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# Method for Calculating Radon Activity and Radon Rejection

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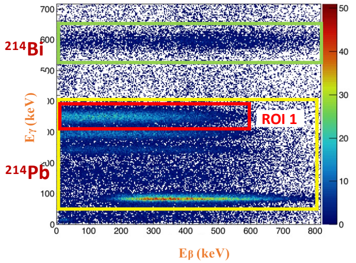
## Introduction

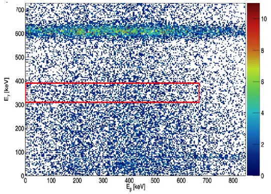
Atmospheric radioxenon systems extract xenon from the atmosphere to monitor for nuclear explosions. The xenon is purified via chemical separation to remove and reject contaminants like radon. A few radon atoms on occasion may still be present in the purified xenon sample and will make it to the nuclear detectors during the sample measurement which can negatively impact the xenon detection sensitivity. The daughter isotopes of $^{222}$Rn, $^{214}$Pb and $^{214}$Bi, decay via $\beta^-$ decay and their decay signatures blanket the entire coincidence histogram used by the net-count method to determine activity concentrations and minimum-detectable-concentrations (MDC). Currently, the net-count method does not quantify radon nor is the rejection level for a radioxenon system predicatively predetermined.



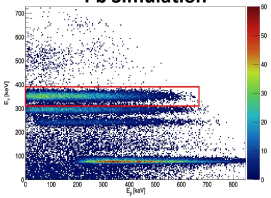

## Radon daughter simulations to determine abundance

Radon is not directly seen on the coincidence plot, but rather its daughter particles of $^{214}$Pb and $^{214}$Bi. Due to the rather short half life of each daughter, it would be challenging to get a pure measurement from either. A Monte Carlo simulation is used to determine the fractional abundance, $F_{214_{Pb}}$, of $^{214}$Pb in ROI 1 to determine the number of counts in ROI 1 directly coming from $^{214}$Pb.

**$^{214}$Bi Simulation**



**$^{214}$Pb Simulation**



## Radon Activity Calculations

The number of counts throughout the measurement from $^{214}$Pb is used to determine the activity of $^{222}$Rn using the Bateman equations. Since only xenon and a few atoms of radon can make it to the nuclear detectors, the activity of radon can only be known at the time of the measurement. If the radon rejection level is accurately known, the activity and concentration of radon can be back calculated to the sample measurement time.

Acquisition Time

$$\Delta C_{214_{Pb}} = \int_0^{T_A} A_{214_{Pb}} dt = A_{222_{Rn}}\Big|_{t=0} \lambda_{214_{Pb}} \left( \frac{1}{\lambda_{218_{Po}} - \lambda_{222_{Rn}}} \frac{\frac{\lambda_{218_{Po}}}{\lambda_{222_{Rn}}}}{\lambda_{214_{Pb}} - \lambda_{222_{Rn}}} \left(1 - e^{-\lambda_{222_{Rn}} T_A}\right) - \frac{1}{\lambda_{218_{Po}} - \lambda_{222_{Rn}}} \frac{1}{\lambda_{214_{Pb}} - \lambda_{218_{Po}}} \left(1 - e^{-\lambda_{218_{Po}} T_A}\right) + \frac{1}{\lambda_{214_{Pb}} - \lambda_{222_{Rn}}} \frac{\frac{\lambda_{218_{Po}}}{\lambda_{214_{Pb}}}}{\lambda_{214_{Pb}} - \lambda_{218_{Po}}} \left(1 - e^{-\lambda_{214_{Pb}} T_A}\right) \right) = A_{222_{Rn}}\Big|_{t=0} B(T_A)$$

Counts in ROI 1

$$A_{222_{Rn}}\Big|_{t=0}(Bq) = \frac{\Delta C_{214_{Pb}}}{B(T_A)} = \frac{\Delta C_{ROI\,1} * F_{214_{Pb}}}{\varepsilon_\gamma \varepsilon_\beta BR_\gamma BR_\beta * B(T_A)}$$

