The STAX Project Progress

Dr. Judah Friese

WOSMIP IX
Santiago, Chile
December 2023

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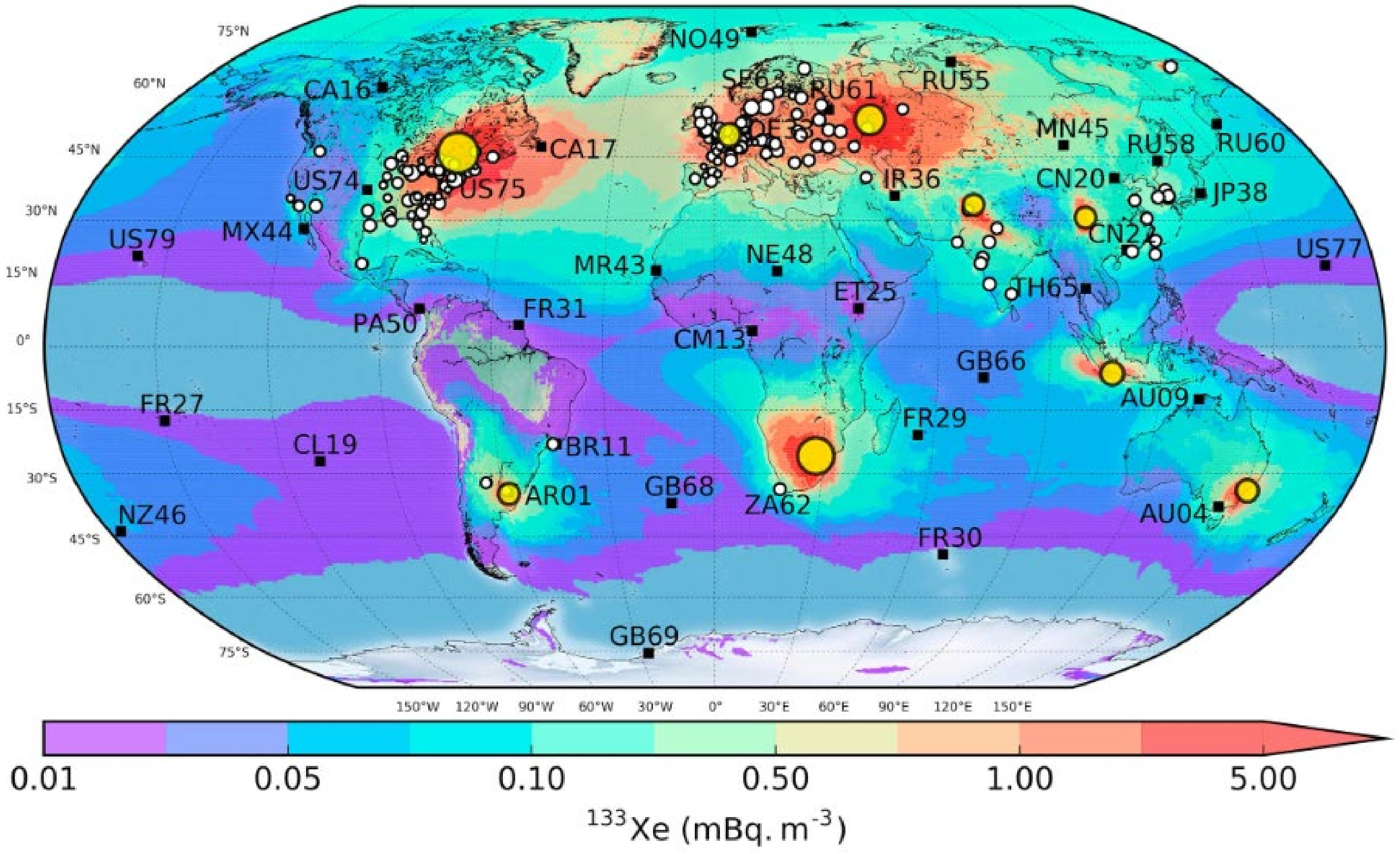
Backgrounds of Xenon and STAX

Average backgrounds of radioactive xenon in the atmosphere



From Generoso, 2017

Fuente: https://www.cia.gov/library/publications/cia-maps-publications
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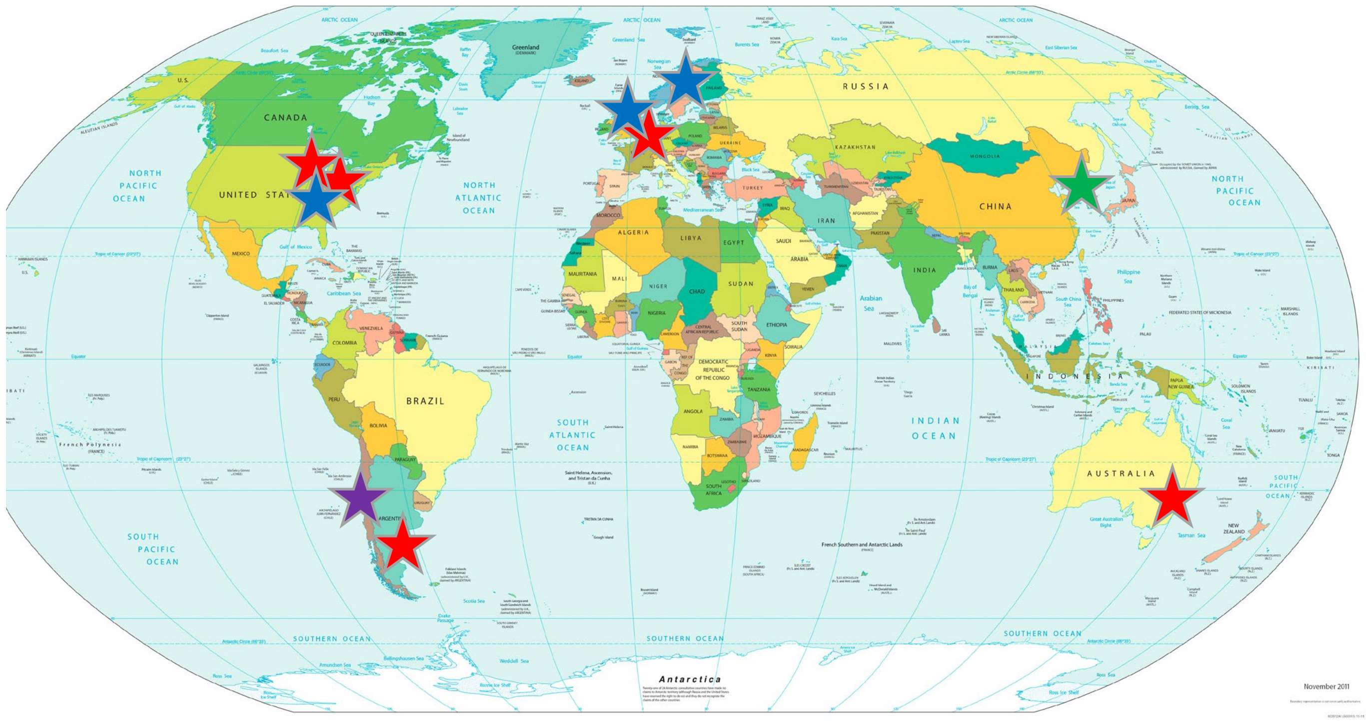
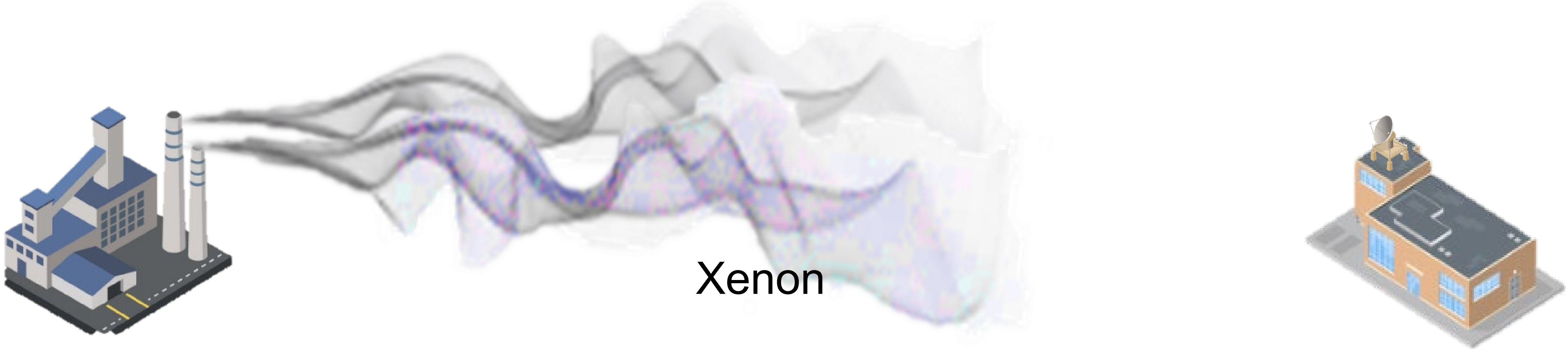


