Radioxenon Measurements using a Well-type Phoswich Detector and Real-time FPGA-based Digital Pulse Processing

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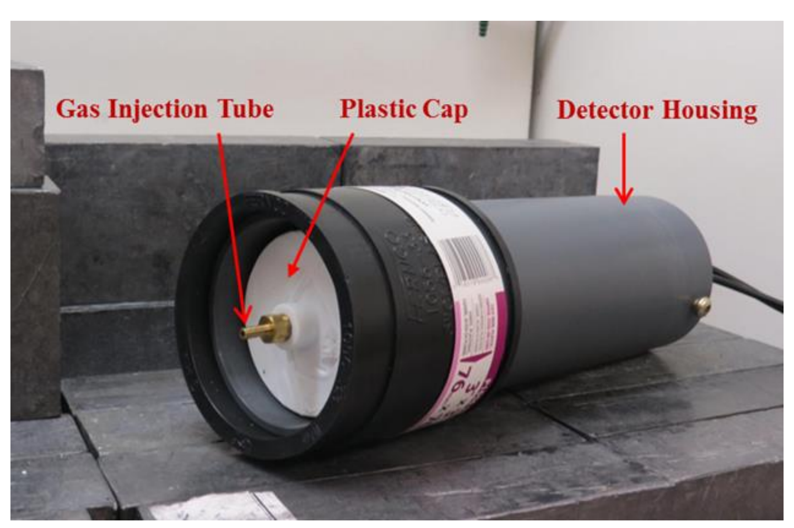
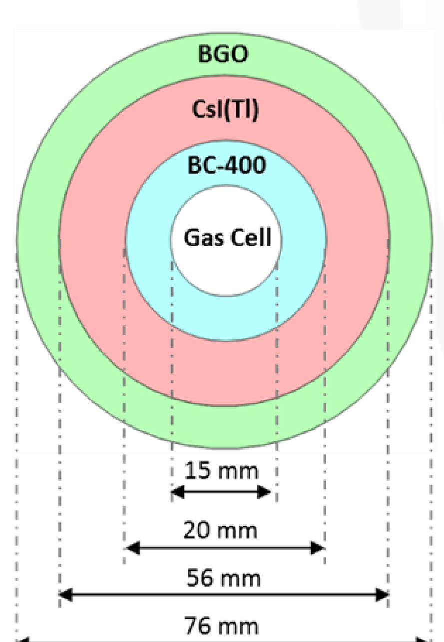
RESEARCH OBJECTIVE

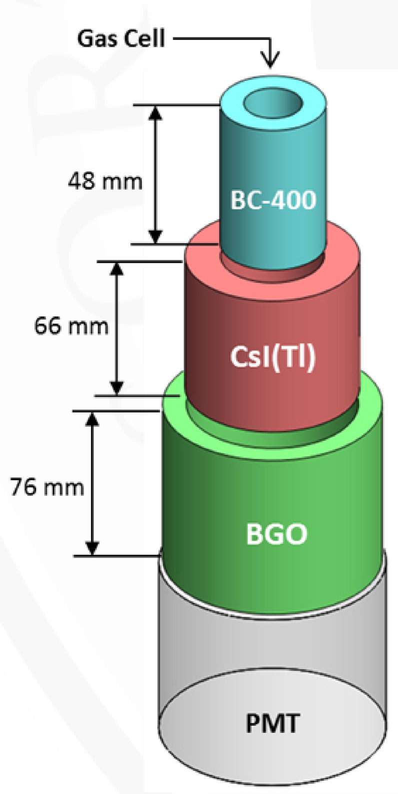
In this work, a well-type phoswich detector with three scintillation layers has been designed and tested for monitoring atmospheric xenon radioisotopes. The detector was made by optically coupling three concentric cylindrical scintillation layers (BC-400, CsI(Tl) and BGO) to a single photomultiplier tube (PMT). Beta-gamma coincidence events from radioxenon isotopes are identified when a coincidence energy absorption is detected in the first (BC-400) and second (CsI(Tl) crystal) scintillation layers. In order to identify and reject scattered photons from the CsI(Tl) crystal, the crystal is surrounded by a BGO scintillation layer.