Detector Efficiency

Branching Ratio

$$MDA_{222_{Rn}}(mBq) = \frac{2.71 + 4.65\sigma_0}{\varepsilon_\gamma \varepsilon_\beta BR_\gamma BR_\beta} \frac{1000}{B(T_A)}$$

## Radon Rejection Levels

Radon interferes with radioxenon activity counts. Therefore, as more radon is introduced to a system, the MDC values for xenon will increase. The interference ratio of a detector was determined by introducing a radon spike into the detector. Using the relationship of counts to activity, simulated levels of radon were introduced to the cell and artificial counts were placed in ROI 1. The corresponding number of counts were placed in the other ROIs using the interference ratio. The MDA for each xenon isotope was then calculated. Starting with a known level of radon, 250 Bq, the impact of different radon rejection levels can be explored to determine the appropriate rejection level needed to minimize impact on MDC.

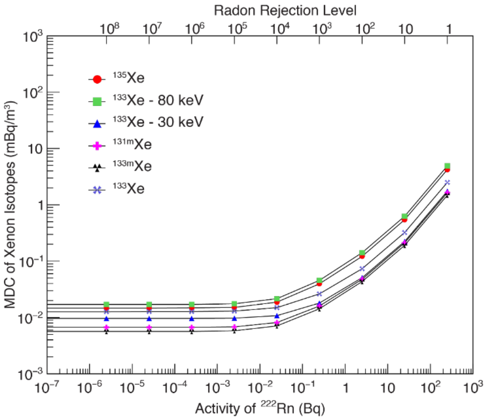
Collection Time

$$MDA_{Xe}(mBq) = \frac{2.71 + 4.65\sigma_0}{\varepsilon_\gamma \varepsilon_\beta BR_\gamma BR_\beta} \frac{1000\lambda T_C}{(1 - e^{-\lambda T_C}) e^{-\lambda T_P} (1 - e^{-\lambda T_A})},$$

Processing Time

$$MDC_{Xe}(mBq/SCM) = MDA_{Xe}/V_{Air}$$

## Radon rejection levels of a sample with 250 Bq of radon in air




## Conclusion

Radon activity measurements can now be performed to quantify the rejection level of a system. In the 250 Bq example, a radon rejection level of $10^5$ is sufficient to limit the impact on the sensitivity of the detector. Atmospheric radon levels vary both geographically and seasonally. Understanding the local levels of radon for the location a detector system will be placed will allow for a better evaluation of the appropriate radon rejection level needed for a system.

# Method for Calculating Radon Activity and Radon Rejection

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ABSTRACT

Radioxenon detection systems chemically separate and purify xenon from the collected atmospheric sample. These systems reject radon to a high degree during this processing step. On occasion, radon will make it to the nuclear detectors and its progeny will interfere with the radioxenon measurement. The minimum-detectable-concentration values of an atmospheric monitoring system will also be negatively impacted by the presence of this radon. To minimize these consequences, it is important to understand how much radon made it to the nuclear detectors and its effect. We have developed a way to calculate the activity of radon in the nuclear detectors using the coincidence beta-gamma spectrum and to determine the impact to the minimum-detectable-concentrations. This presentation will discuss the method to calculate the radon rejection levels needed to maintain optimal radioxenon detection sensitivity and the impact of radon on radioxenon uncertainties.