STAX idea for mitigating the impact on IMS is becoming a reality.



Emission Level

Atoms Released

10^{18} atoms/day

(Predictable) IMS Station Detection

Atoms Detected

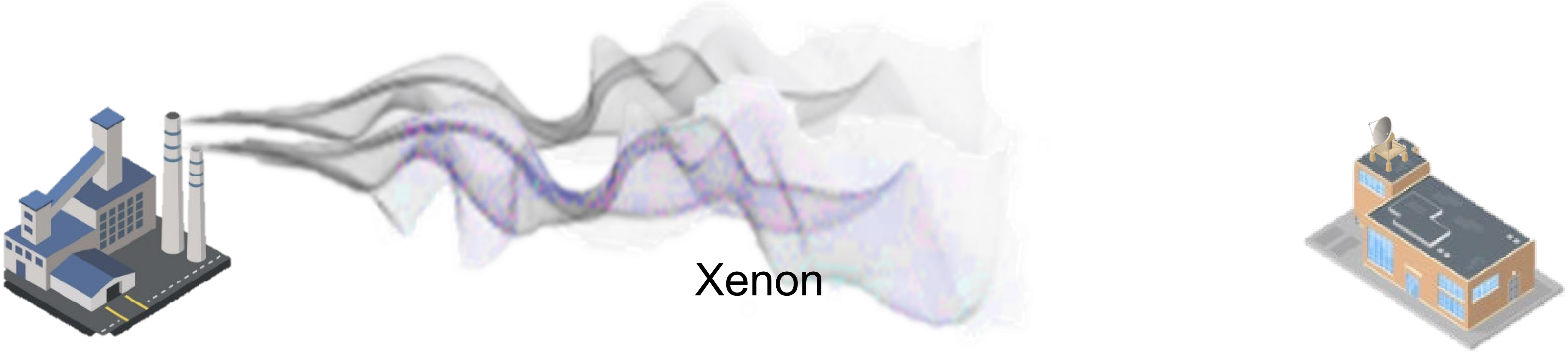
10^{4} atoms/day

Xenon

Emission Source

IMS Station

STAX idea for mitigating the impact on IMS is becoming a reality.



Xenon

Emission Source

IMS Station

Stack measurement (B) → ATM calculation (C)

Bq/hour

Bq/m^3

Measurement at station (A)

