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Radioxenon isotopic composition of release scenarios based on realistic models of underground nuclear explosion cavity evolution and subsurface gas transport

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INTRODUCTION

The presentation is to understand gas transport from a UNE, resulting in a realistic model about post-detonation cavity processes.

METHODS/DATA

The evolution of isotopic activity ratios is modelled by the cavity partitioning process, slow seepage, and/or prompt release of gases from the cavity.

START

RESULTS

A library of radioxenon composition in the cavity and host rock can be simulated with different parameters.

CONCLUSION

Release scenarios can be used for event discrimination and further for estimation of the detonation time with respect to noble gas measurements at IMS stations.

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Summary

- Isotopic ratios of radioxenons can be used to verify the occurrence of an underground nuclear explosion (UNE).
- Simplified analytical models and closed-form solutions using Bateman equations simulate a idealized radioactive decay/ingrowth chain in a closed and well-mixed system.
- The partitioning of the radionuclide inventory between a gas phase and rock melt created by the detonation and the gas transport from the cavity to host rock or ground surface are not addressed properly. Either subsurface transport or prompt release that is principally responsible for gas signatures is inconsistent with the simple closed-system assumption.
- In this study, a realistic model about post-detonation cavity processes were developed. A closed-form solution representing time-dependent source-term activities is extended by considering the cavity partitioning process, slow seepage, and/or prompt release of gases from the cavity and applied to realistic systems, influencing the evolution of isotopic ratios over the course of UNE histories.
- A library of radioxenon composition in the cavity and host rock can be simulated with different parameters, which is used for event discrimination and further for estimation of the detonation time with respect to noble gas measurements at IMS stations. It can also be used for the event discrimination based on machine learning.

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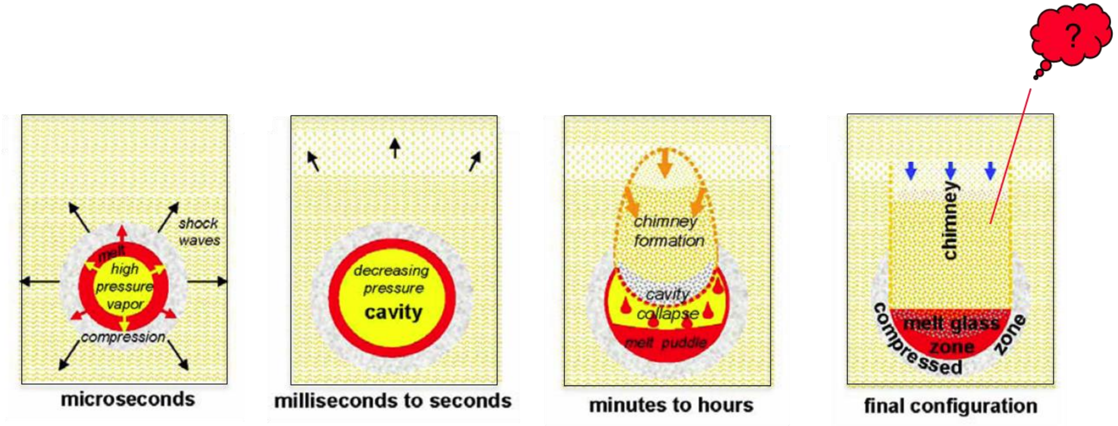
Objectives

- Well-mixed and closed system is an ideal but unrealistic case that contains all radionuclides within the cavity. However, it is contradictive scenario. Since everything is contained, how can we get signals from ground surface or offsite?
- Baneberry test is labelled as a complete containment failure. Massive, prompt, uncontrolled releases of fission products, were driven by the pressure of steam or gas. The prompt venting is an extreme case.
- In between those extreme cases, there is a wide spectrum of UNE cases that make slow leakage or delayed signature from subsurface transport.

Right after a detonation, a cavity forms and grows; to a certain size, the cavity pressure deceases; then chimney collapses, to form the final configuration for subsurface gas transport. In those 4 steps, radionuclide chain reactions are involved in cavity, melt puddle, and host rock. The reaction products, such as iodine and xenon, become the signature for recovering UNE source processes. .



