PNNL-25226

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

WOSMIP V - Workshop on Signatures of Medical and Industrial Isotope Production

Hosted by the Preparatory Committee for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), the Belgian Nuclear Research Centre (SCK•CEN) and Pacific Northwest National Laboratory (PNNL).

Egmont Palace, Brussels, Belgium
May 12–14, 2015

May 2016

This report was compiled by PNNL from presentations, materials and discussions at the fifth Workshop on Signatures of Medical and Industrial Isotope Production (WOSMIP).

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov


This document was printed on recycled paper.
(8/2010)

DISCLAIMER

The views expressed herein are those of the authors and do not necessarily reflect the views of the CTBTO Preparatory Commission.

PNNL-25226

WOSMIP V - Workshop on Signatures of Medical and Industrial Isotope Production

Hosted by the Preparatory Committee for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), the Belgian Nuclear Research Centre (SCK•CEN) and Pacific Northwest National Laboratory (PNNL).

Egmont Palace, Brussels, Belgium, May 12 – 14, 2015

This report was compiled by PNNL from presentations, materials and discussions at the fifth Workshop on Signatures of Medical and Industrial Isotope Production (WOSMIP).

May 2016

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

The fifth Workshop on Signatures of Medical and Industrial Isotope Production (WOSMIP) was held in Brussels, Belgium on May 12-14, 2015. The focus of the workshop was to bring together representatives from the medical isotope production (MIP) and nuclear explosion monitoring communities to discuss ways to mitigate the effects of radioxenon emissions from fission-based MIP on the verification efforts for the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Discussions at this workshop focused on new developments in International Monitoring System (IMS) noble gas network and sensors, the science of radioxenon emissions and atmospheric transport, updates from medical isotope producers on production processes and facilities, technologies used to measure radioxenon stack releases, research and development targeted at reducing radioxenon emissions and methods for data sharing between the communities. This overview presents major outcomes from the workshop.

WOSMIP V featured the largest representation of current and prospective isotope producers of any WOSMIP workshop to date. Fourteen current or prospective medical isotope producers attended the meeting and shared detailed information on current and future MIP. This information will aid the community to better understand the effects of MIP on monitoring. Additionally, several producers announced their intent to work toward achieving the voluntary radioxenon release goal of 5x109 Bq/day as derived from scientific studies presented at WOSMIP IV, and one major producer states that it is already meeting the goal in routine operations.

During the introductory session, the International Atomic Energy Agency (IAEA) introduced a coordinated research project (CRP) on the sharing and developing of protocols to further minimize radioactive gaseous emissions to the environment in MIP. This CRP, which complements the WOSMIP effort, will seek to identify important technical issues related to radioxenon releases from current and possible future MIP facilities with the goal of creating guidelines on how to minimize and mitigate radioactive gaseous emissions. The IAEA has already received several requests from member states to participate in the CRP, and other interested parties are encouraged to participate.

The session focused on stack release measurements detailed the potential for stack release data from MIP facilities to assist the CTBTO in studying the impact of MIP on IMS network performance and assisting NDC experts in their tasks related to treaty verification. Using stack release data along with atmospheric transport modeling (ATM) has the potential to quantify the effect of MIP releases on the observations made at stations of the IMS. While several producers have already shared stack data on a provisional basis, several additional producers also offered to share stack release data. Additionally, the CTBTO announced that it will begin collecting stack data on an experimental basis for the purpose of scientific studies relevant to the CTBT. The CTBTO will also continue to work with producers on issues related to data confidentiality and data surety.

A session covering other aspects of MIP combined several diverse subjects including: lessons learned from highly enriched uranium (HEU) to low enriched uranium (LEU) conversion and how they relate to radioxenon emissions; and development of disposable radioxenon scrubbers. Furthermore, representatives from the Republic of Korea discussed the importance that they place on minimizing radioxenon emissions from their future production facility so as not to negatively affect continued efforts to monitor for nuclear explosions.

During the session on the ATM technology, as well as during the introductory session, various numerical simulation studies using hypothetical values of MIP emissions were reported. The focus of those studies is the impact that MIP emissions have on global radioxenon background, as exhibited in the IMS network. A new line of developments was drawn with scientific studies undertaken to estimate

uncertainties in an atmospheric transport model. It was also emphasized that all presented studies would largely benefit from a reliable inventory of stack release data. Moreover, as illustrated with the results from the ATM Challenge, these inventories coupled to the IMS measurements, constitute an invaluable framework for further development, testing and validation of the atmospheric transport models. Findings on the importance of reliable inventories of stack release data for the IMS network performance were complemented with experimental studies illustrating their potential interference with underground detection capabilities during an on-site inspection for the CTBT.

In the final session of the workshop, research on new emission abatement technologies was shared with the community. Currently, the Belgian Nuclear Research Centre (SCK•CEN) has a contract from the CTBTO under EU funding to develop equipment that will soon be tested at the Institute for Radioelements (IRE) and potentially other isotope production facilities. In addition to technical solutions, the importance of communicating with the technical personnel at medical isotope production facilities was stressed. It was agreed that abatement remains the ideal solution to the radioxenon background problem, but other approaches such as sharing of stack release data are also important and can have significant impact.

Overall, WOSMIP V was a great success. Several positive outcomes from the workshop were achieved. The IAEA CRP for the reduction of gaseous emissions from MIP has been initiated. Many producers are working toward reducing radioxenon emissions and are willing to cooperate in sharing of stack release data. The CTBTO has agreed to accept stack data on an experimental basis, and advancements in mitigation technology are being made in several areas. Looking forward, the community agreed that the next WOSMIP should take place roughly 1 ½ years after WOSMIP V.

Acknowledgments

The workshop hosts CTBTO, SCK•CEN and PNNL would like to thank WOSMIP participants for their contributions to the workshop and this report. The agenda contains more information on individual roles in relation to the workshop, see Appendix A.

Participant	Country	Role	Affiliation
P. Achim	France	Presenter	Research Engineer; Commissariat à l'Énergie Atomique et aux Énergies Alternatives
D. Amaya	Argentina	Presenter	Project Manager; INVAP SE
M. Auer	CTBTO	Co-organizer, Session Chair and presenter	Vice Provisional Technical Secretariat; Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization
G. Ball	South Africa	Presenter	Chief Technology Officer; NTP Radioisotopes SOC Ltd.
R. Berg	Canada	Presenter	Radiation Systems and Field Specialist; Health Canada
T. Bowyer	United States of America	Co-organizer and presenter	Laboratory Fellow; Pacific Northwest National Laboratory
R. Brown	United States of America	Presenter	Senior Director; Mallinckrodt Pharmaceuticals
E. Carranza	Argentina	Presenter	Head of Fission Radioisotope Production Plant; Head of Radiological Protection
I. Cameron	United States of America	Co-organizer and presenter	Specialist – Arms Control and Nonproliferation; Pacific Northwest National Laboratory
J. Camps	Belgium	Co-organizer and presenter	Scientific Staff; Belgian Nuclear Research Centre
Z. Chen	China	Presenter	Associate Professor; CTBT Beijing National Data Center and Beijing Radionuclide Laboratory
R. DeCaire	Canada	Presenter	Health Physicist; Nordion
B. Deconninck	Belgium	Co-organizer and presenter	Environmental and Metrology Dept. Manager; National Institute for Radioelements ELiT
A. Delcloo	Belgium	Presenter	Research Scientist; Royal Meteorological Institute
P. De Meutter	Belgium	Presenter	Scientific Staff; Belgian Nuclear Research Centre
M. Di Tada	Argentina	Presenter	Radiation Monitoring Systems Design
J. Dix	Austria	Session Chair and Presenter	International Atomic Energy Agency
C. Doll	United States of America	Co-organizer	Research Scientist; Pacific Northwest National Laboratory

J. Friese	United States of America	Co-organizer, Session Chair and presenter	Research Scientist; Pacific Northwest National Laboratory
H. Gheddou	CTBTO	Session Chair and Presenter	Comprehensive Nuclear Test-Ban-Treaty Organization
J. Ginter	United States of America	Session Chair	Research Scientist; Pacific Northwest National Laboratory
I. Goldman	United States of America	Presenter	Project Manager; International Atomic Energy Agency
C. Gueibe	Belgium	Presenter	Scientific Collaborator; Belgian Nuclear Research Centre
C. Haass	United States of America	Presenter	Vice President; Northwest Medical Isotopes
R. Hamilton	United States of America	Presenter	National Nuclear Security Administration
J. Harvey	United States of America	Presenter	Chief Science Officer; NorthStar Medical Technologies, LLC
E. Hoffman	Australia	Session Chair and Presenter	Manager; Nuclear Assurance Services; Australian Nuclear Science and Technology Organisation
Y. Imardjoko	Indonesia	Presenter	President Director; PT INUKI (Persero)
A. Ivan	Romania	Presenter	Engineer; Infrastructure for Production of Radioisotopes and Progress in Mo^{99} Production from LEU Targets
C. Johnson	United States of America	Presenter	Researcher; The University of Texan at Austin
M. Kalinowski	CTBTO	Co-organizer, Session Chair and presenter	Head of the Scientific Methods Unit in the IDC Division; Comprehensive Nuclear Test-Ban-Treaty Organization
J. Lee	Republic of Korea	Presenter	Project Manager; Korea Atomic Energy Research Institute
S. Lee	Republic of Korea	Presenter	Korea Atomic Energy Research Institute
A. Malkawi	Jordan	Presenter	Section Head; Jordan Atomic Energy Commission
M. Marghem	Belgium	Presenter	Belgium Minister of Energy; Environment and Sustainable Development
G. Meskens	Belgium	Presenter	Researcher and Lecturer; University of Ghent
L. Metz		Co-organizer and Session Chair	Research Scientist; Pacific Northwest National Laboratory
D. Moyaux	Belgium	Presenter	Researcher; R&D Department; Belgian Nuclear Research Centre

P. Saey	IAEA	Co-organizer and presenter	Nuclear Safeguards Inspector; International Atomic Energy Agency
M. Schoeppner	United States of America	Presenter	Researcher; Princeton University
G. Vandegrift	United States of America.	Presenter	Argonne Distinguished Fellow; Argonne National Laboratory
K. van der Meer	Belgium	Co-orgaizer and speaker	Head Society & Policy Support (SPS), Environment, Health& Safety; Belgium Nuclear Research Centre
S. Wu	China	Presenter	Senior Researcher; Northwest Institute of Nuclear Technology
C. Zaw	Myanmar	Presenter	Ministry of Science and Technology
L. Zerbo	CTBTO	Speaker	Executive Secretary; Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization

Acronyms and Abbreviations

AEMI	gaseous Air Effluent Monitor
ANSTO	Australian Nuclear Science and Technology Organisation
ARIX	Russian Analyzer of Xenon Radioisotopes
ATM	Atmospheric Transport Model
CEA	Commissariat à l'Énergie Atomique et aux Énergies Alternatives
CNL	Canadian Nuclear Laboratories
CPU	Central Processing Unit
CRP	Coordinated Research Project
CTBT	Comprehensive Nuclear-Test-Ban Treaty
CTBTO	Comprehensive Nuclear-Test-Ban Treaty Organization
ECMWF	European Centre for Medium-Range Weather Forecasts
FDA	U.S. Food and Drug Administration
FLEXPART	FLEXible PARTicle dispersion model
FPM	Fission Produced Material
HEU	Highly enriched uranium
IAEA	International Atomic Energy Agency
IDC	International Data Centre
IMS	International Monitoring System
INUKI	PT Industri Nuklir Indonesia (formally PT Batan)
IRE	National Institute for Radioelements, Belgium
JRTR	Jordan Research and Training Reactor
KAERI	Korean Atomic Energy Research Institute
LEU	Low-enriched uranium
LPDM	Lagrange Particle Dispersion Model
MDC	Minimal Detectable Concentration
MIP	Medical Isotope Producer/Medical Isotope Production
MURR	Missouri University Research Reactor Center
NCEP	National Centers of Environmental Prediction
NDC	National Data Center
NEA	Nuclear Energy Agency
NG	Noble Gas
NNSA	U.S. National Nuclear Security Administration
NPP	Nuclear Power Plant
NTD	Neutron Transmutation Doping
NTP	NTP Radioisotopes Ltd, South Africa

NWMI	Northwest Medical Isotopes
OSI	On-Site Inspection
OSU	Oregon State University
PE	Pulmonary Embolism
PNNL	Pacific Northwest National Laboratory
PTS	Provisional Technical Secretariat
RERTR	Reduced Enrichment for Research and Test Reactors
RMI	Royal Meteorological Institute of Belgium
SAFARI	South African Fundamental Atomic Research Installation
SAUNA	Swedish Automated Unit for Noble Gas Analysis
SCK•CEN	Belgian Nuclear Research Centre
SOH	State of Health
SPALAX	French Automated Unit for Noble Gas Analysis
SPECT	Single-photon emission computed tomography
WOSMIP	Workshop on Signatures of Medical and Industrial Isotope Production
WGB41	41st Session of Working Group B of the Comprehensive Nuclear Test-Ban-Treaty Organization Preparatory Commission

Contents

Figures

Tables

1.0 Introduction

Radioisotopes have many peaceful applications in industry, research and medicine. In nuclear medicine, radioisotopes are useful as tools for the diagnosis and treatment of disease – of the approximately 3 million treatments per year, about 90% are diagnostic. The most common radioisotope used for diagnosis is ^{99m}Tc (the daughter of ^{99}Mo), accounting for 80% of nuclear medicine procedures worldwide. Information gained from these procedures allow for quick diagnosis of patients' heart, liver, thyroid, and blood flow and detection of tumors in the prostate, breast, and bone. The production of fission-based ^{99}Mo, which decays to ^{99m}Tc, is the main method of ^{99m}Tc production. In this method, ^{235}U is irradiated in a reactor resulting in the production of ^{99}Mo along with other fission products, including radioxenon and radioiodine, which have the potential to be released to the atmosphere. In contrast to nuclear power plants (NPP), signatures of gaseous emissions from medical isotope production (MIP) are similar to a nuclear explosion because the process involves dissolution of a uranium target shortly after irradiation. This relatively rapid dissolution after irradiation releases radioxenon with isotopics similar to a nuclear explosion, inadvertently creating a radioxenon background that creates a challenge for Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification.