Bq/m^3

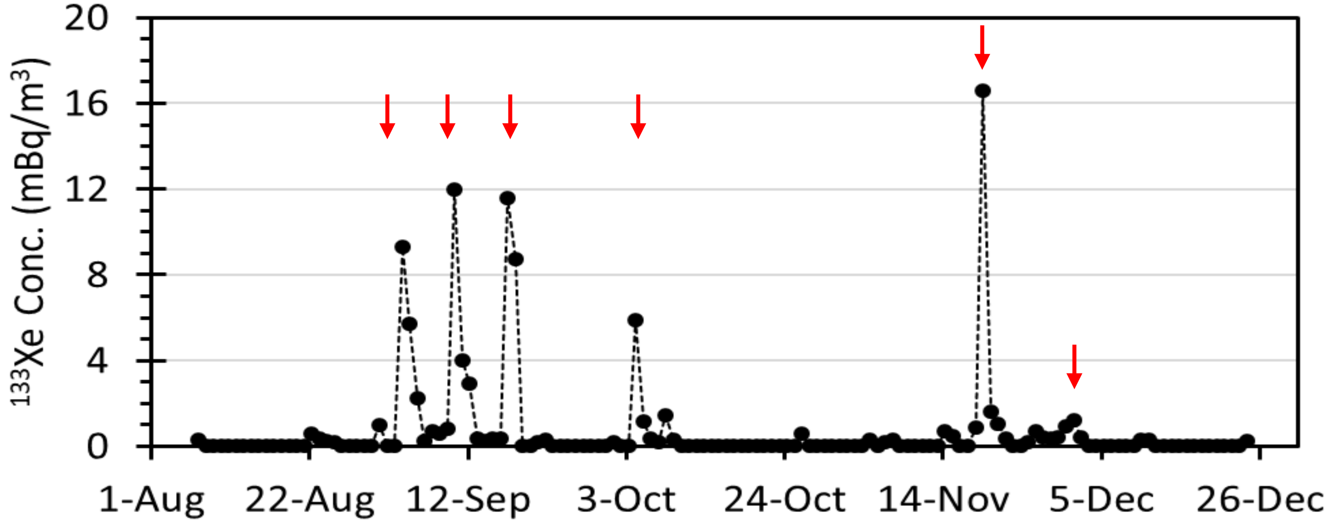
Net Signal = A – C

= Bq/SCM at station – Bq/SCM from stack measurement

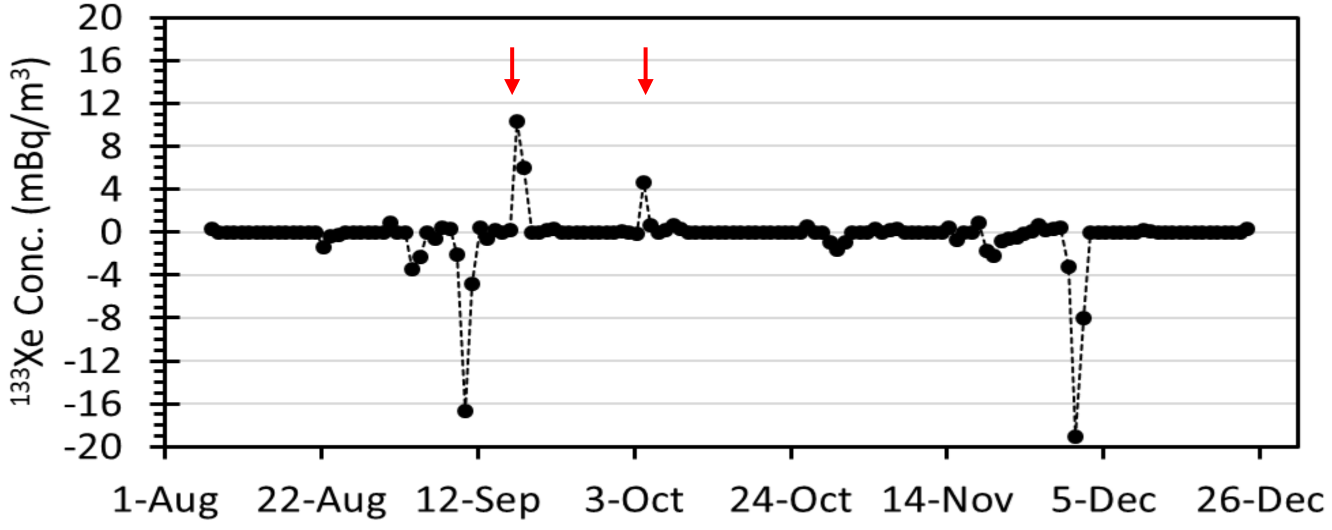
Use of STAX Data to Remove Background

- The use of data collected at known facilities may prove useful to remove the effect of these sources
- For example, using data from IRE (Belgium), one may subtract off its effect at DEX33
- Many IMS station detections can be screened out

Measured ^{133}Xe at DEX33



Net signal (Measured – Predicted)



Use IRE stack release rate
ATM: HYSPLIT & NOAA's 0.25°, 3-hr global met data. Difference between the measured and modeled

Scientific Contributions using STAX data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Addressing the quantification of
atmospheric transport simulation

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A R T I C L E I N F O

Handling Editor: Dr Andreas Bollhoefer

A B S T R
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1. Introduction

Atmospheric Transport Modelling (ATM) is one of
available to National Data Centers (NDC) to help categori
noble gas measurements of the International Monitoring
The IMS monitors waveforms and radionuclides around
the verification of the Comprehensive Nuclear-Test-Ban
Nearly 90% of the expected 40 noble gas stations are
measure four radioactive isotopes of xenon (radioxenons
$= 11.96$ d), ^{133}Xe ($T_{1/2} = 5.24$ d), ^{133m}Xe ($T_{1/2} = 2.19$ d)
$= 9.14$ h) (Ringbom et al., 2003; Fontaine et al., 2004;
2005). This monitoring has revealed an industrial rad
ground, which has to be discriminated from nuclear explo

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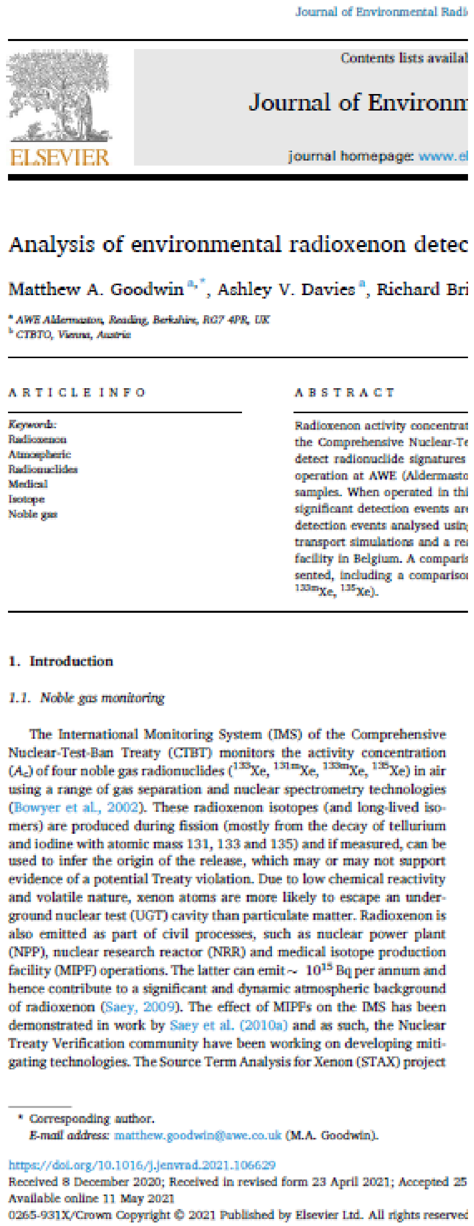
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Analysis of environmental radioxenon detec

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A R T I C L E I N F O

Keywords:
Radioxenon
Atmospheric
Radionuclides
Medical
Isotope
Noble gas

A B S T R A C T
Radioxenon activity concentra
the Comprehensive Nuclear-Te
detect radionuclide signatures
operation at AWE (Aldermasto
samples. When operated in thi
significant detection events ar
detection events analysed usin
transport simulations and a re
facility in Belgium. A comparis
sented, including a compariso
^{133m}Xe, ^{135}Xe).