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## INTRODUCTION

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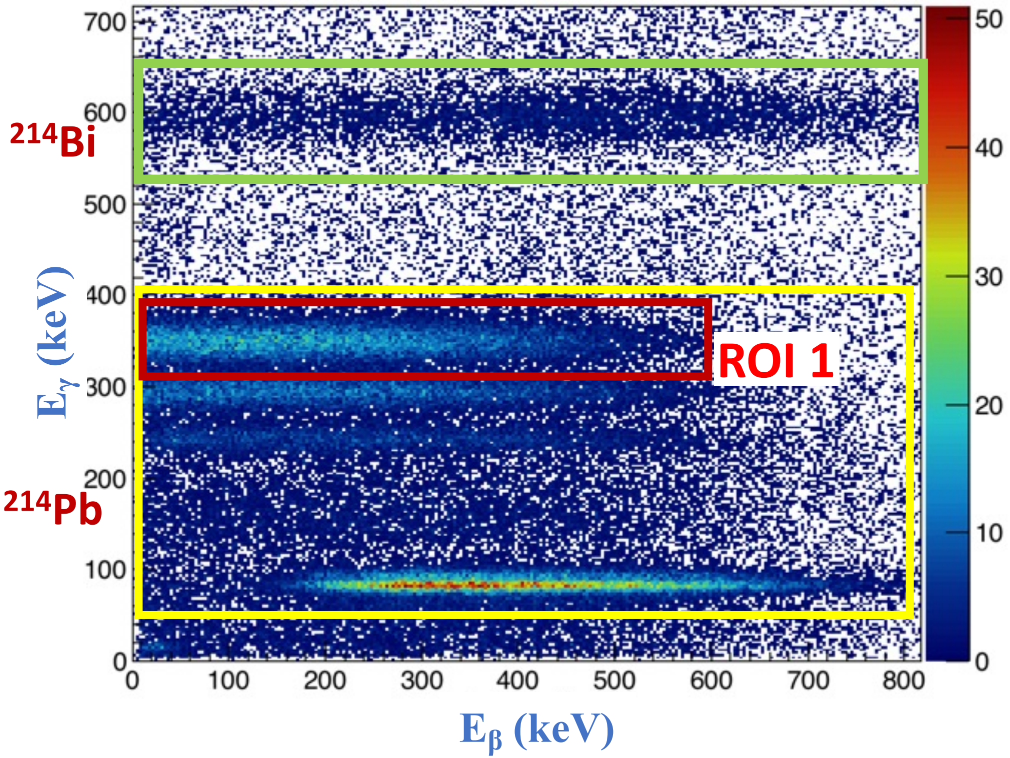

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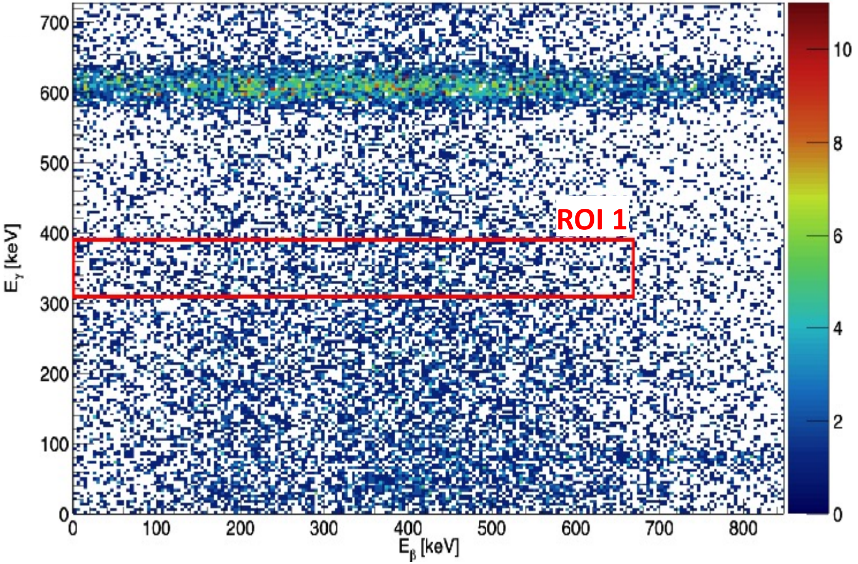
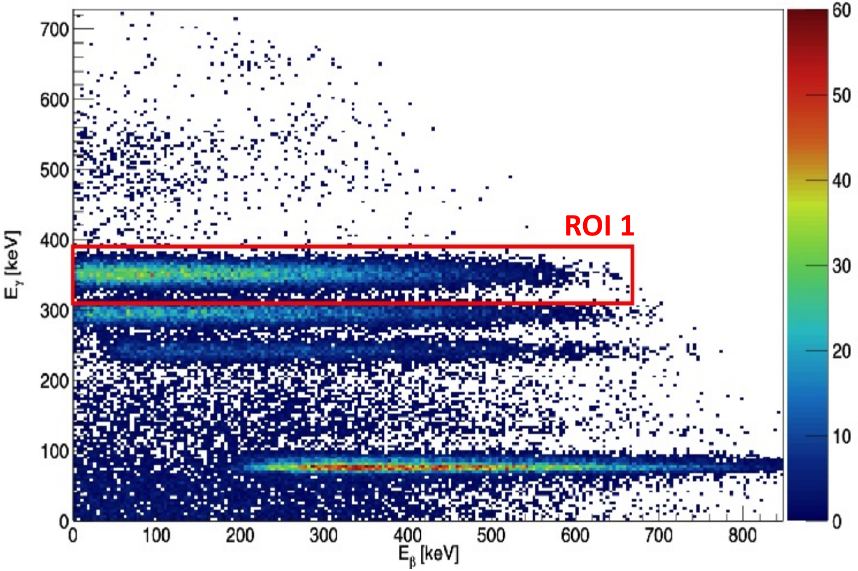
## RADON DAUGHTER SIMULATIONS TO DETERMINE ABUNDANCE

