CTBTO.ORG

WOSMIP
4 - 7 December 2023
Santiago, Chile

CTBTO
PREPARATORY COMMISSION

COMPREHENSIVE
NUCLEAR-TEST-BAN
TREATY ORGANIZATION

Updating Algorithms of Isotopic Activity Ratios and associated Thresholds for Screening CTBT-relevant Nuclear Events

Boxue Liu, Joshua Kunkle, Yuichi Kijima, Robin Schoemaker, Mark Prior
IDC/CTBTO, Vienna, Austria

Introduction: A staged UNE event characterization

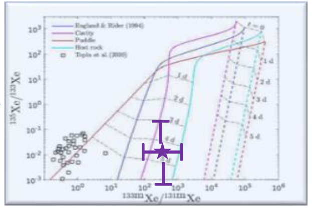
UNE release scenarios

RN detections at IMS stations

Event Characterization - Source Identity Hypothesis Testing

UNE Isotopic Evolution Scenario Library

Cavity-To-Surface Transport Scenario



Atmospheric Transport Scenario

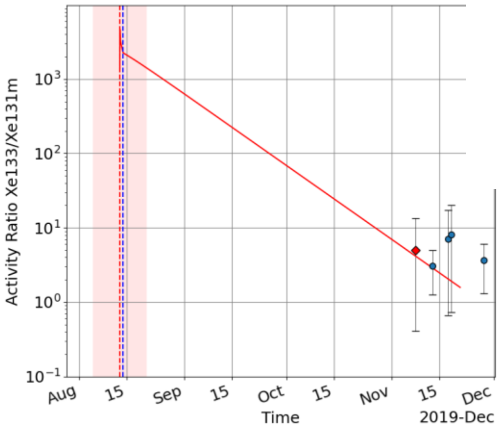
Sampling - Concentration Profile Scenario

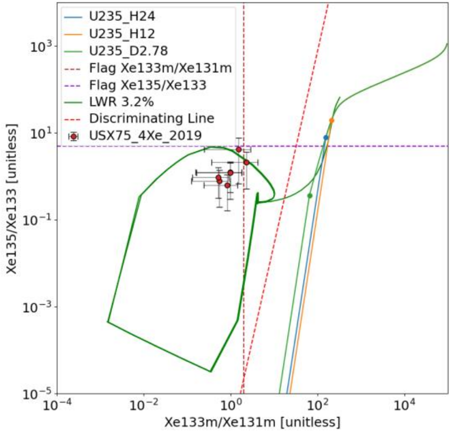
IDC spectrum analysis of IMS samples

Evolution of isotopic activity ratios over time connects sample measurements at IMS RN stations to an assumed UNE scenario.

Introduction: Event characterization

- Event characterization of CTBT-relevant nuclear events is performed using the four radioxenon plot, 2D plots of activity concentrations and evolution plots of activity ratios of paired isotopes.
- It is based on the evolution through activities released at the explosion site to activity concentrations in the plume of air over IMS stations.
- This work focus on the event screening using isotopic ratios: algorithms and associated thresholds.

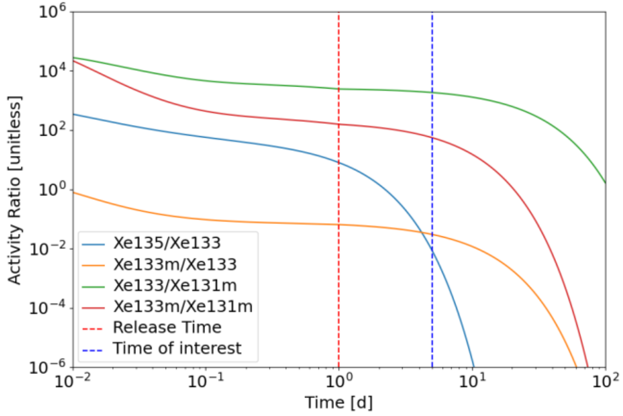




Issues for event screening

Bayesian limits for event screening flag in A/RRRs

- Lower limits of isotopic ratios are used.
  - Xe-135/Xe-133>5,
  - Xe-133m/Xe-133>0.3,
  - Xe-133m/Xe-131m>2,
  - Xe-133/Xe-131m>1000 (to be implemented)
- How should we set these thresholds?
  - 0.3 of Xe-133m/Xe-133 is < 1 day.
  - 5 of Xe-135/Xe-133 is by 1 day.
- What should these thresholds be based on?
  - Release scenarios by given days post of UNE, or
  - Distributions of isotopic ratios at IMS stations.