1. Introduction

1.1. Noble gas monitoring

The International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) monitors the activity concentration (A_c) of four noble gas radionuclides (^{133}Xe, ^{131m}Xe, ^{133m}Xe, ^{135}Xe) in air using a range of gas separation and nuclear spectrometry technologies (Bowyer et al., 2002). These radioxenon isotopes (and long-lived isomers) are produced during fission (mostly from the decay of tellurium and iodine with atomic mass 131, 133 and 135) and if measured, can be used to infer the origin of the release, which may or may not support evidence of a potential Treaty violation. Due to low chemical reactivity and volatile nature, xenon atoms are more likely to escape an underground nuclear test (UGT) cavity than particulate matter. Radioxenon is also emitted as part of civil processes, such as nuclear power plant (NPP), nuclear research reactor (NRR) and medical isotope production facility (MIPF) operations. The latter can emit ~ 10^{15} Bq per annum and hence contribute to a significant and dynamic atmospheric background of radioxenon (Saey, 2009). The effect of MIPFs on the IMS has been demonstrated in work by Saey et al. (2010a) and as such, the Nuclear Treaty Verification community have been working on developing mitigating technologies. The Source Term Analysis for Xenon (STAX) project

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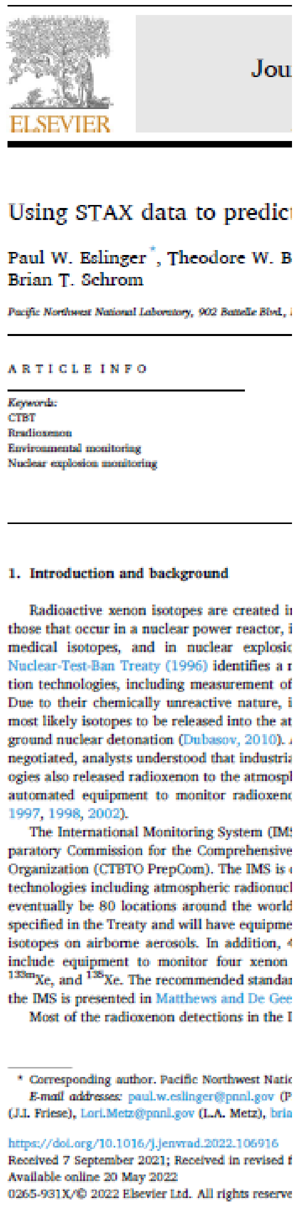
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Using STAX data to predic

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Brian T. Schrom
Pacific Northwest National Laboratory, 902 Battelle Blvd.,

A R T I C L E I N F O

Keywords:
CTBT
Rradioxenon
Environmental monitoring
Nuclear explosion monitoring

1. Introduction and background

Radioactive xenon isotopes are created i
those that occur in a nuclear power reactor, i
medical isotopes, and in nuclear explosio
Nuclear-Test-Ban Treaty (1996) identifies a
tion technologies, including measurement o
Due to their chemically unreactive nature,
most likely isotopes to be released into the a
ground nuclear detonation (Dubasov, 2010).
negotiated, analysts understood that industri
ogies also released radioxenon to the atmosp
automated equipment to monitor radioxen
1997, 1998, 2002).

The International Monitoring System (IM
paratory Commission for the Comprehensive
Organization (CTBTO PrepCom). The IMS is
technologies including atmospheric radionuc
eventually be 80 locations around the world
specified in the Treaty and will have equipme
isotopes on airborne aerosols. In addition,
include equipment to monitor four xenon
^{133m}Xe, and ^{135}Xe. The recommended standa
the IMS is presented in Matthews and De Gee

Most of the radioxenon detections in the I

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(J.I. Friese), Lori.Metz@pnnl.gov (L.A. Metz), bria

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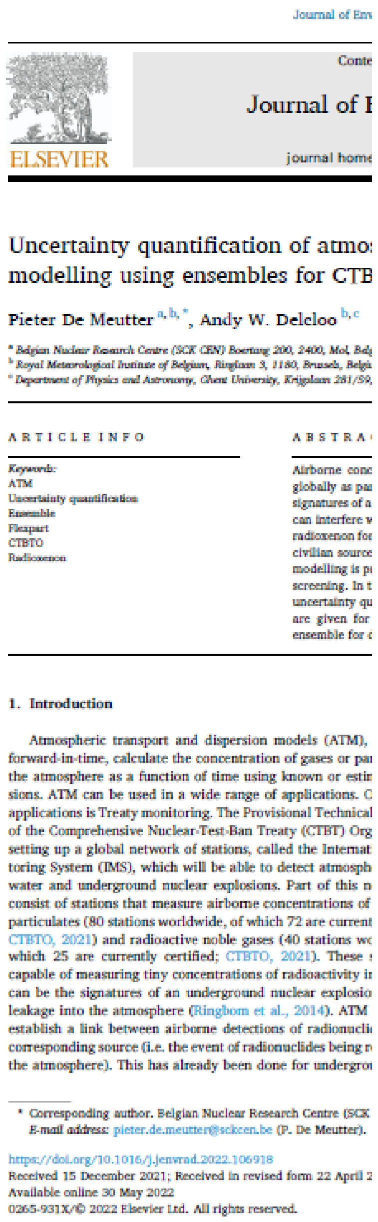
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Uncertainty quantification of atmos
modelling using ensembles for CTB

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A R T I C L E I N F O

Keywords:
ATM
Uncertainty quantification
Ensemble
Flexpart
CTBTO
Radioxenon

A B S T R A
Airborne conc
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radioxenon fo
civilian source
modelling is p
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1. Introduction

Atmospheric transport and dispersion models (ATM),
forward-in-time, calculate the concentration of gases or pa
the atmosphere as a function of time using known or esti
sions. ATM can be used in a wide range of applications. C
applications is Treaty monitoring. The Provisional Technical
of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) Org
setting up a global network of stations, called the Internat
toring System (IMS), which will be able to detect atmosph
water and underground nuclear explosions. Part of this n
consist of stations that measure airborne concentrations of
particulates (80 stations worldwide, of which 72 are curren
CTBTO, 2021) and radioactive noble gases (40 stations w
which 25 are currently certified; CTBTO, 2021). These
capable of measuring tiny concentrations of radioactivity i
can be the signatures of an underground nuclear explosio
leakage into the atmosphere (Ringbom et al., 2014). ATM
establish a link between airborne detections of radionucli
corresponding source (i.e. the event of radionuclides being
the atmosphere). This has already been done for undergro