WASPD DESIGN

The International Monitoring System (IMS) is a worldwide sensor network established for the purpose of detecting nuclear weapon tests. One way this can be done is to monitor concentrations of key xenon radioisotopes in the atmosphere. The Well-type Actively-Shielded Phoswich Detector (WASPD) was developed to measure trace quantities of radioxenon isotopes in the atmosphere via beta-gamma coincidence method.







Scintillator	BC-400	CsI(Tl)	BGO
Decay time (ns)	2.4	~1000	300
Light output (photon/MeV)	13,000	65,000	8200
Peak emission (nm)	423	540	480
Refractive Index	1.58	1.8	2.15
Density (g/cm³)	1.032	4.51	7.13

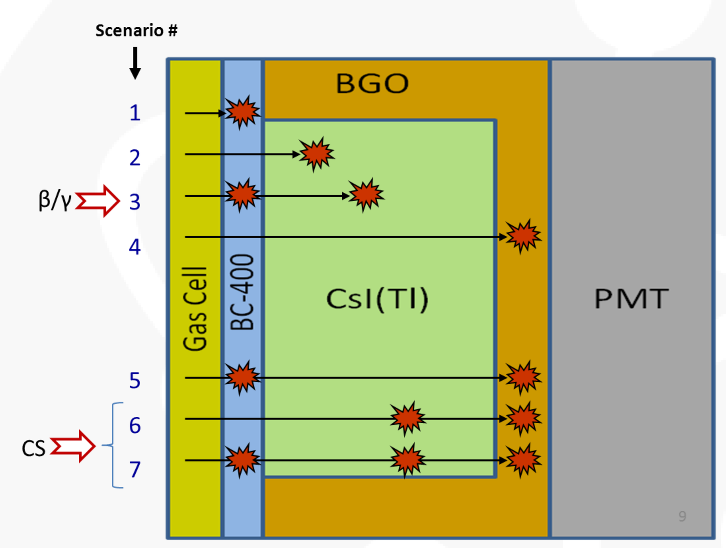
Physical properties of scintillators used in the phoswich detector.

DIGITAL PULSE PROCESSING

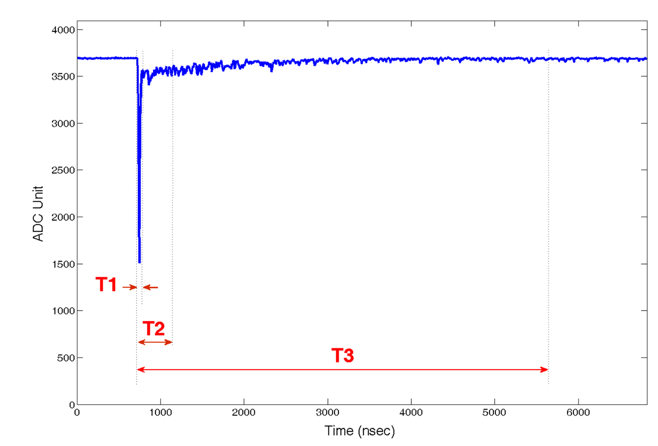
In order to discriminate between scintillator pulses, each anode pulse is integrated over three time intervals T1, T2, and T3. These three integrations yield three integration values: S1, S2, and S3. Two ratios, called the fast-component ratio (FCR) and slow-component ratio (SCR) are calculated based on these integration values.

$$FCR = \frac{S1}{S2} \qquad SCR = \frac{S2-S1}{S3-S1}$$

The FCR and SCR values for each pulse determine whether an event is recorded as a beta, gamma, or coincidence event.



Depending on how the radiation interacts with the phoswich, seven possible pulse shapes or types could be generated.



A typical coincidence pulse from the phoswich detector. In order to discriminate pulses from different events, each valid pulse is integrated over three time intervals (T1, T2 and T3).