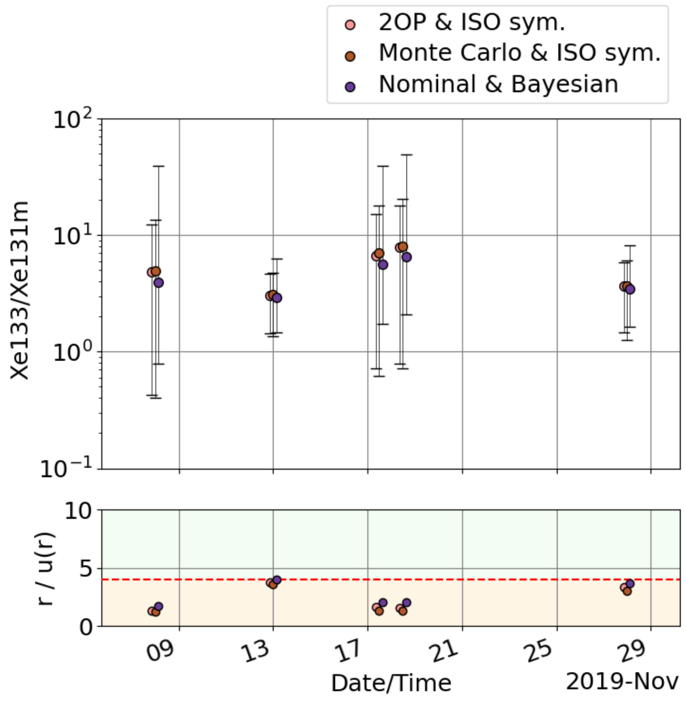


Days	Xe133m/ Xe131m	Xe133/ Xe131m	Xe133m/ Xe133	Xe135/ Xe133
1	155	2410	0.0645	7.94
2	118	2250	0.0525	1.29
5	55.9	1840	0.0303	0.00937
10	13.3	1240	0.0108	7.53E-7
20	1.26	634	0.00198	1.38E-13

- Plume transport from a release site to an IMS station might take a few days.

Algorithms of isotopic ratio estimation

- The isotopic ratio can be calculated:
    - Nominal (1^{st}-order polynomial, linear model)
    - 2OP (2^{nd}-order polynomial, non-linear model)
    - Monte Carlo Method (MCM)
- Bayesian limits in the current IDC products are inconsistent with MCM for large uncertainty.
- Limits of the coverage interval by 2OP are consistent with MCM.



- For uncertainties <30%, there is no large impact on ratio estimation amongst different methods.
- Larger uncertainties of concentrations, Larger impact.

Event screening based on IMS detection(s)

Screening a nuclear explosion source from the radioxenon background:

- *Hypotheses test on nuclear explosion source*
  - ✓ *Based on* isotopic ratios detected in a sample, related to *activity concentrations estimated by radioxenon detections at IMS stations*
  - ✓ Null hypothesis H_0: radioxenon background
  - ✓ Alternative H_1: nuclear explosion source

	True radioxenon background	True nuclear explosion
Do not reject H_0	Correct radioxenon background	False negative
Reject H_0	False positive	Correct nuclear explosion

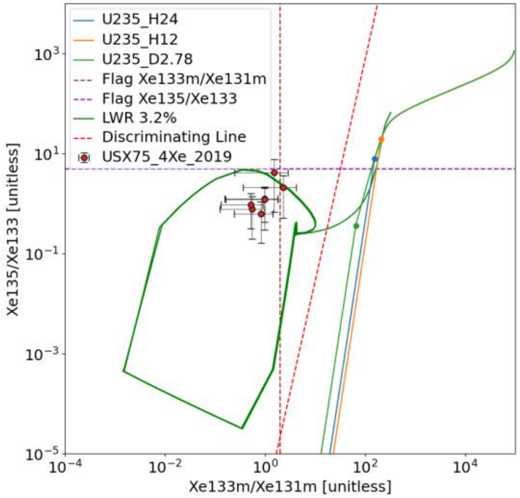
Screening thresholds

- Given coverage interval of 90% or 95% (false positive/negative)
- Based on UNE release scenarios or PDF measured at IMS stations