Radon is not directly seen on the coincidence plot, but rather its daughter particles of $^{214}$Pb and $^{214}$Bi. Due to the rather short half life of each daughter, it would be challenging to get a pure measurement from either. A Monte Carlo simulation is used to determine the fractional abundance, $F_{^{214}Pb}$, of $^{214}$Pb in ROI 1 to determine the number of counts in ROI 1 directly coming from $^{214}$Pb.

**$^{214}$Bi Simulation**




**$^{214}$Pb Simulation**



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## RADON ACTIVITY CALCULATIONS

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Acquisition Time

$$\Delta C_{214_{Pb}} = \int_0^{T_A} A_{214_{Pb}} dt = A_{222_{Rn}}\Big|_{t=0} \lambda_{214_{Pb}} \left( \frac{1}{\lambda_{218_{Po}} - \lambda_{222_{Rn}}} \frac{\frac{\lambda_{218_{Po}}}{\lambda_{222_{Rn}}}}{\lambda_{214_{Pb}} - \lambda_{222_{Rn}}} \left(1 - e^{-\lambda_{222_{Rn}} T_A}\right) - \frac{1}{\lambda_{218_{Po}} - \lambda_{222_{Rn}}} \frac{1}{\lambda_{214_{Pb}} - \lambda_{218_{Po}}} \left(1 - e^{-\lambda_{218_{Po}} T_A}\right) + \frac{1}{\lambda_{214_{Pb}} - \lambda_{222_{Rn}}} \frac{\frac{\lambda_{218_{Po}}}{\lambda_{214_{Pb}}}}{\lambda_{214_{Pb}} - \lambda_{218_{Po}}} \left(1 - e^{-\lambda_{214_{Pb}} T_A}\right) \right)$$

$$= A_{222_{Rn}}\Big|_{t=0} B(T_A)$$

Counts in ROI 1

$$A_{222_{Rn}}\Big|_{t=0} (Bq) = \frac{\Delta C_{214_{Pb}}}{B(T_A)} = \frac{\Delta C_{ROI\,1} * F_{214_{Pb}}}{\varepsilon_\gamma \varepsilon_\beta BR_\gamma BR_\beta * B(T_A)}$$

Detector Efficiency

Branching Ratio

$$MDA_{222_{Rn}}(mBq) = \frac{2.71 + 4.65\sigma_0}{\varepsilon_\gamma \varepsilon_\beta BR_\gamma BR_\beta} \frac{1000}{B(T_A)}$$