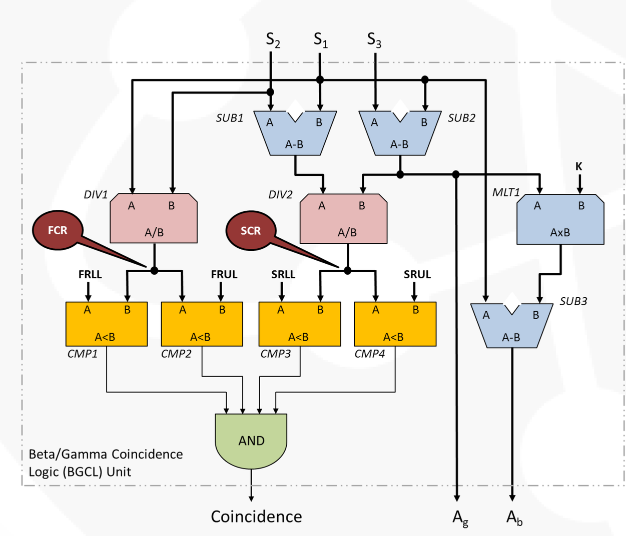


Illustration of the beta-gamma coincidence logic . The FCR and SCR are calculated based on integration values S1, S2, and S3. The FCR and SCR together determine event coincidences.

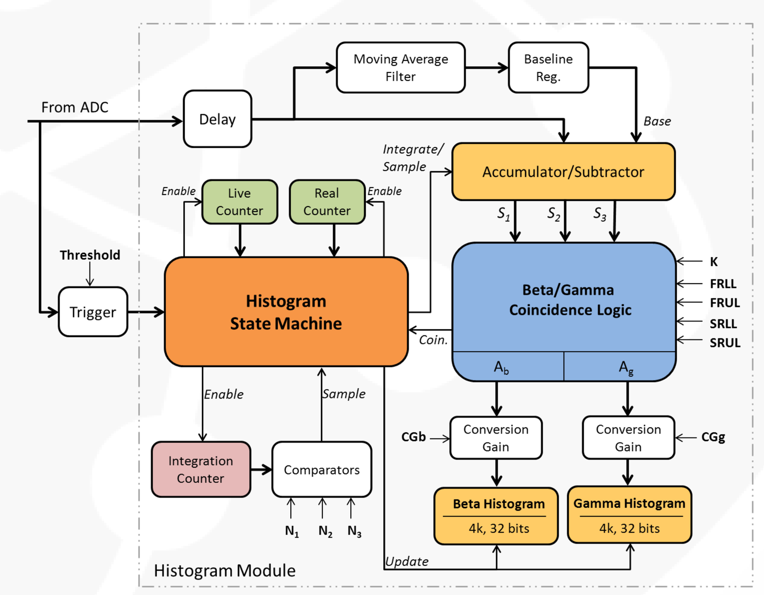
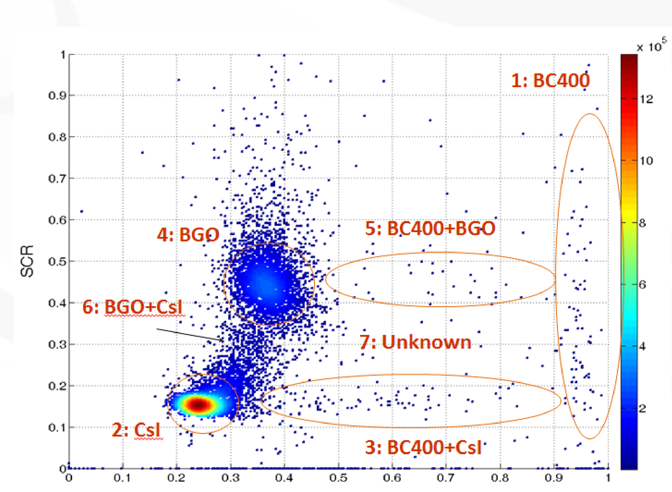


Illustration of the histogram generation algorithm. The histogram is updated with the energy values for beta and gamma interactions as dictated by the coincidence logic.



Scatter plot of SCR vs FCR values for a set of real WASPD pulses. The seven regions illustrated correspond to the seven different types of interactions with the different scintillator layers.