The Workshop on Signatures of Medical and Industrial Isotope Production (WOSMIP) has been held five times with the goal of bringing together the isotope production and the treaty monitoring communities with the purpose of mitigating the effects of isotope production on the monitoring without disrupting the supply of isotopes. These five workshops (held in 2009, 2011, 2012, 2013 and 2015) have helped raise awareness of the issues and concerns surrounding emissions from MIP facilities and to look for ideas to solve these problems without affecting production capability. These workshops have helped achieve cooperation between the communities to search for answers to mitigating the effects of MIP on the monitoring community.

The first WOSMIP (2009) brought together the production and monitoring communities to define and outline the problem. During WOSMIP II (2011), the problem was more distinctly refined; scientific and political boundaries were established; and possible directions for the communities to work together and move forward were identified. Highlights from this meeting included the demonstration of observations of radioxenon emissions from MIP by the International Monitoring System (IMS); examples of technology being developed to lower emissions; and examples of lowered emissions in real-world facilities. Questions about new producers remained: Who were they? Where were they located? At what levels do they produce? At WOSMIP III (2012), a number of important observations were made, including that emissions released from MIP at current levels are detected by IMS daily. In addition, it was concluded that sharing of stack release along with reduction at the source were both crucial to solving the problem. Goals of WOSMIP IV (2013) were to find ways to break down barriers, to identify scientific investigations required to fill gap in knowledge, and to take advantage of new political decisions and new strategic relationships. Four producers signed the pledge to reduce radioxenon emissions and to share information on emission levels with the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO): Korean Atomic Energy Research Institute (KAERI), Australian Nuclear Science and Technology Organization (ANSTO), Indonesian National Nuclear Energy Agency (PT Batan), and Coqui Radiopharmaceuticals. Prior to WOSMIP IV, the pledge was signed by the National Institute for Radioelements (IRE) and more recently Northstar has signed the pledge.

The fifth workshop built on the foundation created by previous WOSMIPs and was successful in advancing the support and scientific understanding of the problem. Some goals of WOSMIP V were to bring the MIP and monitoring technical communities together; update the community on the status of scientific projects related to MIP abatement; continue to inform about the issue; and discuss technical issues related to stack release data. WOSMIP V was held at the Egmont Palace, Brussels in May 2015 and

hosted by the CTBTO, the Belgian Nuclear Research Centre (SCK•CEN) and PNNL. The workshop began with a message from Klaas van der Meer, Head Society and Policy Support, Environmental Health and Safety for SCK•CEN, who stressed the importance of the WOSMIP community. A message was delivered on behalf of Mrs. Marie Christine Marghem, Belgian Minister of Energy, Environment and Sustainable Development, supporting the WOSMIP and stating that SCK•CEN and IRE are studying possible options to mitigate radioxenon emissions. A final welcoming statement was given by Lassina Zerbo, CTBTO Executive Secretary, stating that the goal of WOSMIP was not to mitigate production but to reduce the effect of MIP emissions.

This report provides a summary of highlights from the three-day workshop. Unavoidably, some presentations and events have been highlighted more than others, but authorship for the report belongs to all presenters, because they all contributed to the success of the meeting.

2.0 Introduction to the Problem

An introduction to issues regarding fission-based MIP and its effect on nuclear explosion monitoring was covered in the first session of the workshop. While this session was a review to past WOSMIP participants, providing this background was important to allow newer participants to fully understand issues faced by each community. Overviews were provided by Pacific Northwest National Laboratory (PNNL) and the Provisional Technical Secretariat (PTS) of the Preparatory Commission for the CTBTO.

2.1 Workshop Overview

The workshop began with an overview of past workshops and goals for WOSMIP V. In 2009, the initial WOSMIP was held to explore issues associated with the production of medical and industrial isotopes. While fission-based MIP was suspected to be the major source of radioxenon interference for the IMS and there were several cases of isotopes measured in the environment that had been attributed to MIP, there were no documented results to confirm these conclusions. Therefore, the first WOSMIP was organized in order to better understand issues related to MIP that affect radioisotope monitoring capability.

Since its inception, WOSMIP has had many positive effects. Current awareness of the problem is good—although education of the issues is still necessary. To date, six companies have signed the non-binding CTBTO pledge to reduce radioxenon emissions and to share information on emission levels with the CTBTO; see Figure 2.1. Scientific projects studying methods to reduce the effects of MIP emissions are being conducted all over the world. One company appears to abate radioxenon to levels that meet the 5×10^9 Bq/day voluntary release limit. With these successes, there are still some issues that may hinder progress, including the potential of new isotope production facilities being built without abatement plans; frequent (daily) observations of MIP releases by the IMS stations; stack release data from MIP is still not used routinely; the high costs associated with meeting the 5×10^9 Bq/day voluntary radioxenon release limit; and MIP emissions can affect CTBTO onsite inspections.

Figure 2.1. Pledge Signing Ceremony during WOSMIP IV Held in Vienna, November 2013. KAERI, ANSTO, PT Batan, and Coqui Radiopharmaceuticals signed the pledge to reduce radioxenon emissions and to share information on emission levels with the CTBTO. In addition, the pledge was signed by IRE prior to WOSMIP IV and more recently by Northstar.

The goals stated for WOSMIP V were to obtain status on scientific projects to abate MIP emissions, scientific endeavors to address the issue, and production plans; continue to inform about the issue and brainstorm new solutions to the issue; bring the two technical communities together; make progress on technical issues related to stack monitoring data; and find new techniques, gaps, and issues that need to be addressed.

2.2 International Monitoring System Overview

An overview of the IMS began with an explanation of the CTBT. Article I of the CTBT states that:

> …each state party undertakes not to carry out any nuclear weapon test explosion or any other nuclear explosion, and to prohibit and prevent any such nuclear explosion at any place under its jurisdiction or control.

In support of the treaty, a comprehensive global monitoring system will be implemented that may consist of atmospheric, underground, underwater, and outer space monitoring. The treaty was opened for signature in 1996 and currently has 183 signatories and 164 states that have ratified. Upon entry into force—which requires all 44 Annex 2 States to ratify the treaty—a verification regime to monitor compliance of the treaty must be in place. Currently, the CTBTO has over 260 staff members from over 70 countries with an annual budget of $125,000,000 (US) to support the development of a treaty verification regime.

For verification of the CTBT, the IMS was developed. The IMS is a network for continuous global surveillance of compliance. Data generated via the IMS is processed and analyzed by the International Data Center (IDC), and when required, On-Site Inspections (OSI) with teams comprising inspectors from state parties; See

Figure 2.1. In order for an OSI to be conducted, data that supports an event must be provided to the member states for analysis by their national data centers and the member states will call an executive council of the member states to vote on whether an OSI is advocated.

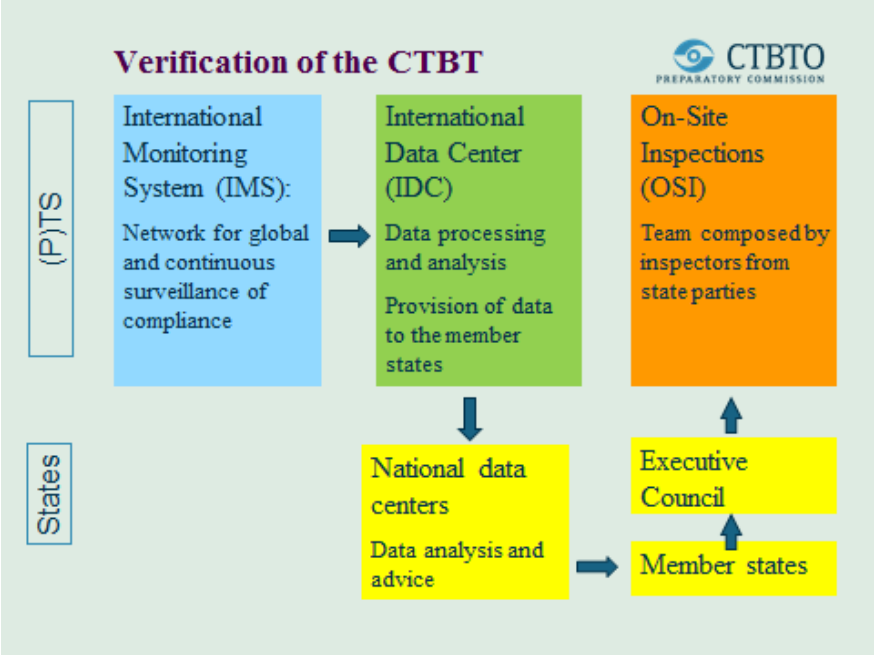


Figure 2.2. Structure of the Verification Regime in Support of the CTBT

The IMS consists of four monitoring technologies to globally monitor for treaty compliance: seismic, hydro-acoustic, infrasound, and radionuclide (radionuclide and radioxenon). These technologies were chosen for their ability to monitor signatures of atmospheric, underground, and underwater nuclear tests. As of May 2015, more than 80% of the network has been installed (281 out of 337 stations). Figure 2.3 shows the 80 radionuclide stations.

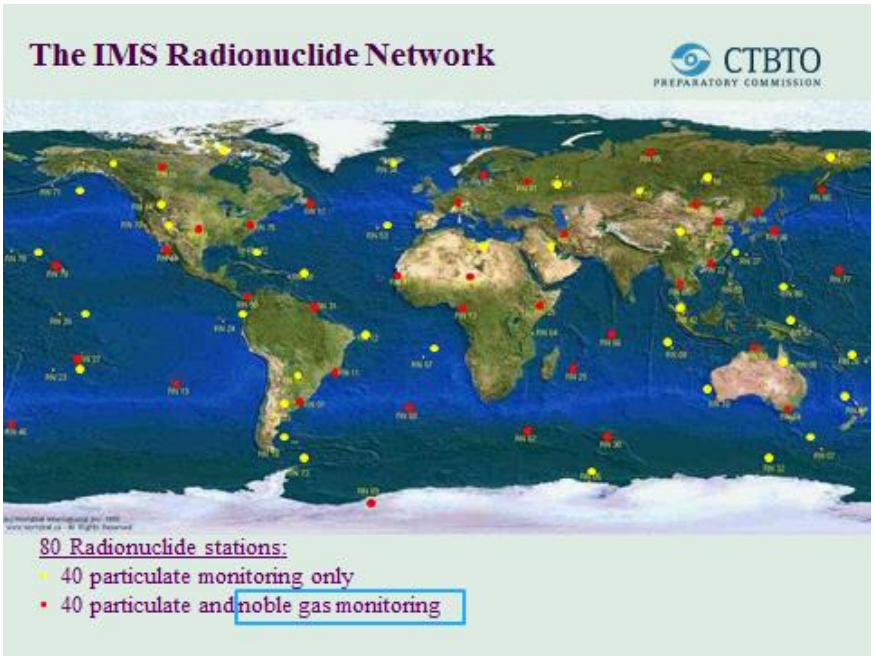


Figure 2.3. The IMS Radionuclide Network

Because noble gases are non-reactive and remain gaseous, they are likely to escape from underground nuclear explosions. Among noble gases, the xenon isotopes ^{131m}Xe, ^{133}Xe, ^{133m}Xe, and ^{135}Xe were determined to be the most suitable for use as a forensic tracer based on their higher fission yields and most suitable half-lives. The minimum requirements for an IMS noble gas system to measure radioxenon are a collection time of 24 hours or less and to be very sensitive; a detection limit of 1 mBq/m^3 for ^{133}Xe is possible with current noble gas systems and with the next-generation state-of-the art technology, 0.1 mBq/m^3 is achievable. Currently, there are three noble gas systems that approach monitoring radioxenon for the IMS differently. These stations are the SPALAX (French Automated Unit for Noble Gas Analysis), SAUNA (Swedish Automated Unit for Noble Gas Analysis), and ARIX (Russian Analyzer of Xenon Radioisotopes) and cost 0.8 – 1.0 million U.S. dollars each to install and 80,000 U.S. dollars each per year to operate.