microseconds | milliseconds to seconds | minutes to hours | final configuration

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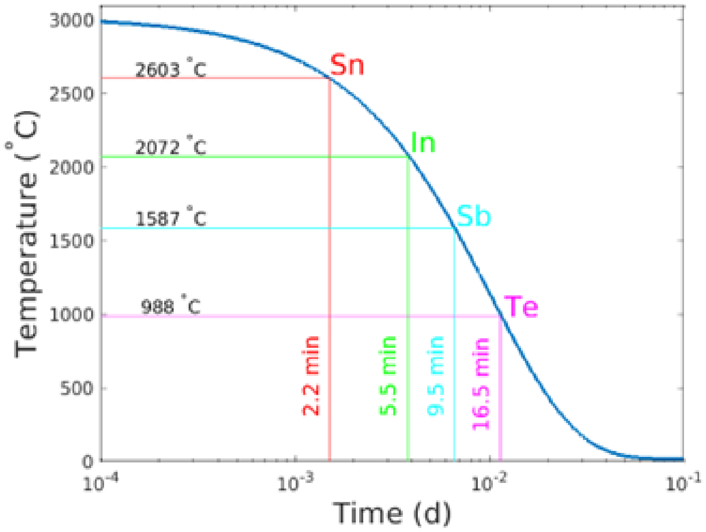
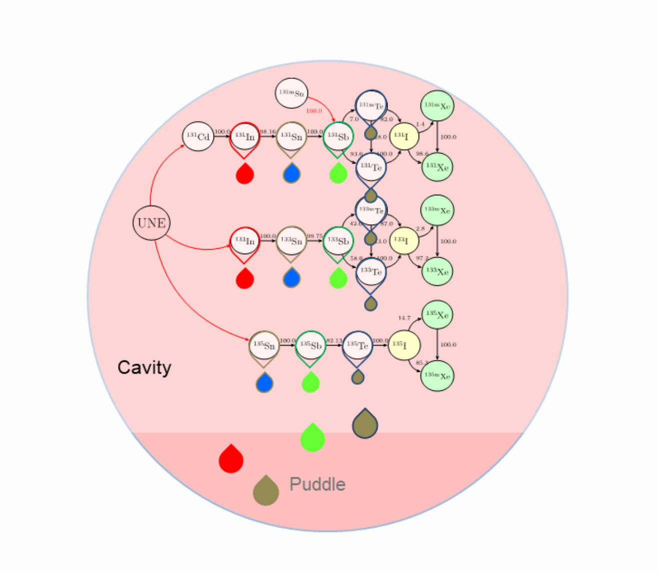
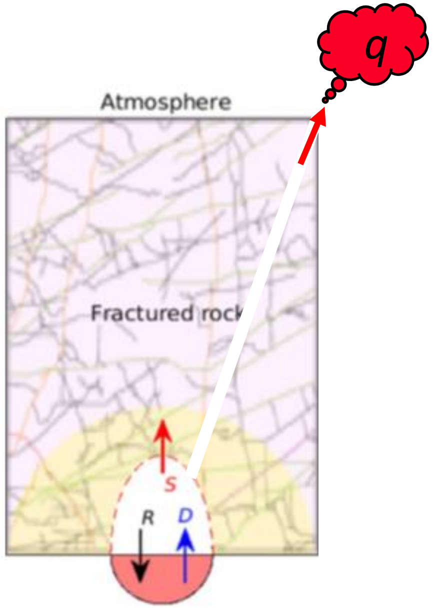
Methods

The basic source-term activities: precipitation of iodine precursors.

- In the early stage when the cavity is formed, radionuclides are redistributed in the cavity and melt puddle.
- As the temperature drops from a few thousand degrees to ambient condition, the precursors of iodine condensate from the cavity to melt puddle.
- The decay reactions are maintained in both cavity and puddle with re-arranged radionuclide inventories.
- The reaction products, xenon isotopes, will possibly diffuse back from the puddle to the cavity.







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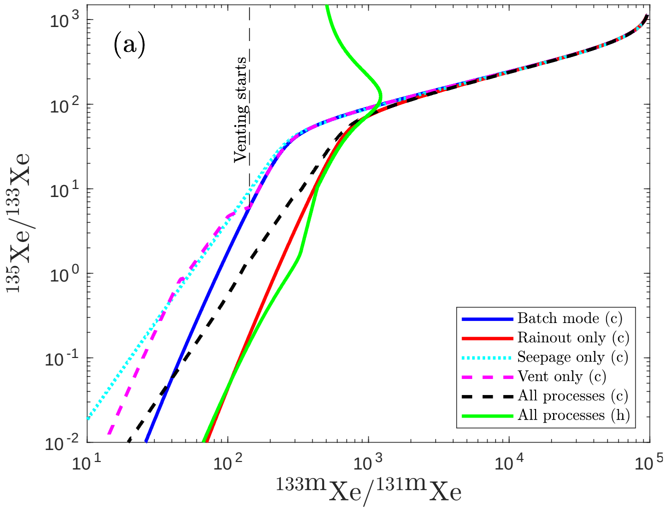
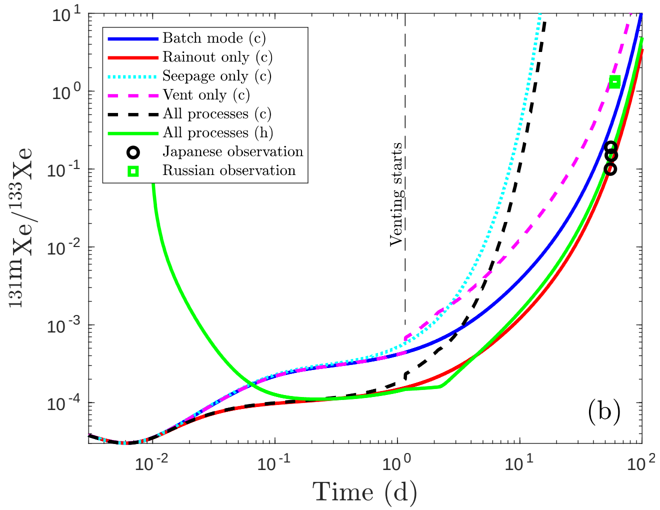
Results