Event screening: False positive/negative with 5%

Hypothesis testing for event screening by isotopic ratio analysis

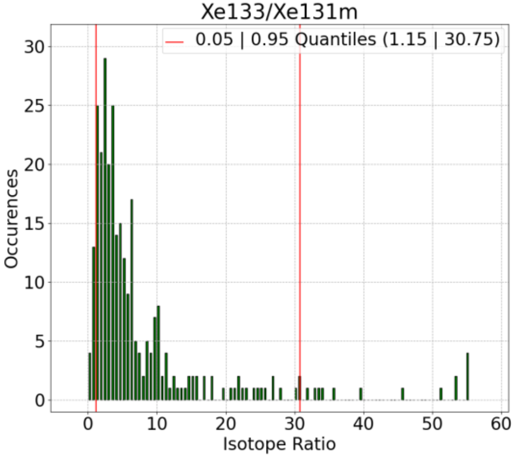
- The coverage interval.
  - PDF of isotopic ratios in a sample can be derived by MCM
  - 95% in Bayesian limit is applied in current A/RRRs
  - 90% is suggested, e.g., 5% false positive/negative
- Hypothesis of event screening in IDC products
  - ✓ This looks like the definition of detection limit (MDA)
  - ✓ The lower limit is used, like false negative
    - ✓ A UNE is identified by false negative 5%
- Hypothesis of identifying a UNE
  - ✓ The definition looks like decision threshold (LC)
  - ✓ The upper limit is used, like false positive
    - ✓ A UNE cannot be ruled out by false positive 5%.



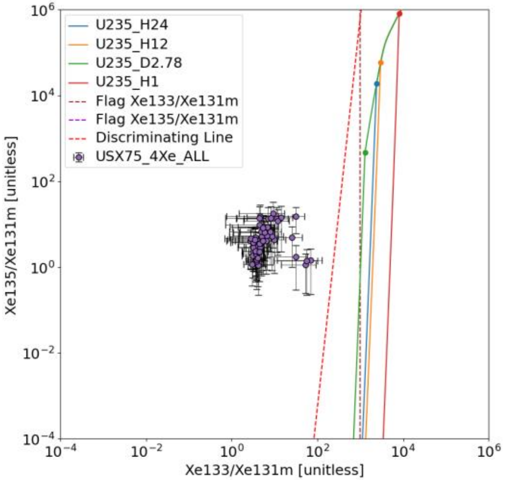
Event screening: Distributions of routine detections 1/4

Radioxenon background measurements

- Distributions of routine IMS xenon samples
  - USX75 in 2014 to 2023
  - Xe-133/Xe-131m



5% at 30, much lower than the threshold of 1000.

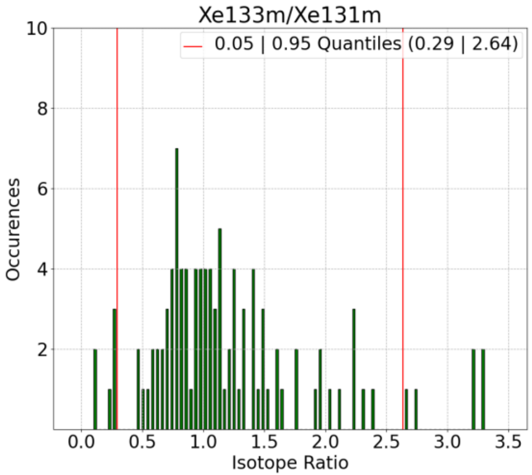


Xe-133/Xe-131m: Routine detected ratios are far below the threshold of 1000.