To detect radioxenon from a nuclear explosion, an understanding of the global radioxenon background is required. Figure 2.4 compares global radioxenon sources. The radioxenon emitted from a 1kT underground nuclear explosion is ~10^{14} Bq. Radioxenon releases from nuclear reactors would have a regional radioxenon background effect, while the effect of hospitals would be minimal and limited to local impact. In contrast, radioxenon released from MIP facilities would have a large-scale impact on the global radioxenon background, including all isotopes and releases. The effect of MIP is similar to an underground nuclear explosion in magnitude and isotopic content.

Radioxenon monitoring is a key component in the verification of the CTBT; among all IMS monitoring technologies, it can provide the strongest evidence for underground nuclear tests. Noble gases released from ^{99m}Tc production are the major source of background and have a composition similar to release from nuclear explosion. Distinction of background from emission from nuclear explosions is crucial for signal interpretation.

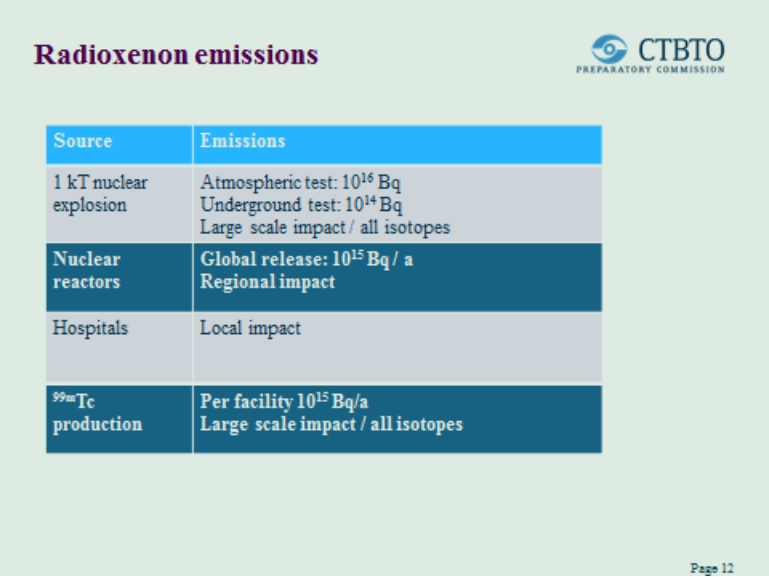


Figure 2.4. Comparison of Radioxenon Emissions from Different Sources

2.3 Background of CTBT Relevant Xenon Isotopes at IMS Stations Based on Reviewed Results in IDC Operations

A summary of noble gas data collected from IDC operations over 30 months (1 September 2012 – 30 April 2015) was presented. This data was compiled from 23 IMS noble gas stations (22 certified systems and 1 under testing and evaluation). The key items covered in this presentation included the processing pipeline and interactive review of the IDC noble gas capability; categorization scheme of noble gas samples; current noble gas systems in IDC operations; time evolution of noble gas data review in IDC operations; the overall picture on sample categorization for noble gas network; observed detections of xenon isotopes; distribution of categorization results by station; frequency of xenon detection vs. IMS location; and monthly detections.

Noble gas processing began in June 2011 when noble gas automated processing software and interactive review tools were installed for IDC provisional operations. At this time, interactive analysis began for the first certified noble gas systems (2 SAUNA and 1 SPALAX systems). On August 2012, a three-level noble gas categorization scheme was implemented in IDC operations, and noble gas data is generated with noble gas category information. In August 2013, Working Group B (WGB) 41 recommended reconsidering ^{131m}Xe for triggering level C samples, resulting in a change in January 2014, when the noble gas categorization scheme recommended by WGB 41 was promoted to IDC operations.

These interactive review tools allow for automated daily analysis of noble gas spectral data, received from the 22 certified IMS noble gas systems currently operating, by IDC Operations. This screening is the first indication for further analysis. The results from the automated analysis are systematically checked in routine mode by IDC analysts to verify sample data quality and accuracy of automatic processing results. Automated and reviewed products are generated and regularly made available to CTBTO member states.

For reliable assessment of radioxenon background at IMS sites, a three-level-based categorization scheme was implemented as a first screening layer of noble gas observations. The generated data contains a

categorization parameter based on the presence of radioxenon and isotopic ratios of present isotopes; see Figure 2.5. This categorization parameter is based on a three-level scheme:

Level A – no radioxenon/background
Level B – radioxenon present/normal event
Level C – above radioxenon threshold/abnormal event

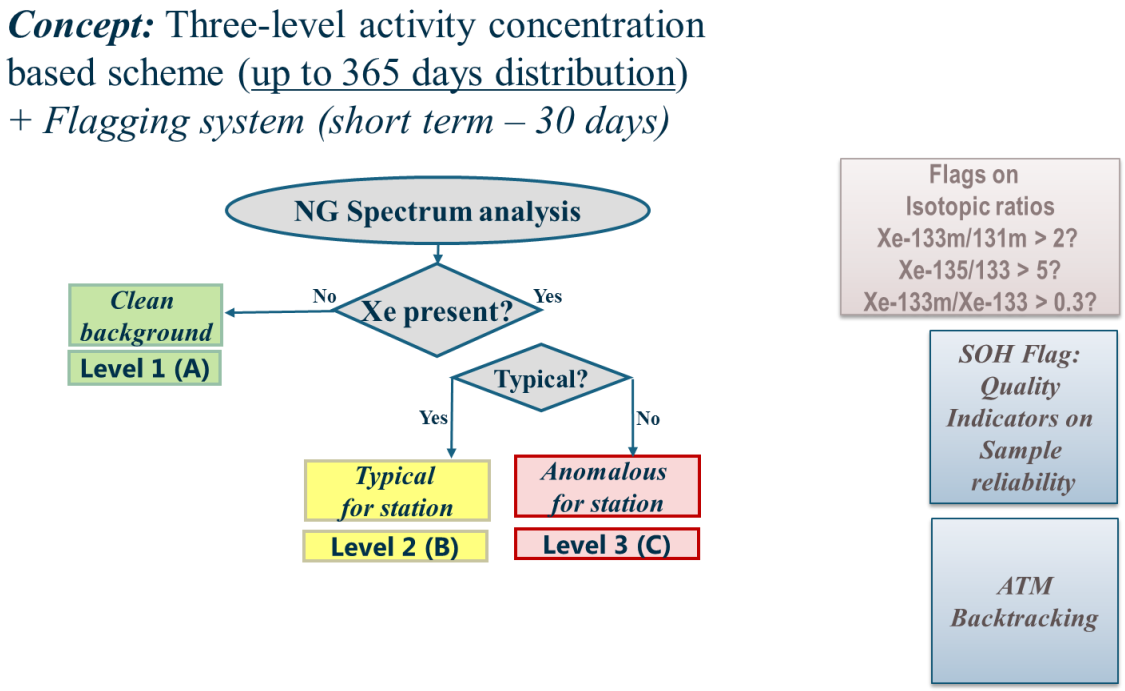


Figure 2.5. Noble Gas Categorization Scheme. Abbreviations used in figure: State of Health (SOH) and Noble Gas (NG)

The threshold for each level is calculated based on the background for that station and is adjusted for each station. While the level can be indicative of an event, other factors need to be ruled out—such as MIP background. This "ruling out" step is required because activity concentrations due to nuclear explosions may fall within the same range (or lower) than emissions from radiopharmaceutical facilities. In addition to sample category in noble gas products, Flags on isotopic ratios and short-term-based statistics (30 days) are also provided for analysts' review. Isotopic ratios are similar for nuclear explosions and emissions from radiopharmaceutical facilities. Approximately 1% of samples are deemed inappropriate for release with categorization after interactive review because minimum requirements are not met for sample metrics.

During the reporting period from 1 September 2012 to 30 April 2015, 28,000 data points from all operational IMS noble gas systems were reviewed in IDC Operations. Radioxenon detections were observed in 46% of the samples (Level C and Level B), with 3% of the samples categorized as a level 3; see Figure 2.6. The concentrations of these detections were up to 100 – 1000 times above the noble gas systems' detection limit. A 3% rate of Level C category detection equates to an average of ~1 sample per day—which is considerable from the CTBT verification perspective considering the resources required to investigate these abnormal events. The radioxenon background varies across the stratosphere with a higher background in Europe. The highest radioxenon activity, levels and detection frequencies were

observed at IMS sites under atmospheric influence of MIP facilities, see Figure 2.7. Geographical distributions of radioxenon detections show a clear impact of emissions from MIP facilities. Therefore, reducing xenon emissions from MIP in the world is expected to mitigate the impact of noble gas background at IMS sites.

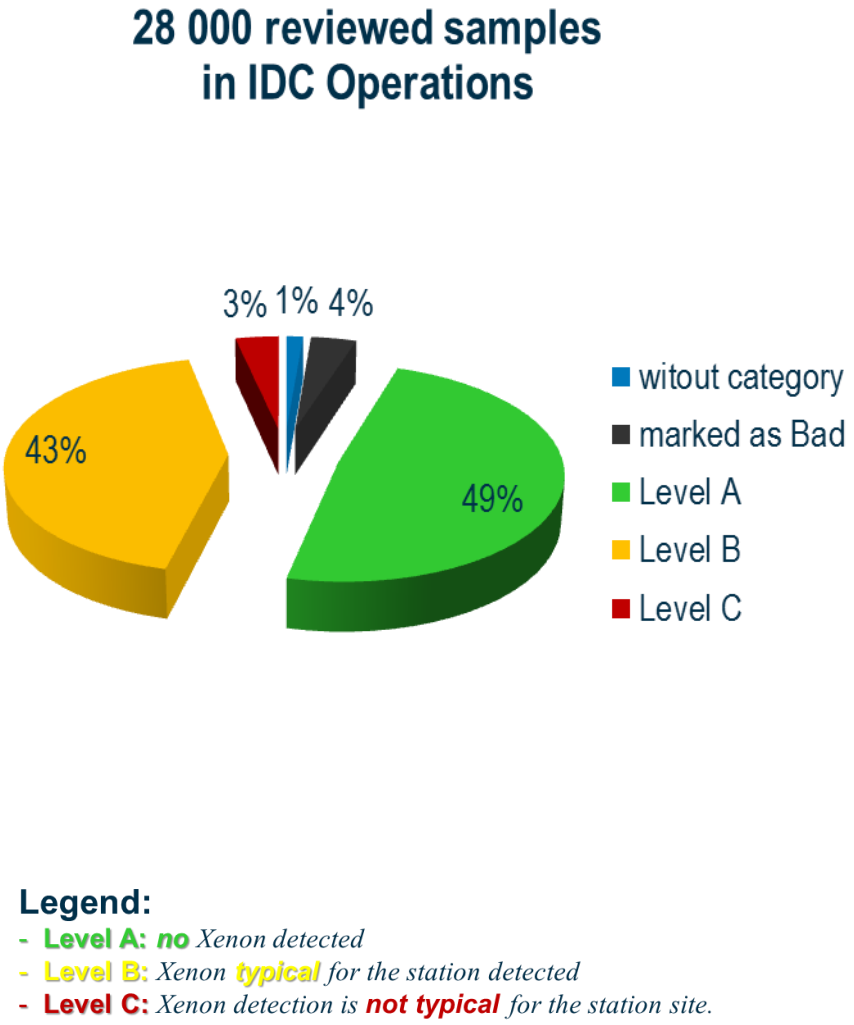


Figure 2.6. Overall Picture of Noble Gas Categorization Results. Level A – no xenon detected, Level B – xenon typical for the station detected, Level C – xenon detection is not typical for the station site.