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RADON REJECTION LEVEL

Radon interferes with radioxenon activity counts. Therefore, as more radon is introduced to a system, the MDC values for xenon will increase. The interference ratio of a detector was determined by introducing a radon spike into the detector. Using the relationship of counts to activity, simulated levels of radon were introduced to the cell and artificial counts were placed in ROI 1. The corresponding number of counts were placed in the other ROIs using the interference ratio. The MDA for each xenon isotope was then calculated. Starting with a known level of radon, 250 Bq, the impact of different radon rejection levels can be explored to determine the appropriate rejection level needed to minimize impact on MDC.

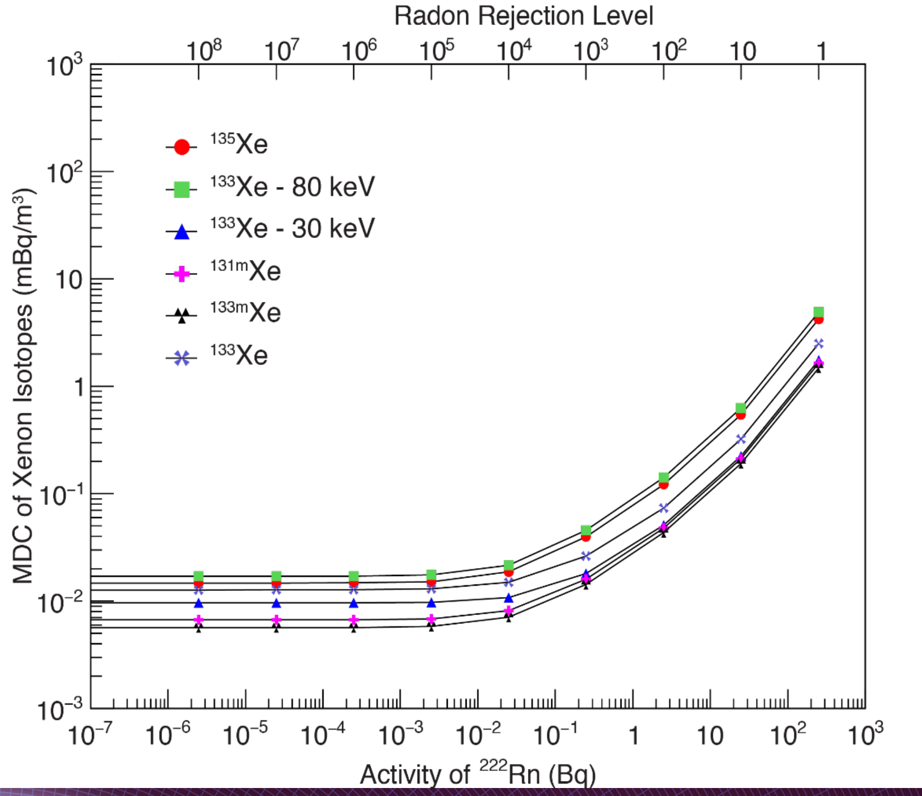
Collection Time

$$MDA_{Xe}(mBq) = \frac{2.71+4.65\sigma_0}{\varepsilon_\gamma \varepsilon_\beta BR_\gamma BR_\beta} \frac{1000\lambda T_C}{(1-e^{-\lambda T_C})e^{-\lambda T_P}(1-e^{-\lambda T_A})},$$

$$MDC_{Xe}(mBq/SCM) = MDA_{Xe}/V_{Air}$$

Processing Time

Radon rejection levels of a sample with 250 Bq of radon in air



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## CONCLUSIONS

Radon activity measurements can now be performed to quantify the rejection level of a system. In the 250 Bq example, a radon rejection level of $10^5$ is sufficient to limit the impact on the sensitivity of the detector. Atmospheric radon levels vary both geographically and seasonally. Understanding the local levels of radon for the location a detector system will be placed will allow for a better evaluation of the appropriate radon rejection level needed for a system.