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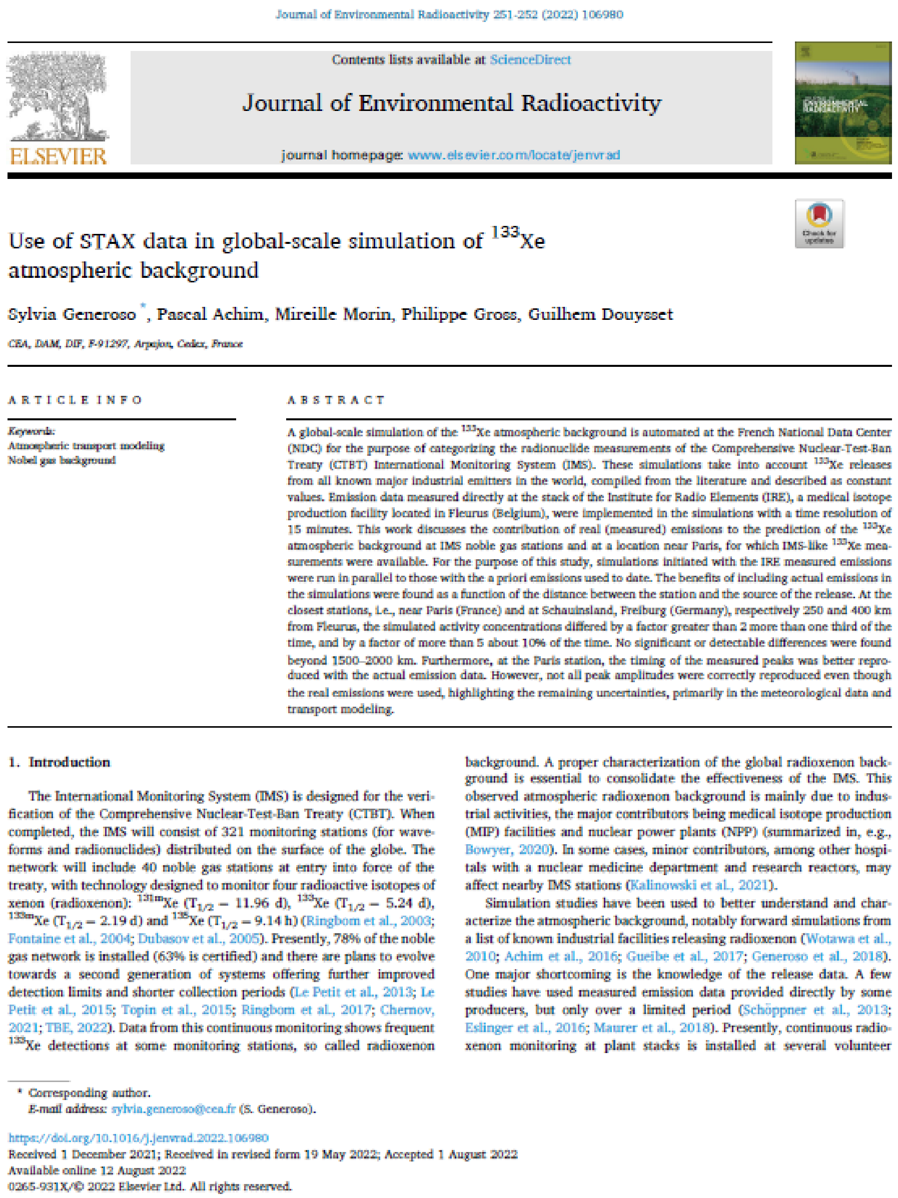
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Use of STAX data in global-scale simulation of ^{133}Xe atmospheric background

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A R T I C L E I N F O

Keywords:
Atmospheric transport modeling
Nobel gas background

A B S T R A C T

A global-scale simulation of the ^{133}Xe atmospheric background is automated at the French National Data Center (NDC) for the purpose of categorizing the radionuclide measurements of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) International Monitoring System (IMS). These simulations take into account ^{133}Xe releases from all known major industrial emitters in the world, compiled from the literature and described as constant values. Emission data measured directly at the stack of the Institute for Radio Elements (IRE), a medical isotope production facility located in Fleurus (Belgium), were implemented in the simulations with a time resolution of 15 minutes. This work discusses the contribution of real (measured) emissions to the prediction of the ^{133}Xe atmospheric background at IMS noble gas stations and at a location near Paris, for which IMS-like ^{133}Xe measurements were available. For the purpose of this study, simulations initiated with the IRE measured emissions were run in parallel to those with the a priori emissions used to date. The benefits of including actual emissions in the simulations were found as a function of the distance between the station and the source of the release. At the closest stations, i.e., near Paris (France) and at Schauinsland, Freiburg (Germany), respectively 250 and 400 km from Fleurus, the simulated activity concentrations differed by a factor greater than 2 more than one third of the time, and by a factor of more than 5 about 10% of the time. No significant or detectable differences were found beyond 1500–2000 km. Furthermore, at the Paris station, the timing of the measured peaks was better reproduced with the actual emission data. However, not all peak amplitudes were correctly reproduced even though the real emissions were used, highlighting the remaining uncertainties, primarily in the meteorological data and transport modeling.

1. Introduction

The International Monitoring System (IMS) is designed for the verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). When completed, the IMS will consist of 321 monitoring stations (for waveforms and radionuclides) distributed on the surface of the globe. The network will include 40 noble gas stations at entry into force of the treaty, with technology designed to monitor four radioactive isotopes of xenon (radioxenon): ^{131m}Xe ($T_{1/2} = 11.96$ d), ^{133}Xe ($T_{1/2} = 5.24$ d), ^{133m}Xe ($T_{1/2} = 2.19$ d) and ^{135}Xe ($T_{1/2} = 9.14$ h) (Ringbom et al., 2003; Fontaine et al., 2004; Dubasov et al., 2005). Presently, 78% of the noble gas network is installed (63% is certified) and there are plans to evolve towards a second generation of systems offering further improved detection limits and shorter collection periods (Le Petit et al., 2013; Le Petit et al., 2015; Topin et al., 2015; Ringbom et al., 2017; Chernov, 2021; TBE, 2022). Data from this continuous monitoring shows frequent ^{133}Xe detections at some monitoring stations, so called radioxenon background. A proper characterization of the global radioxenon background is essential to consolidate the effectiveness of the IMS. This observed atmospheric radioxenon background is mainly due to industrial activities, the major contributors being medical isotope production (MIP) facilities and nuclear power plants (NPP) (summarized in, e.g., Bowyer, 2020). In some cases, minor contributors, among other hospitals with a nuclear medicine department and research reactors, may affect nearby IMS stations (Kalinowski et al., 2021).

Simulation studies have been used to better understand and characterize the atmospheric background, notably forward simulations from a list of known industrial facilities releasing radioxenon (Wotawa et al., 2010; Achim et al., 2016; Gueibe et al., 2017; Generoso et al., 2018). One major shortcoming is the knowledge of the release data. A few studies have used measured emission data provided directly by some producers, but only over a limited period (Schöppner et al., 2013; Eslinger et al., 2016; Maurer et al., 2018). Presently, continuous radioxenon monitoring at plant stacks is installed at several volunteer

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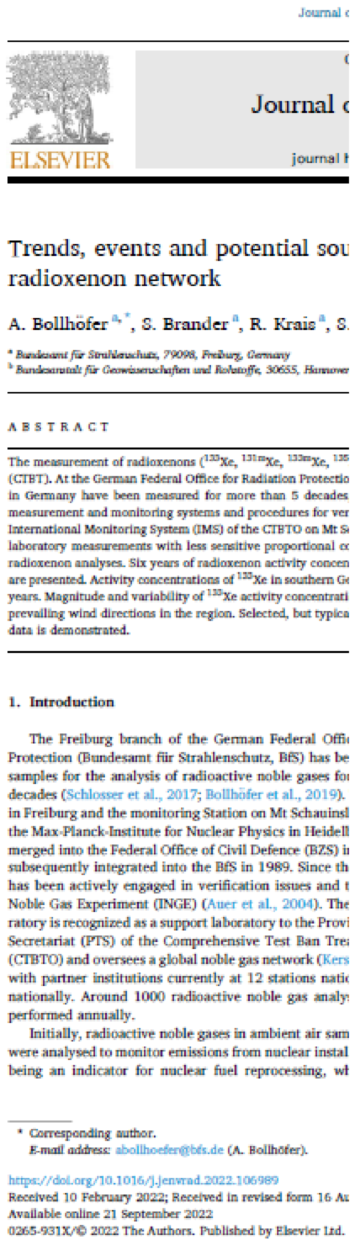
Scientific Contributions using STAX data