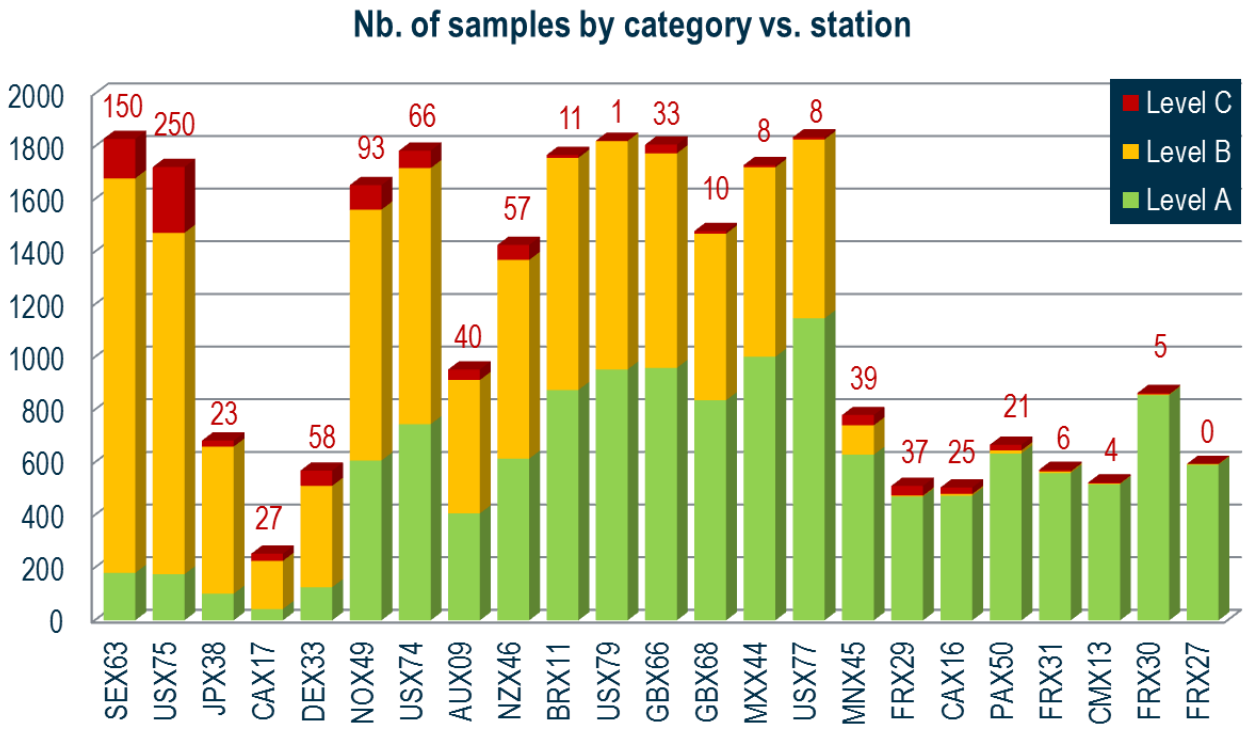


Figure 2.7. Review of Noble Gas Data in IDC Operations

2.4 Simulation of Worldwide ^{133}Xe Atmospheric Background

In the framework of CTBT, monitoring atmospheric radioxenon is relevant in its ability to provide evidence of nuclear weapon tests. However, when the IMS was designed, the impact of radiopharmaceutical facilities and nuclear power plants was not perceived at all. It is now well known that these facilities discharge daily releases of radioxenon into the atmosphere, leading to a significant worldwide radioxenon background. Consequently, the effective IMS network capability to detect nuclear tests may be degraded.

Currently, there are thirty operational IMS noble gas stations each generating one to two samplings per day. To understand this large amount of radioxenon data received daily from the monitoring network, criteria for analyzing the data need to be in place. The data is first screened for any event that is considered to be a detection event. A detection, or event of interest, has been defined as a signal whose amplitude and/or isotopic composition are singular with respect to the detection history of a station. A non-detection event, excluding signals not complying with quality assurance criteria, is a signal whose amplitude is below the critical level or is compatible with the station database and explained from ATM analysis. The use of ATM to simulate the xenon industrial background is one way to help discriminate between civilian and military releases in addition to localization methods, isotopic ratios analysis, etc..

Global ^{133}Xe background has been studied at Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) for several years. Simulations of the global ^{133}Xe background have been modeled using ATM to assess the contributions of the main industrial sources on routine IMS detections. In 2010, 4 MIP and 195 Nuclear Power Plants (NPP) (440 reactors) were modeled by CEA and estimated to release ~35 TBq of ^{133}Xe/day. These releases were determined to contribute significantly to the average

global background, contributing to background levels greater than 5 mBq/m^3 of ^{133}Xe near MIP facilities. The most affected IMS stations (with backgrounds > 0.2 mBq/m^3) are located in North America, Europe, and East Asia; see Figure 2.8. ATM simulations during the 2-year study were in quite good agreement with measured values from IMS stations over the same period; this finding confirms that the main contributors to ^{133}Xe background were identified in the study. The origin of local radioxenon background can be the result of a complex mixture of contributions from local and distant sources. Additionally, there is a decrease in ^{133}Xe levels with altitude (decay and dilution). These factors along with weather patterns contribute to a significant variability of daily activity concentrations at each station.

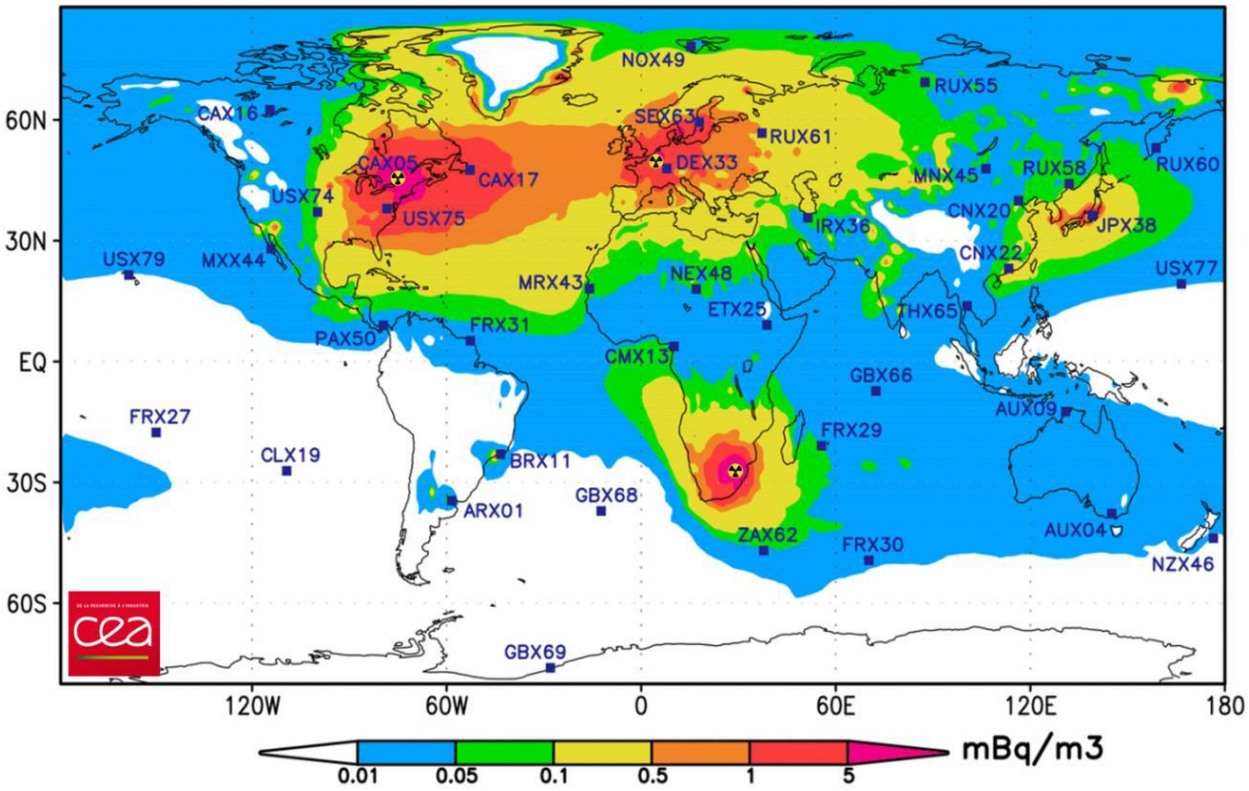


Figure 2.8. Simulation of Global ^{133}Xe Background (2010 Results; Average Calculated over 3 Years). The most affected IMS stations located in North America, Europe, and East Asia are near MIP facilities.

A second more recent simulation of the ^{133}Xe background was performed to include 6 additional MIP facilities. This study, which included 10 MIP facilities and 195 NPPs (440 reactors), estimated the total ^{133}Xe release to be approximately 80 TBq. All identified sources are considered to be in operation. For calculation of daily releases from MIP and NPP, it was assumed that NPP released continuously for 24 hours a day and MIP facilities had 5-hour duration daily releases. ATM simulations were performed over a two-year period (incorporating 2013-2014 meteorology). For each release, the ^{133}Xe dispersion was calculated over 30 days on a 380 Central Processing Unit (CPU) cluster, and 12-hour collection periods for IMS noble gas systems were assumed (2 per day). The results determined for the average industrial background from this simulation are presented in Figure 2.9. In this simulation, the average levels of ^{133}Xe are greater than 0.1 mBq/m^3 in a large part of the Northern Hemisphere. Throughout much of Europe, the ^{133}Xe levels are higher than 0.5 mBq/m^3 and some locations—near MIP facilities—levels are greater than 5 mBq/m^3. The predicted background levels of ^{133}Xe observed in the southern hemisphere are lower as a result of fewer MIP facilities and meteorological characteristics (mixing of atmosphere between the northern and southern hemisphere is relatively slow compared to the half-life of radioxenon).

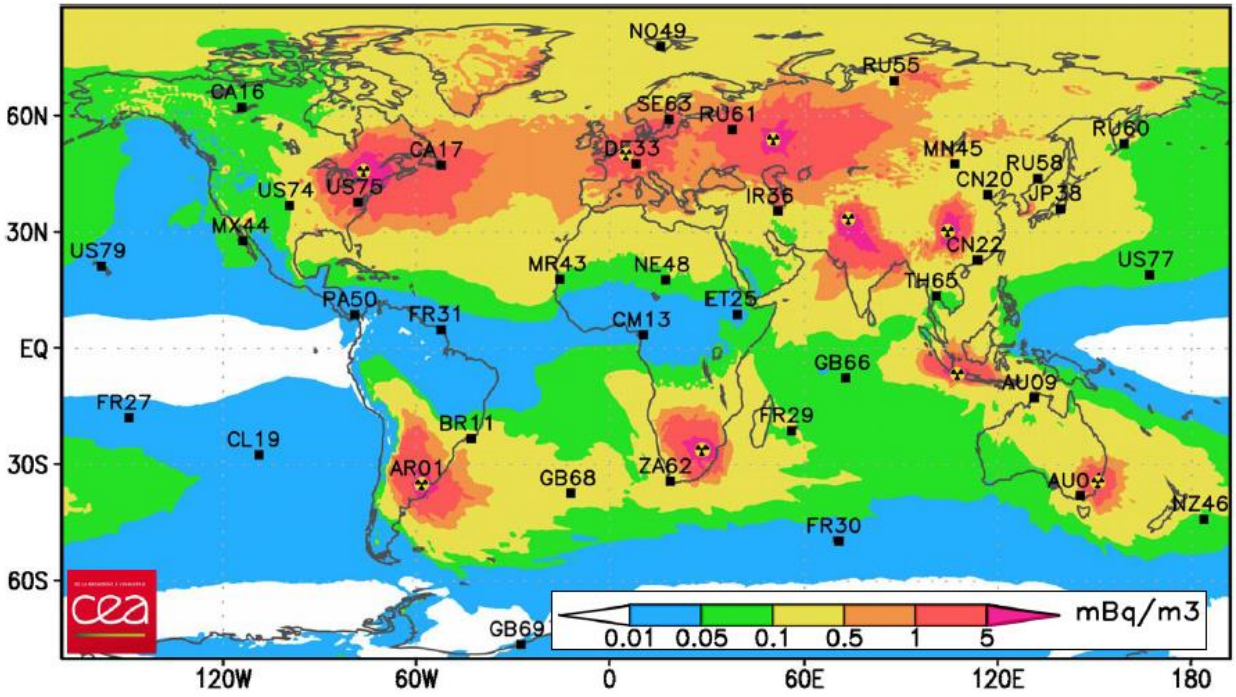


Figure 2.9. Updated Average Industrial Background in ^{133}Xe (layer 0-100mAGL)

In this second study, the expected percentages of ^{133}Xe detections per year above a given detection limit were also modeled. The detections per year were found to be highly dependent on the minimal detectable concentration (MDC) assumed for the IMS noble gas system. Detections per year were investigated assuming MDCs of 0.1, 0.2, 1.0 and 5.0 mBq/m^3. A MDC of 0.1 would lead annually to 40% of detections per year for the whole Northern Hemisphere, 25% for the whole globe, and 10% in the Southern Hemisphere.

An automatic tool was developed at CEA to provide a daily estimate of ^{133}Xe background for each IMS station. All known industrial sources are taken into account. This tool was based on the FLEXible PARTicle dispersion model (FLEXPART) Lagrange Particle Dispersion Model and National Centers of Environmental Prediction (NCEP) 0.5º wind fields (20 CPUs cluster). The results from this tool were compared to IMS noble gas station measurements. The results were in quite good agreement during the simulated period. Origin of ^{133}Xe varies daily (mainly Fleurus, European and Asian NPPs, Chalk River Laboratories, etc.). Examples from IMS noble gas stations SE63, Stockholm, Sweden (October 2014) and NZ46, Chatham Island, New-Zealand (April – May 2014) were presented; Figure 2.10 shows a comparison simulated and measured data for the SE63 station.