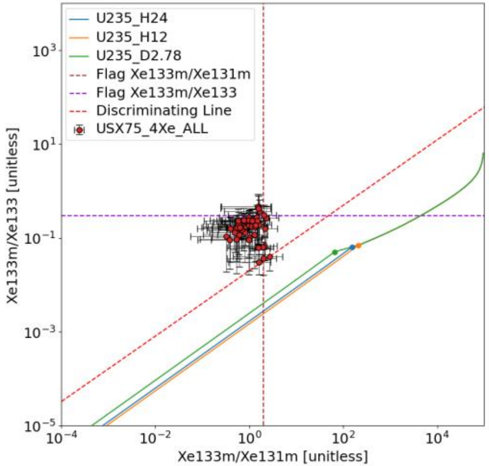
Event screening: Distributions of routine detections 2/4

Radioxenon background measurements

- Distributions of routine IMS xenon samples
  - USX75 in 2014 to 2023
  - Xe-133m/Xe-131m



More than 5% above the threshold of 2

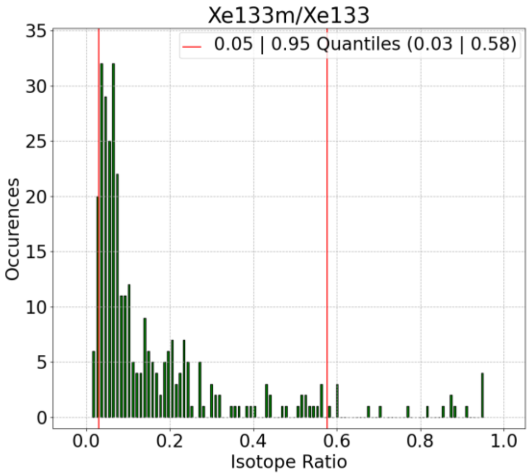


Xe-133m/Xe-131m: Routine detected ratios might above the current threshold of 2, but below a suggested new one of 50.

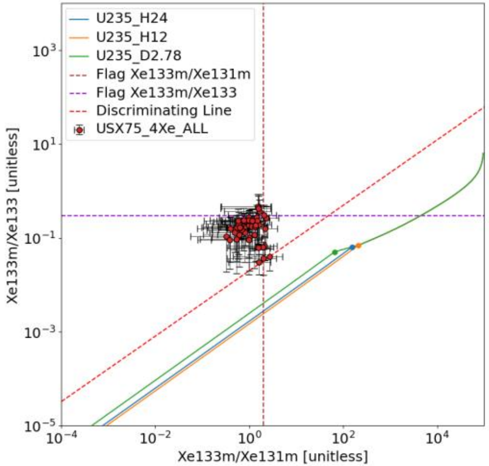
Event screening: Distributions of routine detections 3/4

Radioxenon background measurements

- Distributions of routine IMS xenon samples
  - USX75 in 2014 to 2023
  - Xe-133m/Xe133



More than 5% above the threshold of 0.3

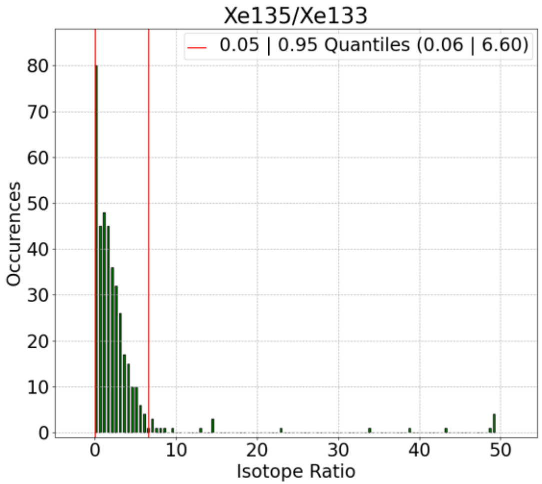


Xe-133m/Xe133: Detected ratios are often above the threshold of 0.3.

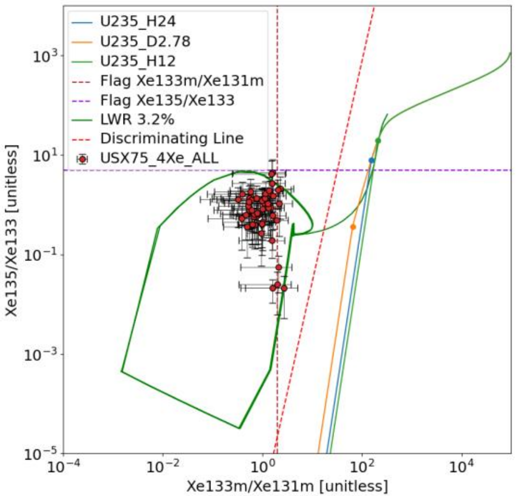
Event screening: Distributions of routine detections 4/4

Radioxenon background measurements

- Distributions of routine IMS xenon samples
  - USX75 in 2014 to 2023
  - Xe-135/Xe-133



More than 5% is above the threshold of 5.

