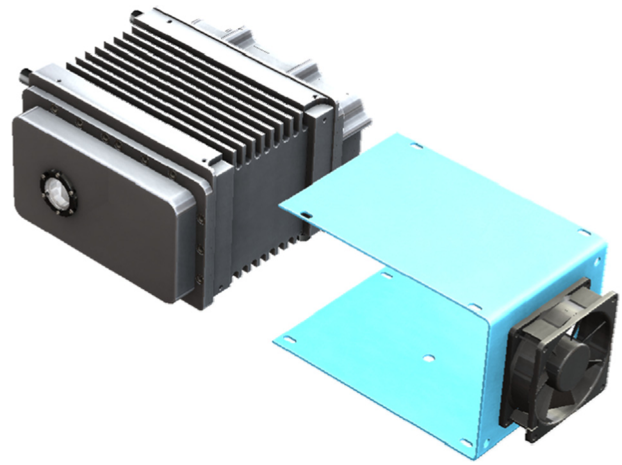

Fig. 1. A drawing of the Polaris-H enclosure, showing the removable fan and shroud that fits over heat-dissipation fins.

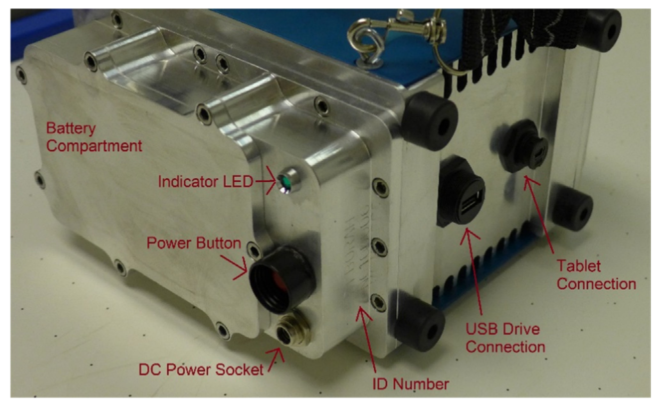

Fig. 2. The Polaris-H enclosure, with important features labeled.

4. Software

The user interface is viewed through a tablet or networked device, and consists of several pages.

The main "observation" page in Fig. 3a gives an overview of the current measurement. Here, the user can view the elapsed time of the measurement, see the real-time spectrum with detected peaks and isotopes highlighted, and see an image for the selected isotope. The selected isotope is also highlighted in red on the spectrum. Further details of the spectrum and image are accessible by clicking on them. Fig. 3 shows some of the other pages for this measurement, to choose isotopes and explore the spectrum and image.

5. Performance

The most important parameters for detection performance of the system are energy resolution, efficiency, and peak-to-total ratio. For imaging, performance also depends on angular resolution, size of side-lobes in the point-spread function, imaging efficiency, and sensitivity over the field of view. Here we report measurements of most of these parameters.

First, energy resolution as a function of energy is shown in Fig. 4 for a representative detector. Resolution was determined from lab measurements of various sources by measuring the width of each peak in the spectrum at half its maximum height. Resolution is below 1.1% full width at half maximum (FWHM) at 662 keV for all events in the detector. When only considering gamma rays that interact once in the detector (under one pixel), the resolution improves to below 0.8% FWHM. This is primarily because less noise is integrated into the signal when only one pixel must be read out. In Fig. 4, the resolution for all events at 1592 keV is better than would otherwise be expected because this line is the double-escape peak from 2614 keV. The