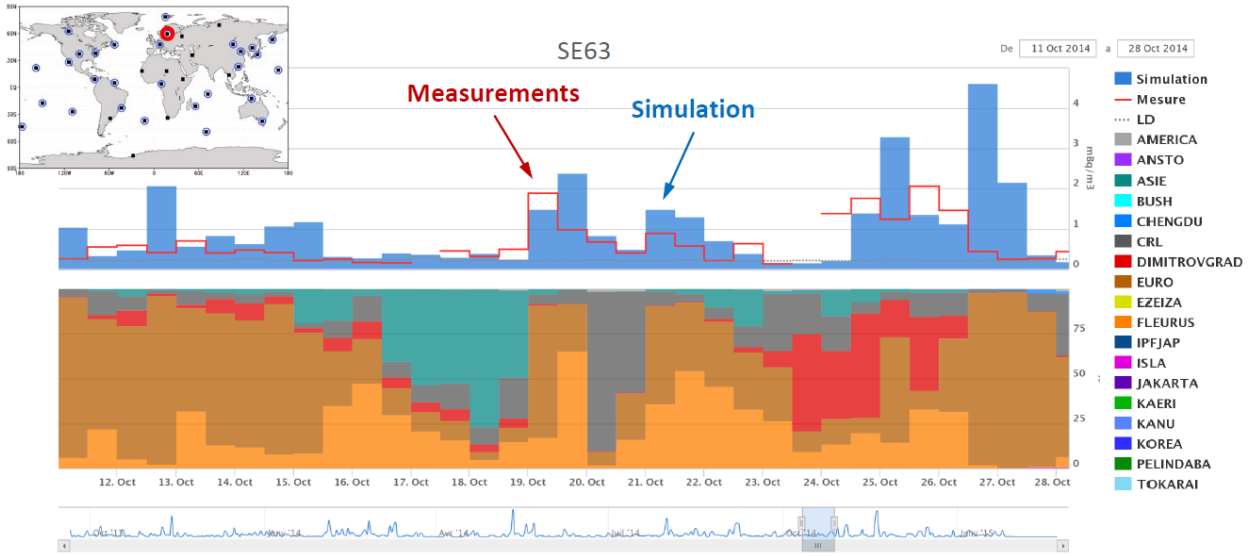


Figure 2.10. Comparison of Measured Results with Simulated Results Using the Automatic Tool (October 11-28, 2014 from the IMS Noble Gas Station SE63 Located in Stockholm, Sweden)

To interpret the daily measurements of ^{133}Xe by the IMS noble gas station network, a comprehensive understanding of the global radioxenon background is required for incorporation as a crucial part of discrimination of civilian/military events at the French National Data Center (in combination with localization methods and isotopic ratios analysis). To fill this need, the CEA has developed an operational automatic tool to provide continuous simulation of the global ^{133}Xe background that is used daily by the National Data Center (NDC) for analysis of IMS data.

2.5 Impact of Radioxenon Emissions from IPFs on the Global Coverage of the IMS Noble Gas Component

A study on the impact of radioxenon emissions from industrial sources on IMS noble gas stations was conducted at Princeton University. This ATM study included 5 MIP facilities and 200 nuclear power plants in their simulations. Backward simulations were performed for 40 IMS noble gas stations assuming 12- or 24-hour sampling using FLEXPART 8.2 + 0.5º NCEP (global National Centers of Environmental Prediction) or 1º ECMWF (European Centre for Medium-Range Weather Forecasts) data for 2010. The ^{133}Xe concentrations were based on the average facility emission inventory per year.

The fingerprint for individual IMS stations was simulated assuming a best-case minimal detectable concentration (MDC) of 0.2 mBq/m^3 ^{133}Xe. With these assumptions, only a few stations have significant data above the best-case MDC (see Figure 2.11). When compared to experimental data from 24 noble gas stations in 2010, the simulated results for America, Europe, and Oceania were quite accurate but the simulated results in Asia were underestimated (see Figure 2.12). This discrepancy in the simulated results in Asia is likely due to underestimating regional emissions.

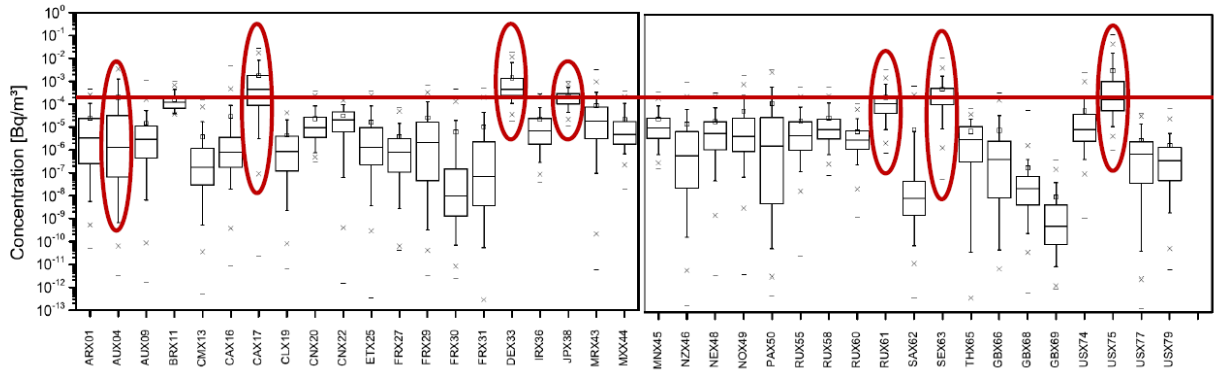


Figure 2.11. Only a Few Stations Have Significant Data above the Best-case MDC

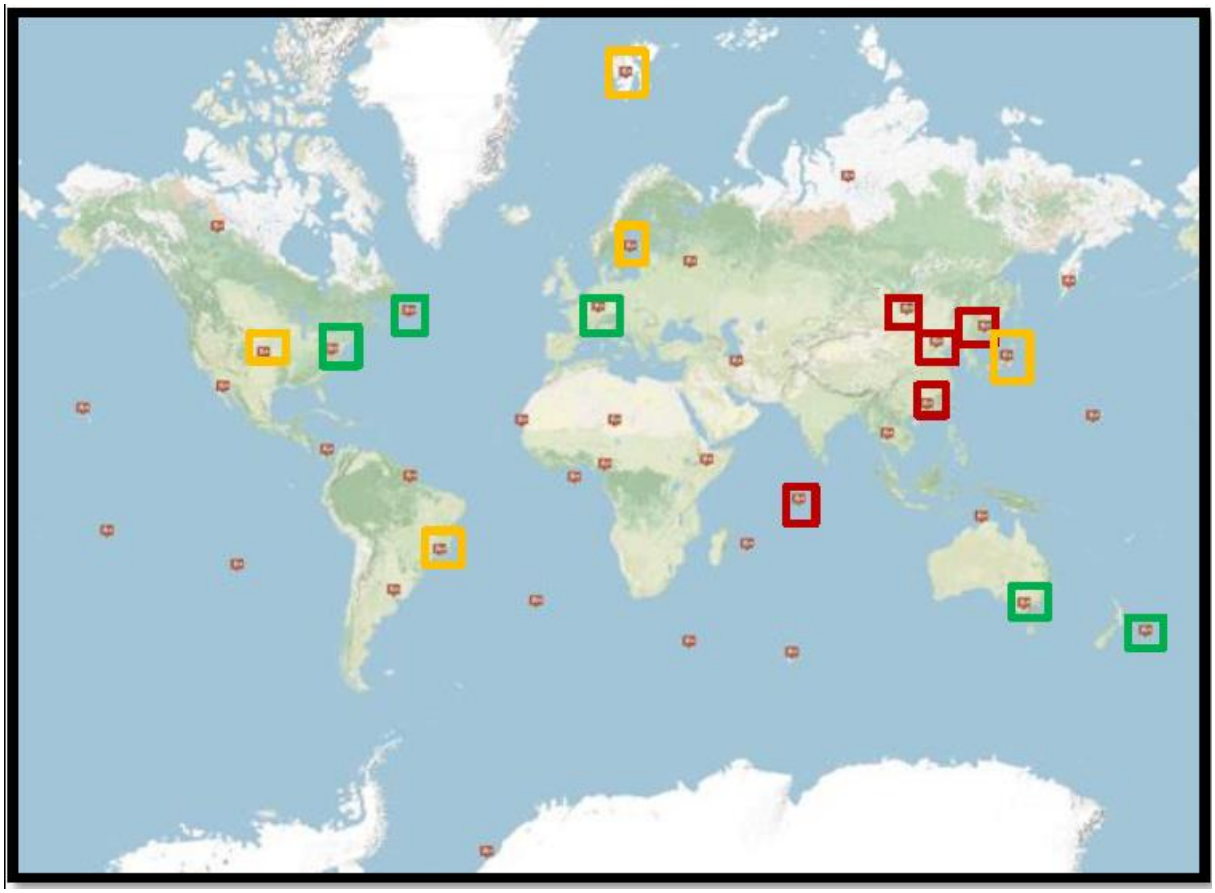


Figure 2.12. America, Europe, and Oceania Simulated Results Were Accurate (Green and Yellow Boxes) while Results for Asia Were Underestimated (Red Boxes)

The impact of the global ^{133}Xe background was investigated by determining the ability to detect underground nuclear tests by comparing ATM simulations under two scenarios: with and without a radioxenon background. A simulated nuclear explosion for every grid point over one year was assumed with the following parameters: underground nuclear tests with 1% leakage from a maximum amount of ^{133}Xe up to 10^{14} Bq; detection criterion: plume from nuclear test reaches monitoring station and concentration greater than standard deviation; comparison of scenarios without and with background. A

clear regional impact from background was observed and thus eliminates the number of detections in high background areas (see Figure 2.13). This background varies with seasonal effects.

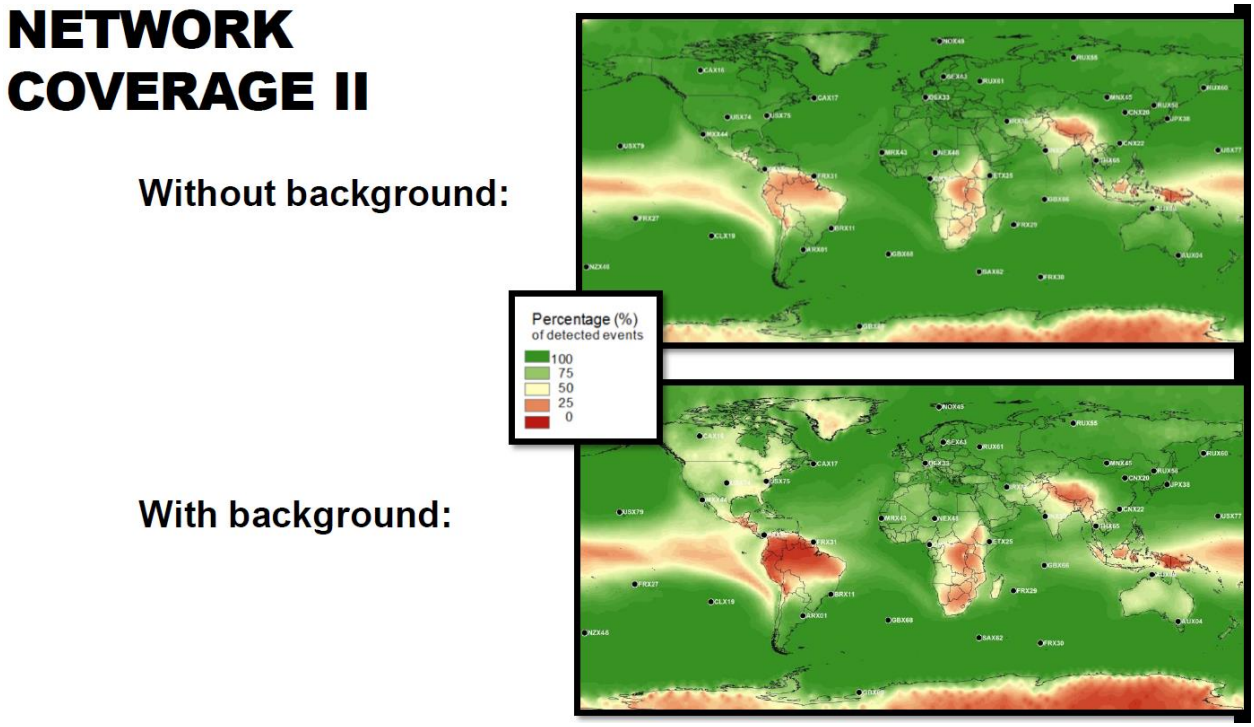


Figure 2.13. Comparison of ATM Simulations with and without ^{133}Xe Background

To reduce the effects of background, retention efforts for MIP facilities will be required. More noble gas monitoring stations may help improve the network sensitivity, especially in equatorial areas to account for meteorological patterns. Creation of a central accessible radioxenon emission inventory from MIP and NPP (e.g., through the virtual Data Exploitation Center or PNNL), in which everyone has access to the same emission data, would allow more research into understanding the global radioxenon background.