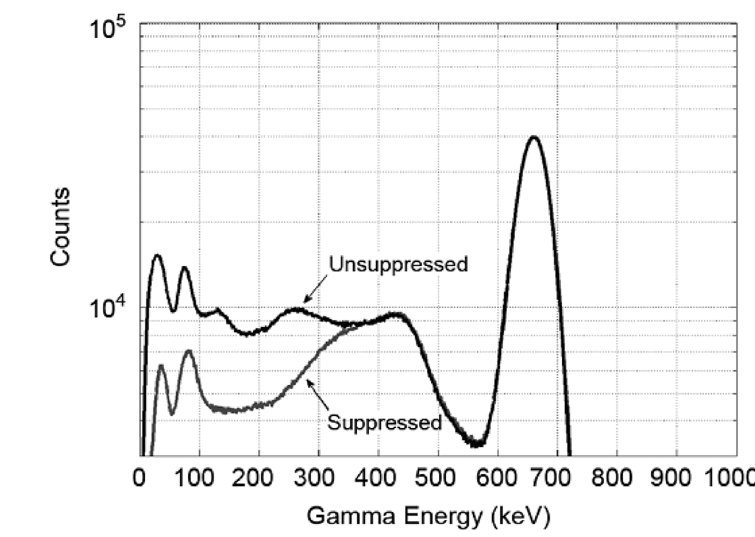
The integration values S1, S2, and S3 are also used to calculate the energy deposited in the CsI(Tl) (Ag) and BC-400 (Ab) layers.

$$Ag = S3 - S1$$

$$Ab = S1 - K(S3 - S1) = S1 - KAg$$

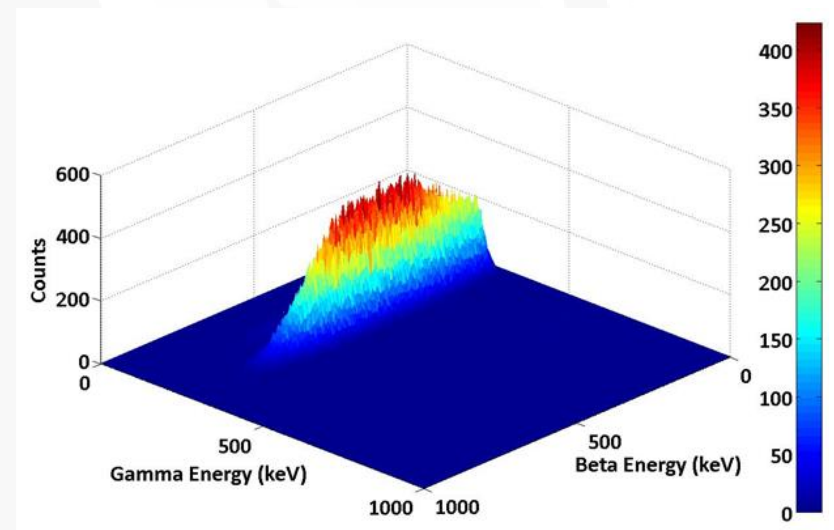
COMPTON SUPPRESSION

The well-type design of the WASPD affords it good Compton suppression capability. This is accomplished by rejecting events that occur in any of the BGO and combined-BGO regions of the FCR/SCR plot.