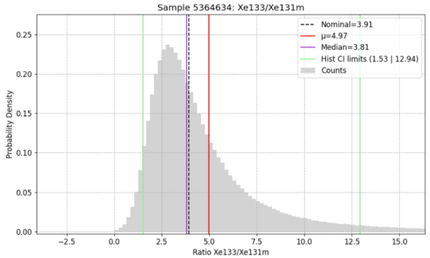


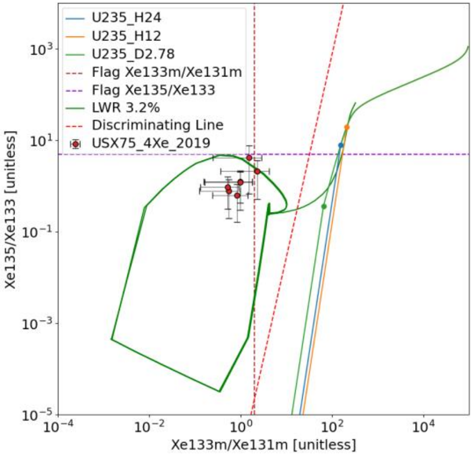
Detected ratios are all on the civil domain in 4Xe-plot; additional pair is needed for screening.

Event screening: Algorithm and associated thresholds

Event screening

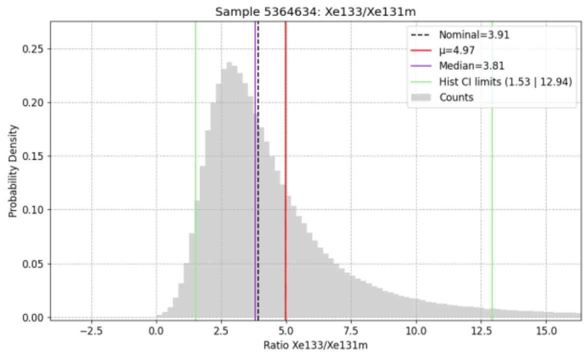
- The thresholds cannot be based on the distributions of measured isotopic ratios at IMS stations but on release scenarios with given days post of UNE.
- The upper and lower limits of the coverage interval (LCIs) are based on the distributions of the isotopic ratios derived from a single measurement of IMS samples.
    - Non-Gaussian PDF
- Event screening is based on statistical testing between the thresholds and estimated LCIs.





Updating algorithms and associated thresholds for event screening

- Suggestions:
  - 2^{nd} Order Polynomial is used for estimation of the ratio and its limits of the coverage interval with 90%.
  - Thresholds are based on UNE scenarios by 5 days.
    - Xe-135/Xe-133: 0.01,
    - Xe-133m/Xe-133: 0.03,
    - Xe-133m/Xe-131m: 50,
    - Xe-133/Xe-131m: 1800
  - Screening decisions
    - LCIs are estimated using the PDF of activities measured in the sample, derived by MCM.
    - Upper limit: False positive of 5%
    - Lower limit: False negative of 5%



Suggested thresholds of Isotopic activity ratios (U235f, full ingrowth and close cavity UNE)

	Xe133m/Xe131m	Xe133/Xe131m	Xe133m/Xe133	Xe135/Xe133
Current	2	1000	0.3	5
Suggestion	50	1800	0.03	0.01
5 days	55.9	1840	0.0303	0.00937

Summary

- Updating thresholds of event screening in the A/RRRs of IDC products
  - Second Order Polynomial approximation is used for estimation of the isotopic activity ratio and its limits of the coverage interval with 90%.
  - Thresholds are based on UNE scenarios related to early releases by 5 days.
  - Event screening is to perform hypothesis testing on the upper and lower limits of the coverage interval against the thresholds.
- More investigations
  - The probability of 90, 95 or 99%, should be used for different false positive/negative
  - Specify an early release for each pair of isotopes at given days
  - Combined screening using the plots of activity ratios of more than 3 isotopes

Thank you for listening!

Any questions?