2.6 The Way Forward in Xenon Emission Mitigation Research

The Belgian nuclear research center, SCK•CEN, presented an update on their xenon emission mitigation research project. In addition to the amount of radioxenon released from a nuclear explosion, the detection capability of the IMS network depends on the number of distribution stations and the background level at the individual station. Therefore, some stations have many false detections resulting from legitimate industrial radioxenon emissions—primarily from MIP. To reduce the false detections, a voluntary recommended release limit of radioxenon from MIP facilities of 5 X 10^9 Bq/day has been proposed (Bowyer et al. 2013). Current releases from MIP facilities are in the range of 2.5 x 10^9 up to 10^{14} Bq/day but are most typically in the range of 10^{12} – 5 x 10^{13} bq/day. These typical releases are up to 4 orders of magnitude higher than the recommended release limit, which poses a challenge for mitigation research and development, although meeting the recommended release limit has proven to be technologically possible if mitigation is integrated from the start (cf. Petten). The amount of radioxenon released is dependent not only on the quantity of ^{99}Mo produced but also on the production process and abatement technology.

In the production of ^{99}Mo via target-based fission production, radioxenon is confined within the target until dissolution. The xenon that is released during dissolution accounts for ~90% of the total radioxenon released during processing. The other 10% of radioxenon released is accounted for by the decay of other fission products after dissolution:

$$^{133}\text{I} \rightarrow {}^{133}\text{Xe} \text{ and } {}^{133m}\text{Xe}$$

$$^{131}\text{I} \rightarrow {}^{131m}\text{Xe}$$

With many projects planned for new MIP installations, radioxenon abatement techniques that can be applied to traditional and alternative fission-based methods have to be considered. For instance, solution-based fission production (e.g., aqueous homogeneous reactor) would have a continuous release of radioxenon during fission in contrast to the large release that occurs during dissolution in target-based production. Ideally, abatement of radioxenon should be incorporated into the design of a new facility to arrive at treatable conditions (e.g., flow rates).

Emissions released from MIP facilities can give complex release patterns and isotopic signatures (see Figure 2.14). Some explanations for the complex patterns are differences in the irradiation conditions of the highly enriched uranium (HEU) targets irradiated at different reactors (different irradiation conditions, neutron flux, irradiation time) before dissolution; variations in the time between the end of irradiation and dissolution targets; and mixing of radioxenon that originates from target dissolution and as the result of decay during subsequent processing steps and waste storage.

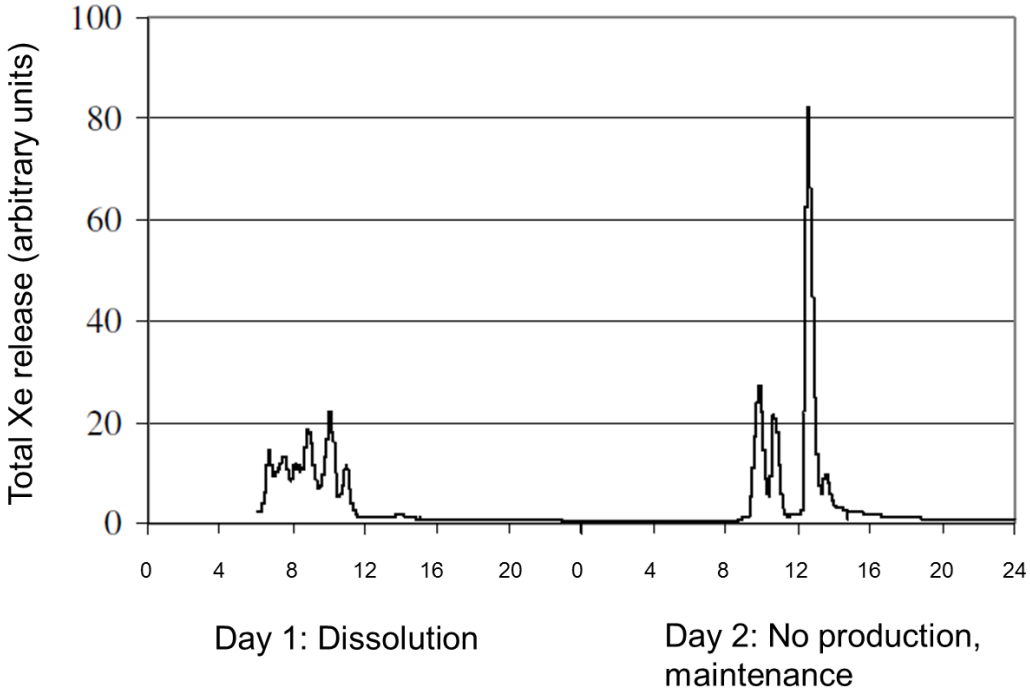


Figure 2.14. Example of complex xenon release patterns

There are many challenges to mitigation of radioxenon in MIP facilities. These challenges vary depending on the facility. Safety issues are created related to mitigation, including radiation protection issues within the laboratory from the increased accumulation to approximately 10^{14} Bq/day of radioxenon instead of releasing it from the facility. This accumulation creates a very strong source, producing a risk for an

incidental release—a sudden release of accumulated xenon activity can be seen as an incident—while the continuous release of that same amount of activity over time would fall within regulatory frame. Moreover, facility off-gas treatment systems (ventilation systems) are not designed for treating radioxenon. Another issue is the availability of space in or near hot cells for abatement equipment and the required shielding—especially in the case of existing facilities. In addition to costs associated with abatement, the cost of shielding can be a large part of the total cost of renovation. To support xenon mitigation by MIPs, research and development is required on efficient mitigation to ensure a system design that is space efficient, cost effective, and operable under normal ambient conditions (depending on the facility).

Xenon abatement is challenging and there are not many options. Xenon is considered an inert gas; although rare, it is not impossible to form compounds with xenon (e.g., XeF_2, XeF_4, etc.). The two methods of xenon abatement most commonly employed are holding tanks and adsorption. Holding tanks are large (73x73 meters) in order to capture the exhaust from hot cells—one hot cell has a flow rate of 250 m^3/h—and contain the radioxenon for 10 half-lives (Xe-133). Additionally, there are safety issues related to release in the event of leakage from the holding tank. Adsorption of xenon gas by a sorbent is best for space limiting.

A pilot study, funded by EU-Joint Action 5, was conducted to reduce radioxenon emissions in an existing MIP facility. The aim of this study was to develop and test a versatile (mobile) pilot radioxenon emission-reduction system at IRE, Fleurus with the goal of gaining experience for reducing emissions in existing facilities and preventing the release in new facilities. A basic xenon abatement solution was designed with the goal of maximizing mitigation of xenon (see Figure 2.15). For this system, an adsorbent material was chosen that is highly selective for xenon and the conditions and installations (flow, dimensions, etc.) were optimized.

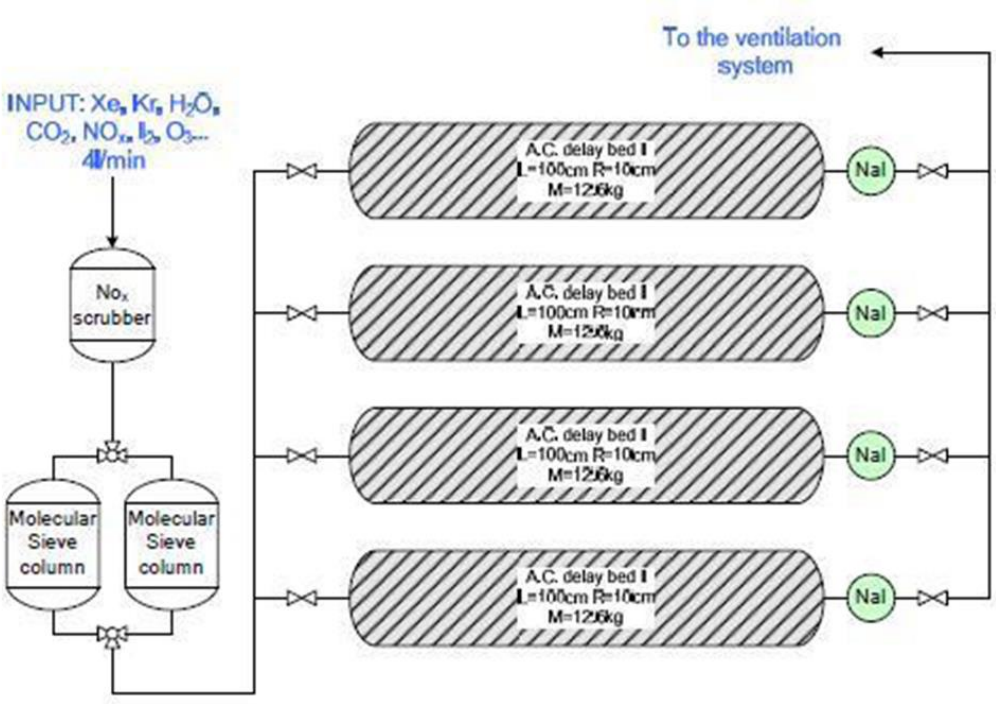


Figure 2.15. Basic Xenon Abatement Solution

In Phase 1 of the study, an optimized absorber material was selected (final report available). During Phase 2, the study investigated trap design and optimization of a trap under different physical conditions (design details and technical drawings available). Finally, in Phase 3, the trap will be installed and tested at different steps of the IRE process (under construction; tests are scheduled for June 2015).

Mitigation of xenon is a challenging issue. The huge flow rates in stack and hot cells make mitigation at these steps very difficult. Treatment of off-gasses at different points in the production steps is easier than treatment for the entire hot cell or facility. For example, dissolution, which has a flow rate of 100 l/h, would be a treatable operational condition, although very limited space is available. Consequently, there was a need for optimization of adsorption materials and conditions. The majority of radioxenon—estimated to be about 90% of xenon released—is expected to be released from dissolution, but the mobile setup allows the possibility to test different places.

Several adsorbent materials were tested in this study (see Figure 2.16). Of these materials, the silver zeolite Ag-ETS-10 provided by the University of Alberta was found to be promising for the prototype system. To be used industrially, this sorbent will need to be mass produced. Other aspects of using this adsorbent for radioxenon capture are that the high adsorption capacity of Ag-ETS-10 results in radioactive heating from the decay of radioxenon isotopes (capacity will decrease with increasing temperature) and the effect of the high dose to the material—around 300 Gy/s for the prototype system (it is very difficult to simulate long-term material degradation with external irradiations).

Moving forward, a prototype trap will be tested at IRE with the new materials and optimization principles used for its construction. These tests will be followed by scaling up the prototype trap to a wider range of operational conditions (higher ventilation rates, use in other parts of the installation). Next, long-term testing of the prototype trap to study the influence of high dose on the material impurities, and other conditions will be conducted. Finally, a study on how the prototype (or the principles used) functions in other existing and new MIP facilities will be conducted.

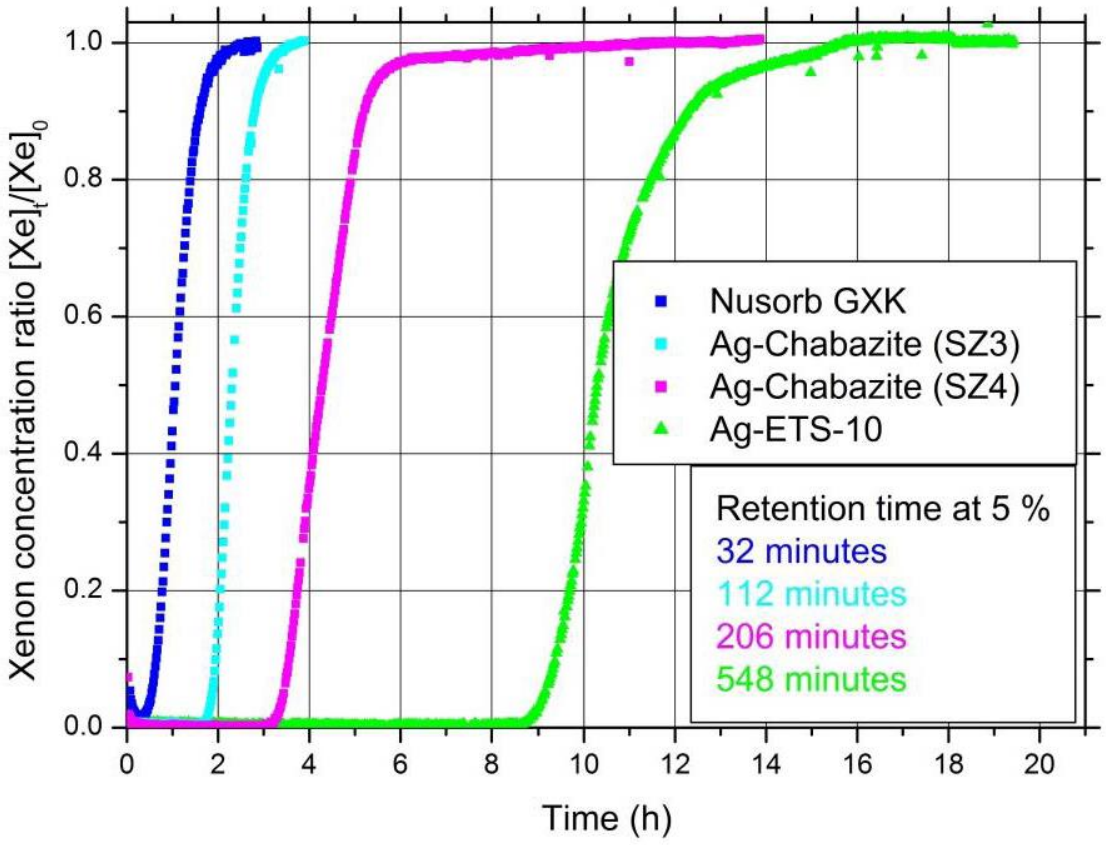


Figure 2.16. Several Adsorbent Materials Were Tested

The effect of Xe mitigation efforts by MIPs on the positive impact on the detection efficiency of noble gas stations/network should be carefully followed. In addition to analysis of station detections, methods such as stack monitoring, atmospheric transport, and dispersion studies should be employed.