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Trends, events and potential sou
radioxenon network

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[b] Bundesanstalt für Geowissenschaften und Rohstoffe, 30655, Hannover

ABSTRACT

The measurement of radioxenons (^{133}Xe, ^{131m}Xe, ^{133m}Xe, ^{135}
(CTBT). At the German Federal Office for Radiation Protectio
in Germany have been measured for more than 5 decades
measurement and monitoring systems and procedures for ver
International Monitoring System (IMS) of the CTBTO on Mt S
laboratory measurements with less sensitive proportional co
radioxenon analyses. Six years of radioxenon activity concen
are presented. Activity concentrations of ^{133}Xe in southern Ge
years. Magnitude and variability of ^{133}Xe activity concentrati
prevailing wind directions in the region. Selected, but typica
data is demonstrated.

1. Introduction

The Freiburg branch of the German Federal Offi
Protection (Bundesamt für Strahlenschutz, BfS) has be
samples for the analysis of radioactive noble gases fo
decades (Schlosser et al., 2017; Bollhöfer et al., 2019).
in Freiburg and the monitoring Station on Mt Schauinsl
the Max-Planck-Institute for Nuclear Physics in Heidel
merged into the Federal Office of Civil Defence (BZS) i
subsequently integrated into the BfS in 1989. Since th
has been actively engaged in verification issues and t
Noble Gas Experiment (INGE) (Auer et al., 2004). The
ratory is recognized as a support laboratory to the Provi
Secretariat (PTS) of the Comprehensive Test Ban Tre
(CTBTO) and oversees a global noble gas network (Kers
with partner institutions currently at 12 stations nati
nationally. Around 1000 radioactive noble gas analy
performed annually.

Initially, radioactive noble gases in ambient air sam
were analysed to monitor emissions from nuclear instal
being an indicator for nuclear fuel reprocessing, wh

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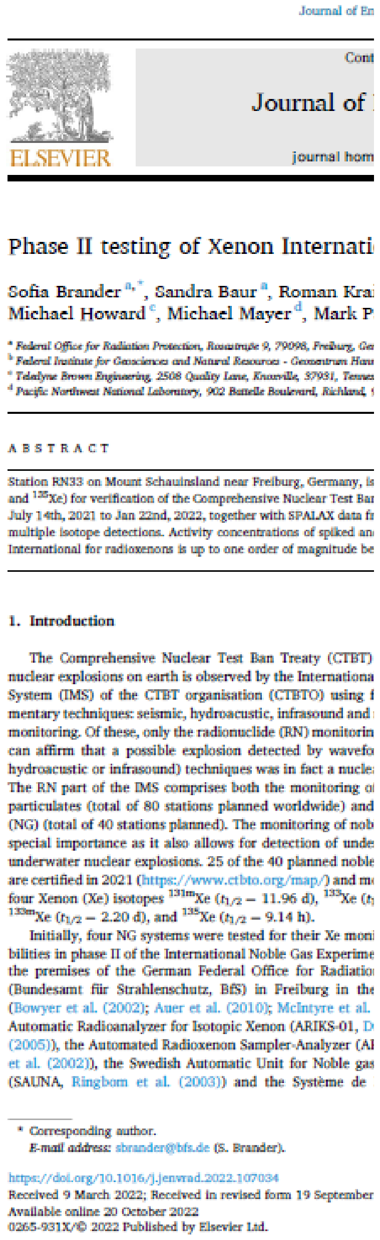

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Phase II testing of Xenon Internati

Sofia Brander [a,*], Sandra Baur [a], Roman Kra
Michael Howard [c], Michael Mayer [d], Mark P

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ABSTRACT

Station RN33 on Mount Schauinsland near Freiburg, Germany, is
and ^{135}Xe) for verification of the Comprehensive Nuclear Test Ba
July 14th, 2021 to Jan 22nd, 2022, together with SPALAX data fr
multiple isotope detections. Activity concentrations of spiked an
International for radioxenons is up to one order of magnitude be

1. Introduction

The Comprehensive Nuclear Test Ban Treaty (CTBT)
nuclear explosions on earth is observed by the Internationa
System (IMS) of the CTBT organisation (CTBTO) using f
mentary techniques: seismic, hydroacustic, infrasound and
monitoring. Of these, only the radionuclide (RN) monitorin
can affirm that a possible explosion detected by wavefo
hydroacustic or infrasound) techniques was in fact a nucle
The RN part of the IMS comprises both the monitoring o
particulates (total of 80 stations planned worldwide) and
(NG) (total of 40 stations planned). The monitoring of nob
special importance as it also allows for detection of unde
underwater nuclear explosions. 25 of the 40 planned noble
are certified in 2021 (https://www.ctbto.org/map/) and m
four Xenon (Xe) isotopes ^{131m}Xe ($t_{1/2}$ = 11.96 d), ^{133}Xe (t
^{133m}Xe ($t_{1/2}$ = 2.20 d), and ^{135}Xe ($t_{1/2}$ = 9.14 h).

Initially, four NG systems were tested for their Xe moni
bilities in phase II of the International Noble Gas Experime
the premises of the German Federal Office for Radiatio
(Bundesamt für Strahlenschutz, BfS) in Freiburg in the
(Bowyer et al. (2002); Auer et al. (2010); McIntyre et al.
Automatic Radioanalyzer for Isotopic Xenon (ARIKS-01, D
(2005)), the Automated Radioxenon Sampler-Analyzer (A
et al. (2002)), the Swedish Automatic Unit for Noble gas
(SAUNA, Ringbom et al. (2003)) and the Système de

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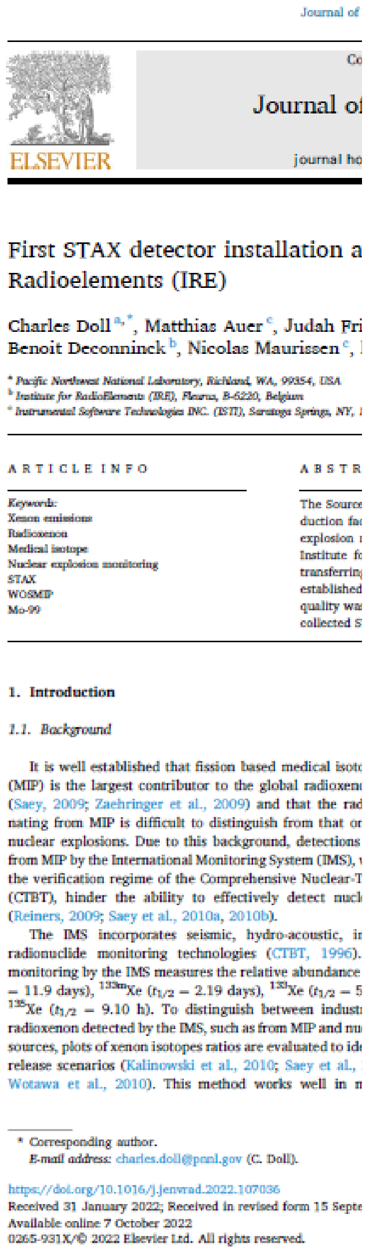