Four radioxenon plots for discriminating UNEs and civilian applications:

- The basic case shows blue curve for the well-mixed and closed system. The red curve on the right side of blue is for rainout only. The dotted cyan curve on the left of blue is for seepage only. The dashed magenta curve also on the left of the blue is for venting only at 1 day.
- The dashed black curve crossing over the blue curve indicates the rainout effect in early time and seepage and venting effect in late time.
- The little (c) in the legend indicates the signal in cavity. The correlation is location dependent. If we check signal in host rock, the correlation in green may be similar to the red curve in cavity.
- For Xe-131m to Xe-133, rainout makes the red curve lower and seepage and venting make their curves higher, with the blue curve as the reference.





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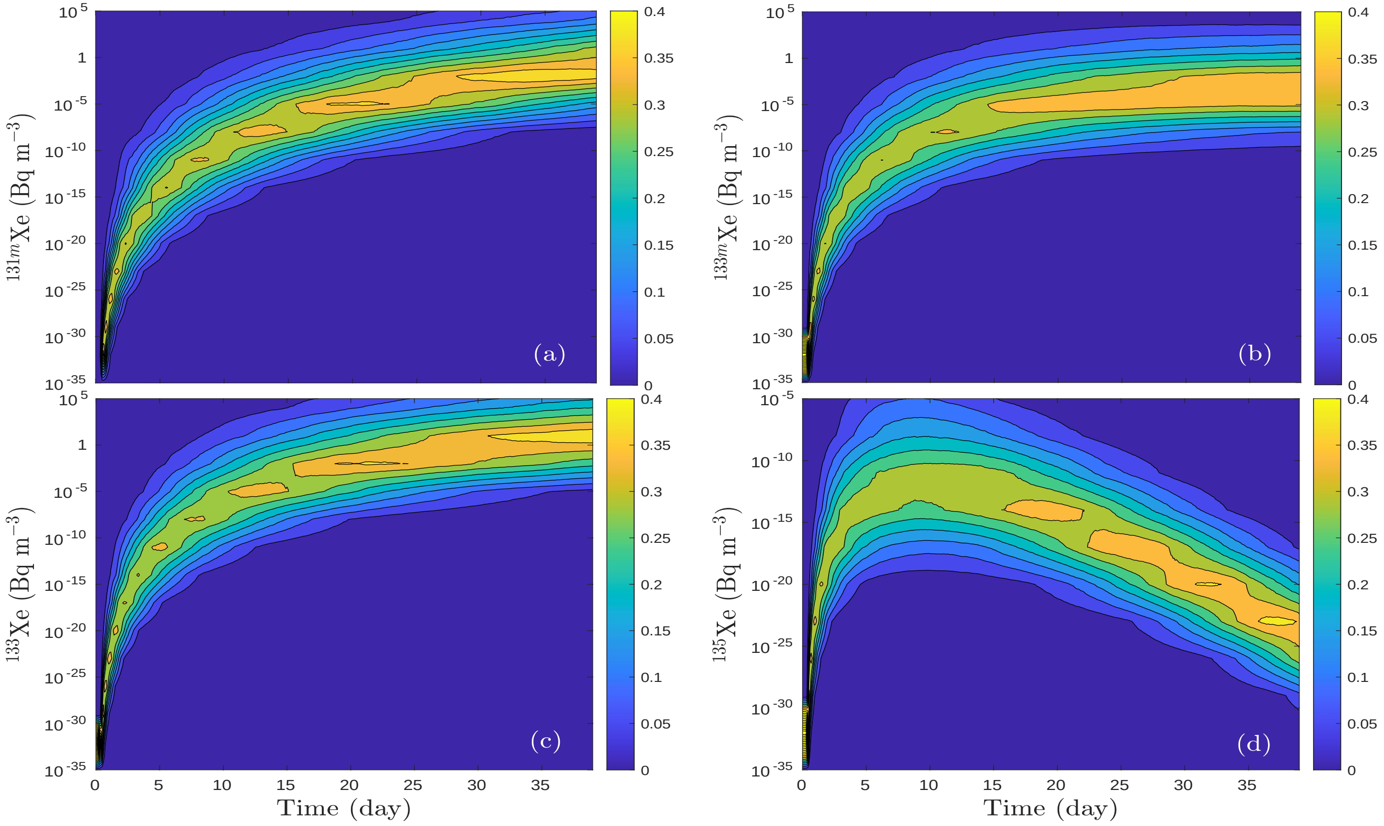
Results

Probability density of xenon radioactivity concentrations at ground surface

- After running the large number of simulations, we post process xenon concentrations and derive probability density.
- Due to the uncertainties, we are not able to derive a deterministic concentration curve, but we know how likely we get certain concentration at given time.



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