In summary, further increasing the sensitivity of the noble gas network can mainly be achieved by mitigation of xenon releases. Using new promising materials, such as Ag-ETS-10, and optimization of the abatement system can reduce the size and cost of mitigation systems (for existing and new facilities). To achieve this reduction, further R&D is needed to continue material studies to identify and test promising materials in MIP environments (high doses, impurities, etc.), develop guidelines for optimized Xe in abatement facilities, and monitor the impact of abatement on noble gas network.

2.7 IAEA Coordinated Research Project Overview

The IAEA is active in several areas related to ^{99}Mo production. These areas include ^{99}Mo supply stability, HEU minimization, indigenous production using non-HEU targets (eg. ^{98}Mo, ^{100}Mo, ^{235}U), small scale production, and new alternatives to ^{99m}Tc. Recently, the IAEA introduced a coordinated research project (CRP) on sharing and developing of protocols to further minimize radioactive gaseous releases to the environment in the manufacture of medical radioisotopes. This CRP, which complements the WOSMIP effort, will seek to identify important technical issues related to radioxenon emissions from current and possible future MIP facilities with the goal of creating guidelines on how to minimize and mitigate radioactive gaseous releases. The IAEA has already received several requests from member states to

participate in the CRP (Belgium, Canada, Germany, Indonesia, Pakistan, Poland, Republic of Korea, and the United States), and other interested parties are encouraged to participate (Argentina, Brazil, China, Egypt, India, Japan, Russia, South Africa, Sweden, and the United Kingdom). This CRP will identify important technical issues and is open to all member states. In addition, observers from other institutions and organizations may be invited to attend at no cost to the agency.

The overall objective of the CRP is to formulate a roadmap to guide the international community in how to address and reduce the emission of radioactive gases. More specifically, the goals of the CRP are as follows:

1. Identify the steps and factors of the process that need proper gaseous emission monitoring and trapping.
2. Determine an internationally accepted target for radioactive gaseous emissions.
3. Produce a summary of the factors that most affect the emission of radioactive gases.
4. Determine methods of treatment and process monitoring that could mitigate the radioactive gaseous emissions.

This CRP is expected to produce a document containing guidelines on how to minimize and mitigate radioactive gaseous releases to the environment resulting from MIP via the irradiation and processing of uranium targets, according to Good Manufacturing Practice and Good Laboratory Practice requirements. The first CRP meeting is planned for 17-21 August 2015 in Vienna, Austria.

3.0 Current ^{99}Mo Production Overview

The second session of the workshop included several presentations from current ^{99}Mo medical isotope producers. These talks provided an update from many producers on their status on current production methods, as well as an update on methods planned for future use. Different considerations related to potential xenon release from these various production methods and some plans for Xe mitigation were also discussed.

3.1 New Radioisotopes Production Plant in Argentina, Argentina

Argentina is building a new reactor (RA-10) to generate radioisotopes and a new radioisotope production plant that they expect to be operational by 2018. A description of the characteristics of these two facilities was presented. The weekly ^{133}Xe inventory was determined for the new plant and different routes for ^{133}Xe release were identified and quantified. Proposals of engineering resources and devices to reach the CTBTO-recommended emission levels for ^{133}Xe of less than 5 GBq per day in the new plant were presented.

The new RA-10 reactor and MIP facility will be located in the Ezeiza Atomic Center and provide a replacement for the RA-3 reactor built in 1967. This reactor will operate on LEU fuel and be a multipurpose facility suitable for radioisotope production, materials and fuel irradiation, neutron technique applications, and silicon doping. Once fully operational, this facility will have the capability to produce 2,500 6-day curies ^{99}Mo per week, which corresponds to a weekly ^{133}Xe inventory of 4.25×10^{14} Bq. The release of xenon from the facility is attributed to three main ways of emissions: "Air," "Hydrogen," and Production Process (see Figure 3.1). The "Air" is used to move liquids in columns and vessels; gases like ^{133}Xe are retained in tanks (lung tank) (to meet the 5 GBq ^{133}Xe levels, the activity would need to be reduced 77,500 times). These gases accumulate from the anion exchange resin column, chelating resin column, and aluminum oxide column. A weekly volume of 3,000 liters of solution passes through the column and the gases are stored in a lung tank before evacuation into the hot cell. The "Hydrogen" stream contains the fission gasses collected from the dissolver in decay tanks (see Figure 3.2) (to meet the 5 GBq ^{133}Xe levels, the released activity would need to be reduced 17,000 times). Several options for the treatment of the "Hydrogen" stream were presented and are shown in Figure 3.3. These options include evacuated tanks, which are simple but require a large volume and therefore the most space ($20m^3$); a hydrogen converter, which would require fewer tanks ($2\ m^3$) but require specialized equipment for heating and cooling processes; and the use of a palladium membrane, which would require the least space ($0.5\ m^3$), but the technology is in the development stage.

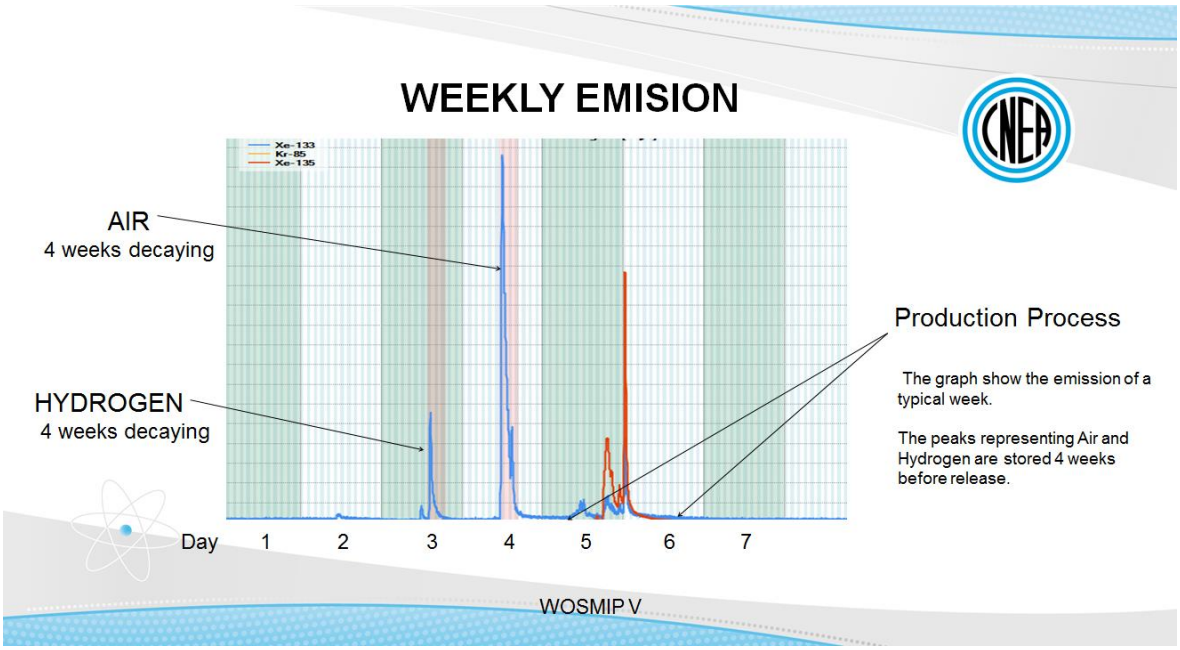


Figure 3.1. Example of Xenon Releases during a Typical Week

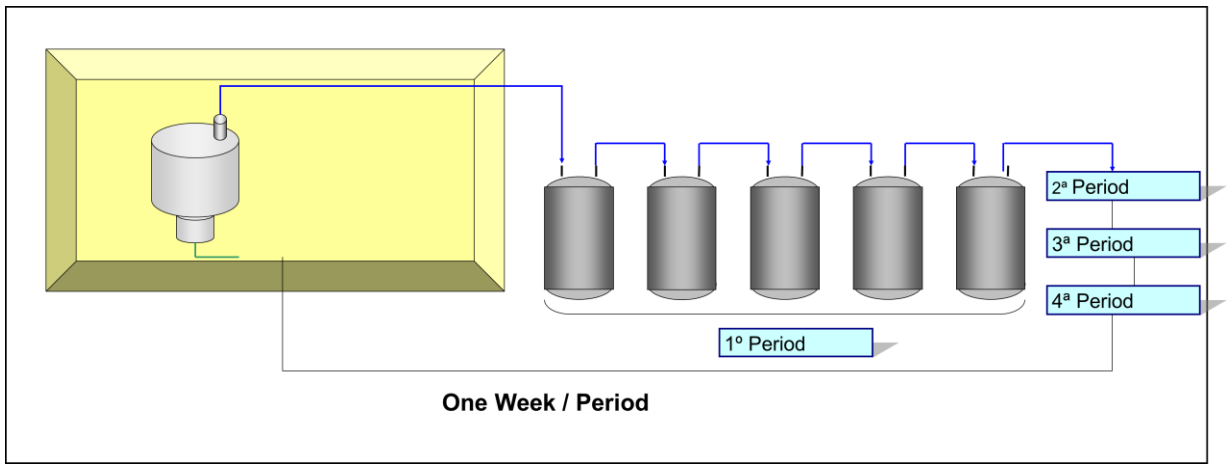


Figure 3.2. Fission Gases Are Captured in Evacuated Tanks for Four Weeks before Releasing into the Dissolution Cell and Passed through the Ventilation Cell System to the Atmosphere

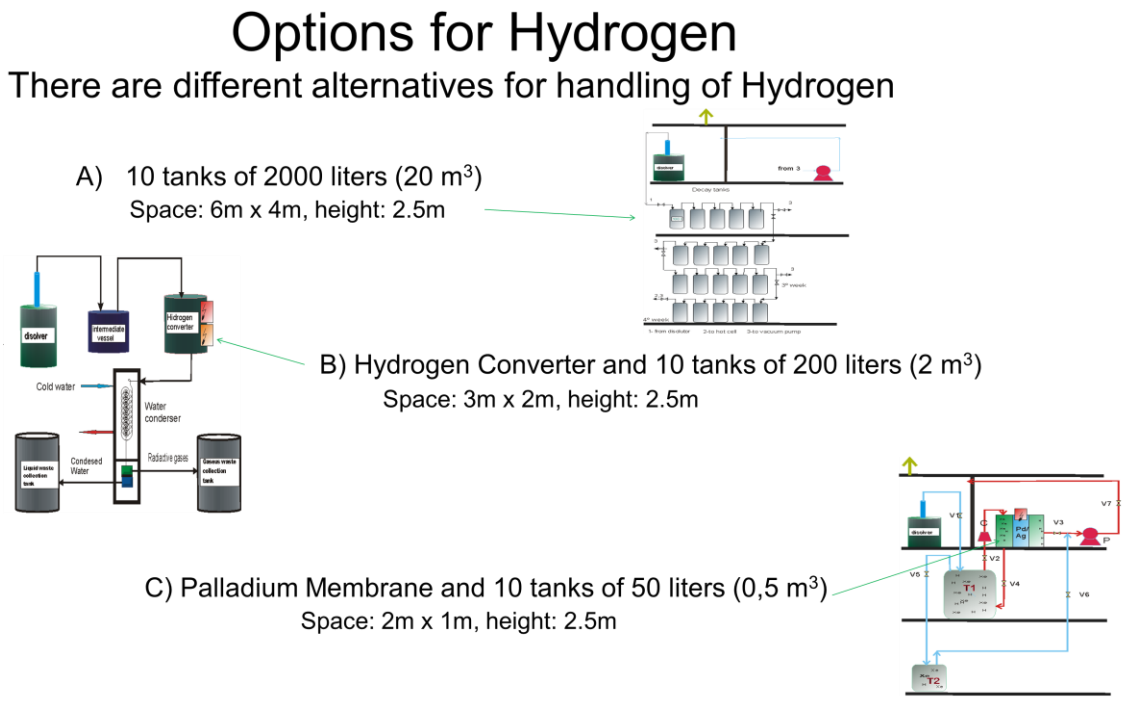


Figure 3.3. Options for Reduction of ^{133}Xe Released during Dissolution

The final identified route of radioxenon release is during the Production Process (to meet the 5 GBq ^{133}Xe levels, the activity from this process would need to be reduced ~400 times). To reduce releases from this route, leaks should be minimized during the process by exchanging PVC tubing to stainless steel and connections by valves and using vessels that are not permeable materials for noble gases. Operator skill must also be considered.