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First STAX detector installation a
Radioelements (IRE)

Charles Doll [a,*], Matthias Auer [c], Judah Fri
Benoit Deconninck [b], Nicolas Maurissen [c],

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ARTICLE INFO

Keywords:
Xenon emissions
Radioxenon
Medical isotope
Nuclear explosion monitoring
STAX
WOSMIP
Mo-99

ABSTR

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1. Introduction

1.1. Background

It is well established that fission based medical isot
(MIP) is the largest contributor to the global radioxen
(Saey, 2009; Zaehringer et al., 2009) and that the rad
nating from MIP is difficult to distinguish from that o
nuclear explosions. Due to this background, detections
from MIP by the International Monitoring System (IMS),
the verification regime of the Comprehensive Nuclear-T
(CTBT), hinder the ability to effectively detect nucl
(Reiners, 2009; Saey et al., 2010a, 2010b).

The IMS incorporates seismic, hydro-acoustic, i
radionuclide monitoring technologies (CTBT, 1996).
monitoring by the IMS measures the relative abundance
= 11.9 days), ^{133m}Xe ($t_{1/2}$ = 2.19 days), ^{133}Xe ($t_{1/2}$ = 5
^{135}Xe ($t_{1/2}$ = 9.10 h). To distinguish between indust
radioxenon detected by the IMS, such as from MIP and nu
sources, plots of xenon isotopes ratios are evaluated to id
release scenarios (Kalinowski et al., 2010; Saey et al.,
Wotawa et al., 2010). This method works well in n

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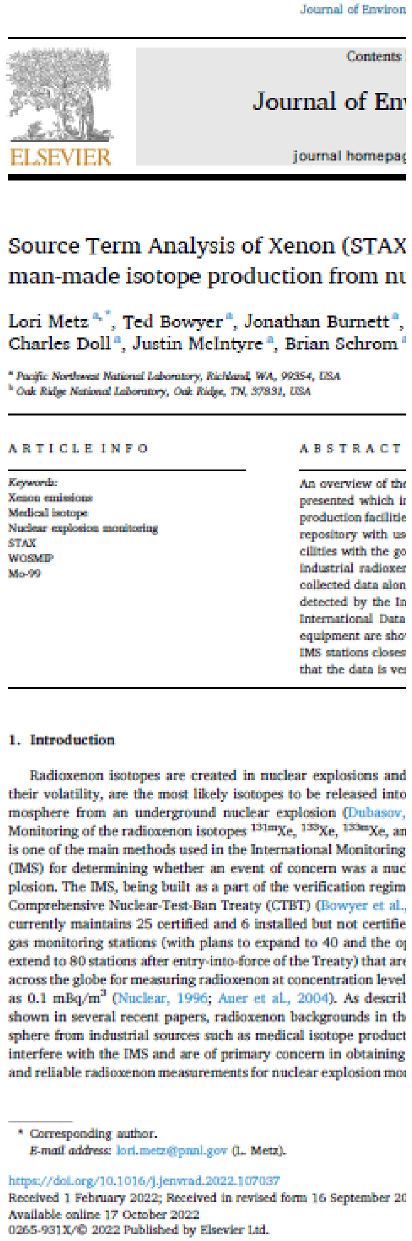

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Contents

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Source Term Analysis of Xenon (STAX
man-made isotope production from nu

Lori Metz [a,*], Ted Bowyer [a], Jonathan Burnett [a],
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ARTICLE INFO

Keywords:
Xenon emissions
Medical isotope
Nuclear explosion monitoring
STAX
WOSMIP
Mo-99

ABSTRACT

An overview of th
presented which i
production faciliti
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cilities with the g
industrial radioxe
collected data alon
detected by the In
International Data
equipment are sho
IMS stations close
that the data is ve

1. Introduction

Radioxenon isotopes are created in nuclear explosions and
their volatility, are the most likely isotopes to be released into
mosphere from an underground nuclear explosion (Dubasov,
Monitoring of the radioxenon isotopes ^{131m}Xe, ^{133}Xe, ^{133m}Xe, a
is one of the main methods used in the International Monitoring
(IMS) for determining whether an event of concern was a nuc
plosion. The IMS, being built as a part of the verification regim
Comprehensive Nuclear-Test-Ban Treaty (CTBT) (Bowyer et al.,
currently maintains 25 certified and 6 installed but not certifie
gas monitoring stations (with plans to expand to 40 and the o
extend to 80 stations after entry-into-force of the Treaty) that ar
across the globe for measuring radioxenon at concentration level
as 0.1 mBq/m^3 (Nuclear, 1996; Auer et al., 2004). As descri
shown in several recent papers, radioxenon backgrounds in th
sphere from industrial sources such as medical isotope product
interfere with the IMS and are of primary concern in obtaining
and reliable radioxenon measurements for nuclear explosion mo

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Pure and Applied Geophysics

A Review of Global Radioxenon Background Research and Issues

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Abstract—Among the most important problems for the worldwide nuclear explosion monitoring is the interference of naturally occurring and man-made radionuclides. The International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) frequently detects these interferences using sensitive radionuclide measurement equipment. We commonly refer to the presence of radionuclides that are relevant to the CTBT but do not originate from a nuclear explosion as "background". Backgrounds are highest near the sources but are known to have regional and global effects on the IMS. This review paper summarizes much of the relevant work in the area of background and discusses issues of interest for nuclear explosion detection.

Keywords: CTBT, radioxenon, nuclear explosion.

1. *Introduction*

The radionuclide monitoring component of the IMS is comprised of both radioactive particulate and radioactive xenon (radioxenon) noble gas measurements (see Fig. 1) (Schulze et al. 2000; Weiss et al. 2000; Auer et al. 2004). Radioxenon isotopes are the most highly sought signatures because they are easily vented and detected even from underground nuclear testing, they are produced in copious quantities from nuclear explosions, and are non-reactive in the environment. The radioxenon isotopes of interest for the CTBT: ^{131m}Xe ($\tau_{½}$ = 11.8 d); ^{133}Xe ($\tau_{½}$ = 5.2 d); ^{133m}Xe ($\tau_{½}$ = 2.2 d); ^{135}Xe ($\tau_{½}$ = 9.1 h) (ENSDF 2019) have half-lives in the range of several hours to nearly 2 weeks making them ideal for detection because they do not build-up in the atmosphere but are long enough lived to allow transport of thousands of kilometers before their decay. Atmospheric radioxenon measurement equipment has been especially designed for CTBT monitoring and several articles have written on the subject (Auer et al. 2010; Haas et al. 2017; Sivels et al. 2017; Cagniant et al. 2018; Ringbom et al. 2018).