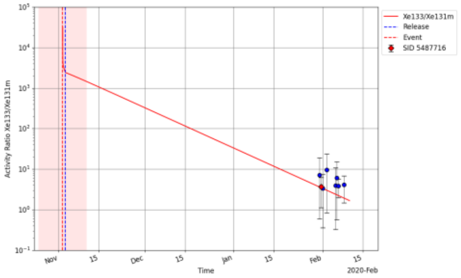
CTBTO
PREPARATORY COMMISSION

Vienna International Centre, PO Box 1200
1400 Vienna, Austria
CTBTO.ORG

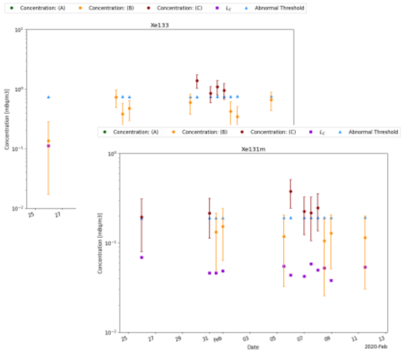
From IMS observations to event characterization by isotopic activity ratios

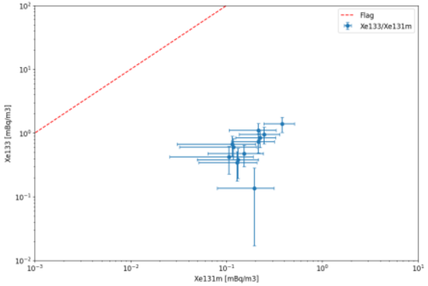
Characterization of CTBT-relevant nuclear events:

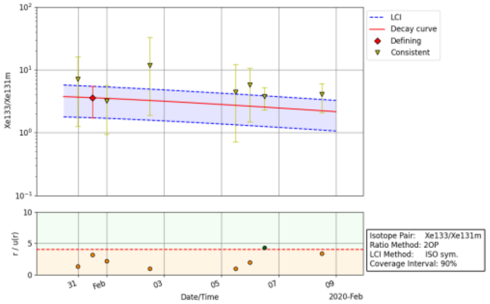
- Screening a nuclear explosion source from releases of nuclear facilities using 4-xenon-plot.
- Estimation of the detonation time using a function of isotopic activity ratios over time.

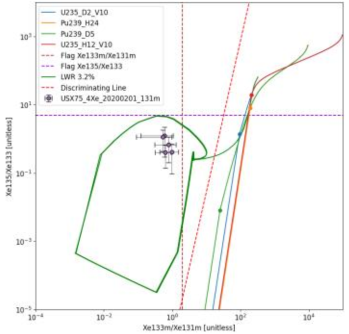


Event characterization









RN detections

Hypothesis tests from IMS sample measurements to event characterization

Three different Hypothesis tests

- *Hypotheses test on radioxenon detection*
  - ✓ *Based on activities collected in a sample*
  - ✓ Null hypothesis H_0: detector background
  - ✓ Alternative H_1: xenon present in the sample
- *Hypotheses test on anomaly radioxenon background*
  - ✓ *Based on concentrations in the plume of air*
  - ✓ Null hypothesis H_0: normal radioxenon background
  - ✓ Alternative H_1: anomaly radioxenon background
- *Hypotheses on nuclear explosion*
  - ✓ Based on isotopic ratios detected in the sample
  - ✓ Null hypothesis H_0: radioxenon background
  - ✓ Alternative H_1: nuclear explosion

	True detector background	True radioxenon detection
Do not reject H_0	Correct detector background	False negative
Reject H_0	False positive	Correct xenon detection

	True normal radioxenon background	True anomaly radioxenon background
Do not reject H_0	Correct normal radioxenon background	False negative
Reject H_0	False positive	Correct anomaly radioxenon background

	True radioxenon background	True nuclear explosion
Do not reject H_0	Correct radioxenon background	False negative
Reject H_0	False positive	Correct nuclear explosion

Radioxenon detection in a sample

Identifying radioxenon detection from the detector background:

- *Hypothesis test on radioxenon detection*
  - ✓ *Based on activities collected in a sample*
  - ✓ Null hypothesis H_0: detector background
  - ✓ Alternative H_1: xenon present in the sample

	True detector background	True radioxenon detection
Do not reject H_0	Correct detector background	False negative
Reject H_0	False positive	Correct xenon detection

Decision threshold

- Currie's model and/or ISO 11929:2019
- Based on the distribution of a detector background