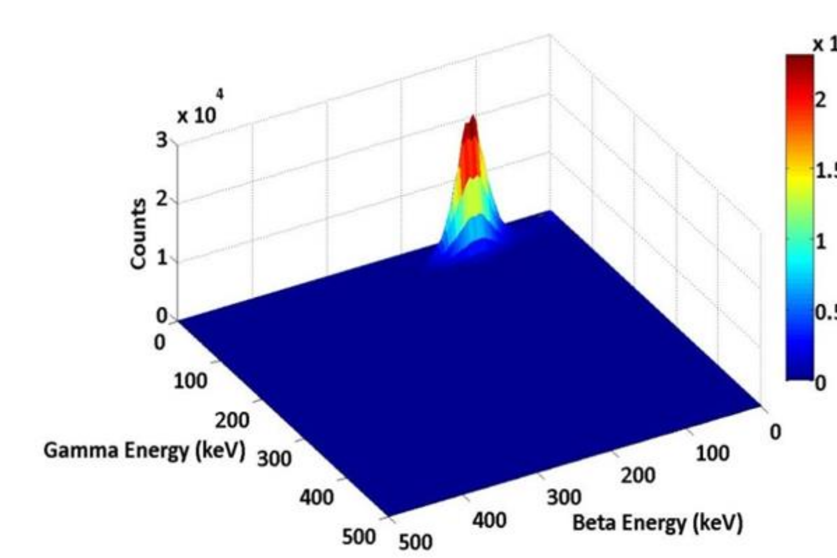


RADIOXENON MEASUREMENTS

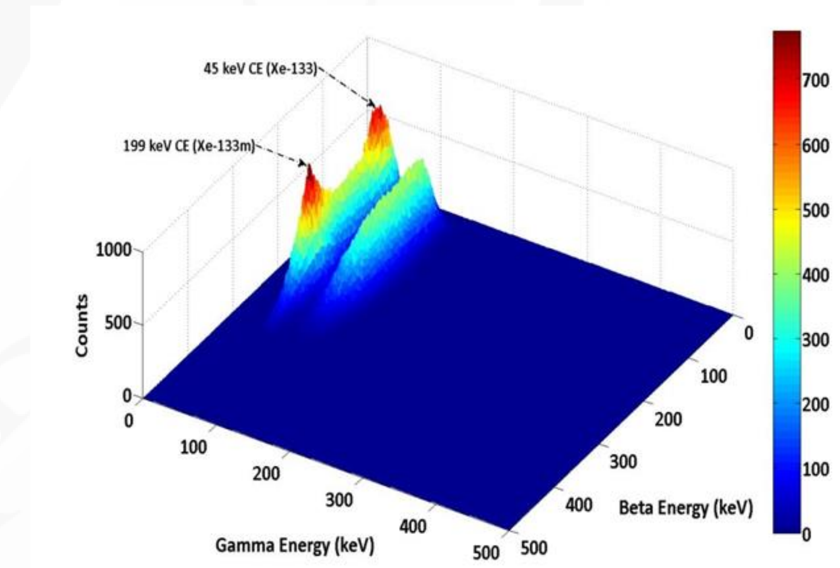
Xe-135, Xe-133m, Xe-133, and Xe-131 samples generated using the OSU TRIGA reactor were all measured using the WASPD. The pulse processing algorithm was able to successfully perform the beta-gamma coincidence gating to generate coincidence spectra using CsI(Tl) + BC400 events in real-time.



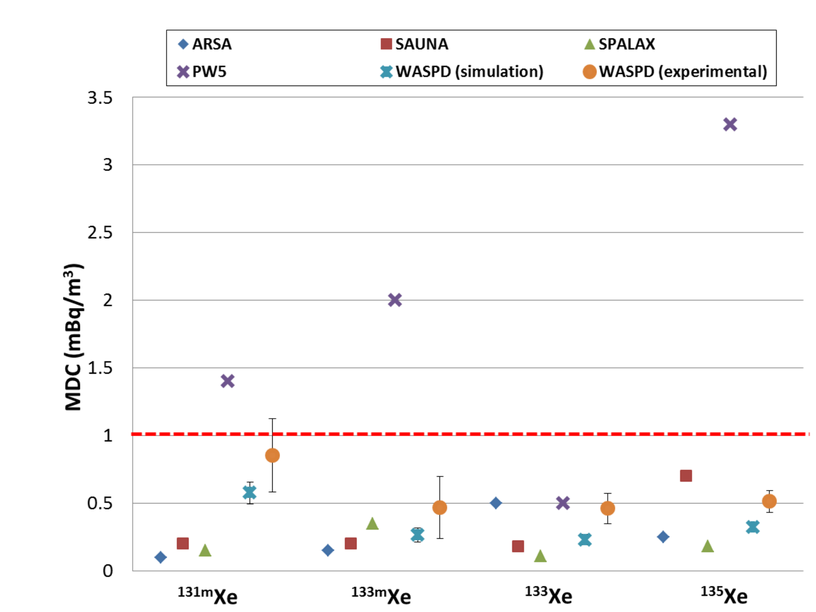
^{135}Xe, 3-D beta-gamma coincidence energy spectrum.



^{133m}Xe/^{133}Xe, 3-D beta-gamma coincidence energy spectrum.



^{131m}Xe, 3-D beta-gamma coincidence energy spectrum.



MDC comparison with other radioxenon detection system. The dashed red line shows the minimum MDC requirement set by the International Monitoring System (IMS).

The percent FWHM for each of the X-ray energies of interest were 51.7% at 31 keV (^{131m}Xe), 47.7% at 31 keV (^{133m}Xe and ^{133}Xe), 27.6 % at 81 keV (^{133m}Xe), and 19.3% at 250 keV (^{135}Xe). MDC calculations on both simulation and experimental data indicate that the WASPD is capable of meeting the minimum 1 Bq/m³ detection requirement.

National Nuclear Security Administration