Atmospheric radionuclide measurements for the IMS were developed starting in the 1990s to supply evidence that a suspect seismic event was of nuclear origin and to detect nuclear explosions, even absent a seismic trigger. During negotiations of the design of the IMS, however, concentrations of radionuclides and in particular radioxenon isotopes in the environment were not well understood or studied. In addition, it is likely that the airborne concentration and distribution of radioxenon isotopes have changed since that time due to evolving activities and locations associated with fission-based medical isotope production and nuclear power generation. However, the Protocol to the CTBT did explicitly refer to backgrounds and implied an issue that needed to be addressed. Therefore, the writers of the Treaty composed text referring to backgrounds of "man-made" (anthropogenic) radionuclides.[1] Following negotiations on the implementation of the verification regime specified in the Treaty and during the development and testing of radionuclide monitoring technology, it was found that radioxenon backgrounds were non-negligible and persistent in parts of North America and Europe despite their short half-lives (Bowyer et al. 1997, 2002; Weiss et al. 2000; Auer et al. 2004; Le Petit et al. 2008). After performing atmospheric transport model calculations (ATM) in the early 2000s, it was determined that sources were consistent

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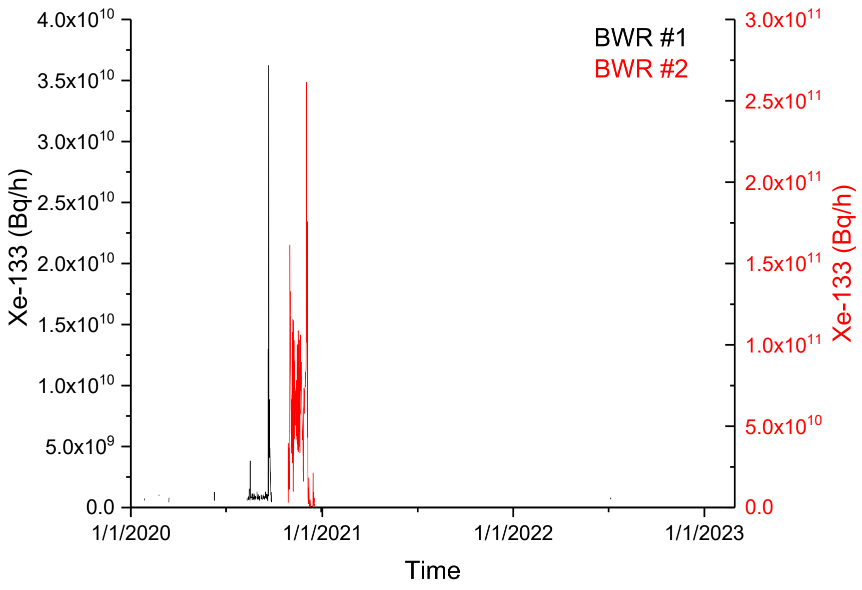
[1] Annex 2 to the Protocol of the CTBT States "*For events detected by the International Monitoring System radionuclide component, the following parameters, inter alia, may be used: concentration of background natural and man-made radionuclides; ...*".

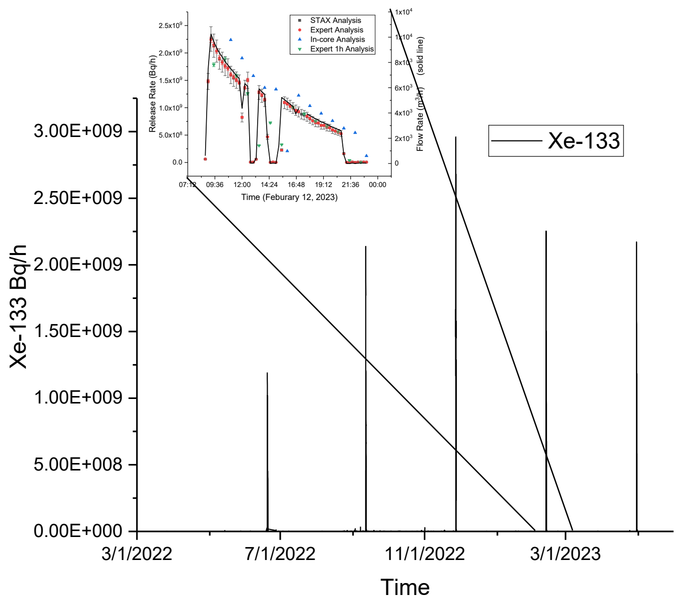
Birkhäuser

Release profile is important for ATM for the IMS

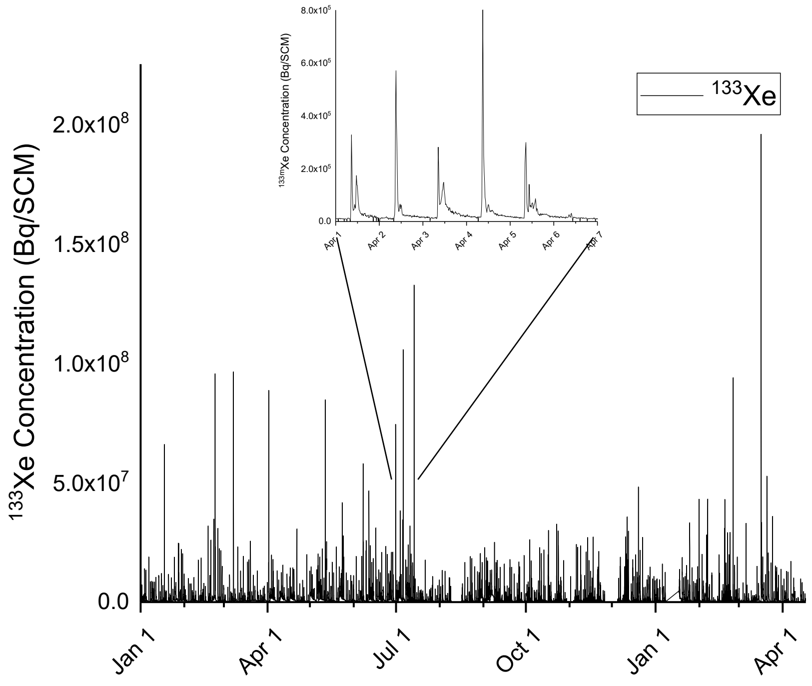
Over two years of radioxenon data from two BWR reactors



One year of radioxenon data from two AGR reactors



1.5 years of radioxenon data from one medical isotope production facility



The Future

- Keep existing facilities generating quality STAX data
- Work with potential future volunteer facilities to address data security and IP issues
- Continue scientific work to make xenon background subtraction reliable
- Include additional voluntary data (research reactors, power reactors, other xenon sources) - See STAX 2 poster

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STAX
Source Term
Analysis of Xenon

Thank you