Radioxenon emissions form the "Hydrogen" stream generated from target dissolution, and the "Air" stream used to move the fluids can be reduced by decay time. The emissions released from the Production Process require cell engineering that take into account connections and materials. Finally, the skill, training, and experience of the operation team are always very important to reducing emissions, particularly during the Production Process.

3.2 ANSTO Update, Australia

An update was given by ANSTO on their current operations. They use alkaline dissolution chemistry and can produce 1,100 6-day Ci/week ^{99}Mo when operating at full capacity (they normally run below full capacity). This capacity limit is determined by the emission levels, which are 1.5-2.5 TBq/day for December to May 2015. Current strategies for emission reduction are the trap and decay strategy for noble gases released from dissolution, carbon adsorption of iodine, and minimal abatement for any releases into hot cells. In addition, switching to base digestion reduced emissions and allowed for increased production, as shown in Figure 3.4.

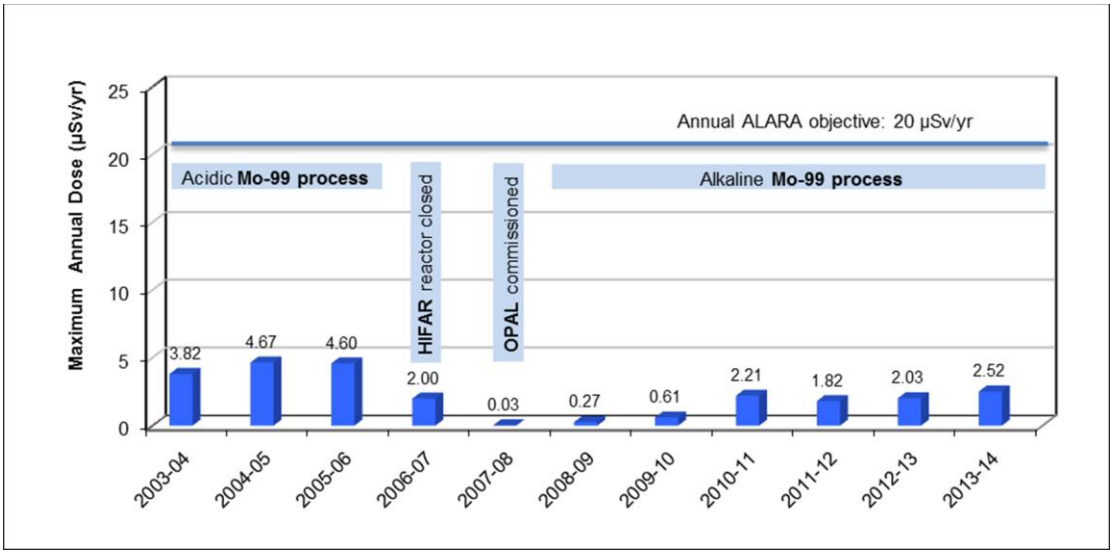


Figure 3.4. Switching from an Acidic to Alkaline Dissolution Significantly Reduced Emissions from the ANSTO Facility

The Opal Reactor is used to irradiate targets and is in operation 80% of the time. In addition to supplying Australia with ^{99}Mo, ANSTO also supplies ^{99}Mo to Japan, China, and the United States and ^{99m}Tc generators to Singapore, China, Hong Kong, Taiwan, Philippines, New Zealand, Thailand, and Burma.

Two new facilities are expected to be operation at ANSTO in 2016, a Nuclear Medicine (ANM) facility and a Synroc waste plant (see Figure 3.5). Features of the ANM plant include a base digestions process, LEU targets, fully integrated onsite OPAL reactor operations and Synroc waste management, and greater production and lower ^{133}Xe emissions. Reduced emissions will be accomplished by installing sealed, low-volume hot cells, trapping dissolution off-gasses in decay tanks for 7 weeks, and passing all releases to atmosphere via carbon columns for an additional week's decay. Construction of the new ANM plant commenced in June 2014 and cold and hot commissioning is expected in 2016.

Figure 3.5. The New ANM ^{99}Mo Facility and Synroc Waste Plant Are under Construction

3.3 IRE Update, Belgium

IRE updated the community on their ^{99}Mo production facility. IRE is a public utility foundation that contributes to public health through two missions: 1) the production of radionuclides for nuclear medicine and environmental monitoring of radionuclides and radioactive waste and 2) consultancy projects to improve nuclear security. The average weekly production at IRE is ~2,300 6-day Ci ^{99}Mo and 290 Ci ^{131}I .

During dissolution, an alkaline chemistry is used that helps keep iodine in the liquid phase and avoids hydrogen production. Since 2008, IRE has been successful in lowering its iodine and xenon releases.

In conjunction with conversion to LEU, a new facility is being designed and is planned to be operational in 2020. This new facility will be planned with the goal of significantly reducing emissions compared to the current facility. In support of this reduction, a project for xenon trapping in the new facility is in progress. This trapping would target each critical step of xenon processing to capture xenon and allow decay in storage tanks (see Figure 3.6). The LEU conversion project is underway and is on time. Higher costs are expected for ^{99}Mo produced from LEU due to the lower efficiency of the process, but there will be no compromise on the security of supply.

An ambitious project has been initiated by IRE to build and move to a new facility that uses a LEU production process and aims to significantly reduce radioxenon releases. Meanwhile, HEU production is continuing with care to control and reduce radioxenon releases.

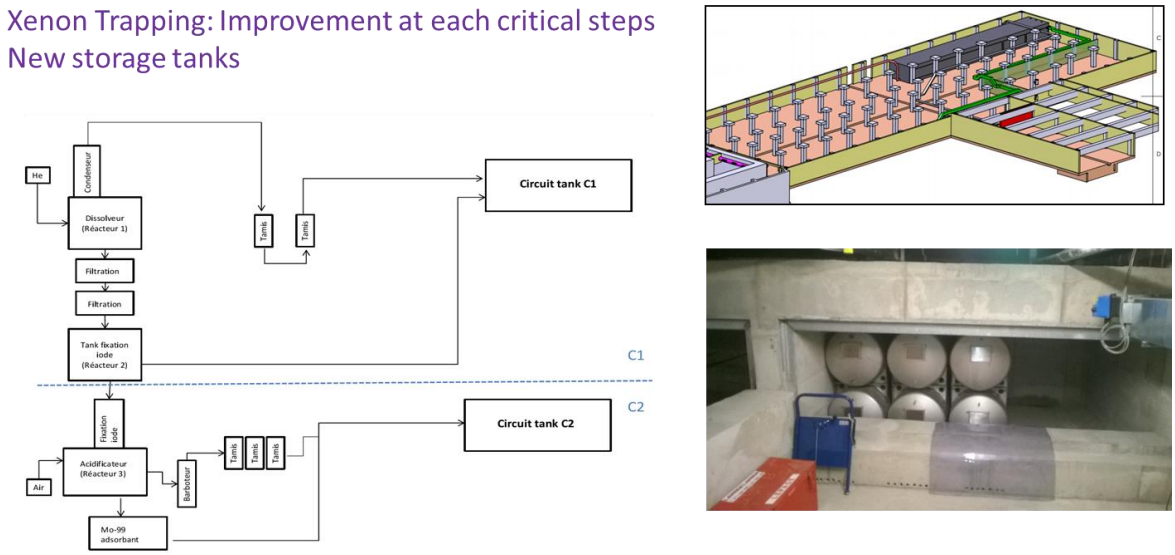


Figure 3.6. IRE Xenon Trapping Project with the Goal of Improvement of Xenon Trapping at Each Critical Step

3.4 Nordion Update, Canada

An update was given by Nordion on their current production and future plans to continue production of ^{99}Mo after decommissioning of the Chalk River Reactor on March 31, 2018. Nordion currently performs processing of ^{99}Mo that is received from Canadian Nuclear Laboratories (CNL) Chalk River facility. Additionally, there are two other Nordion sites: one in Vancouver that produces cyclotron-based isotopes and the other in Montreal that is an industrial irradiator testing/training facility. Nordion employs acidic dissolution chemistry and processes targets several days per week, eleven months of the year. The annual radioxenon releases are reported to regulators were 30,735 GBq/year for ^{133}Xe in 2013. Table 3.1 lists reported radioxenon releases for 2009-2013.

Table 3.1. The Reported Radioxenon Releases from Nordion for 2009-2013

Year	Xe-133 (GBq/yr)	Xe-135 (GBq/yr)	Xe-135m (GBq/yr)
2009	26,407	14,439	20,444
2010	9,066	6,407	9,366
2011	34,967	17,239	27,688
2012	36,153	23,943	39,498
2013	30,735	28,193	43,383

In February 2015, Nordion announced a new isotope supply agreement with U.S.-based Missouri University Research Reactor Center (MURR) and General Atomics. This agreement will replace their supply when Chalk River closes in 2018. A new technology for ^{99}Mo production, General Atomics' patented Selective Gaseous Extraction technology, will be used. The targets, which will incorporate LEU, will be irradiated at MURR and shipped to Nordion for processing.

3.5 Mallinckrodt Update, Netherlands

Mallinckrodt gave an informative presentation on their current ^{99}Mo production. They are the largest global ^{99m}Tc generator manufacturer and user of ^{99}Mo and currently produce approximately 182,000 6-day Ci per year (3,500 6-day Ci per week). This amount allows them to supply more than 75% of the U.S. market and 60% of the global market. Since 1990, they have operated two ^{99}Mo production lines in Petten on a four-day per-week schedule. The use of three reactors (HFR, BR2, and Maria reactors) allows them to maintain this production schedule with no scheduled down time. Alkaline chemistry is used for target dissolution. Additionally, ^{99}Mo may be purchased from all five of the major global ^{99}Mo producers as part of their routine supply and backup as needed.

Low xenon emissions were initially engineered into the Mallinckrodt processing facility, which uses a bank of charcoal filters for radioxenon decay (see Figure 3.7). This system has allowed them to maintain their annual ^{133}Xe releases from the ^{99}Mo production site to less than 700 GBq in 2014 (1.9 GBq/day). During the presentation, they stated that they have stack data for ^{133}Xe, ^{135}Xe, and ^{131}Xe and that they would look into sharing this data with the CTBTO.

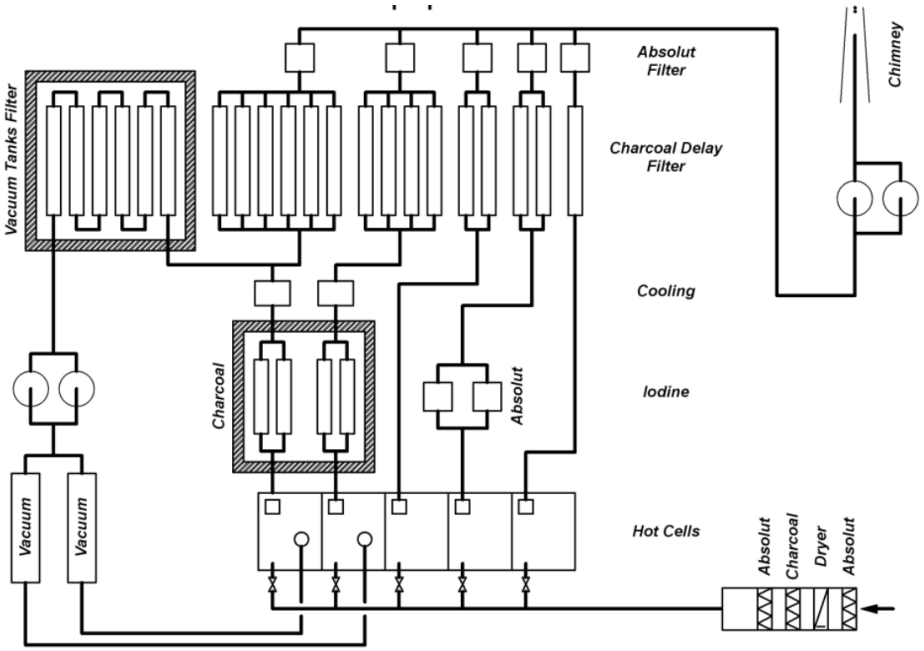


Figure 3.7. Schematic of Xe Trapping System at Mallinckrodt

3.6 INUKI Update (BATAN), Indonesia

PT Industri Nuklir Indonesia (INUKI) was established in March 2014 (previously PT Batan TEKNOLOGI) and focuses on the businesses of radioisotope production, radiopharmaceutical production, nuclear fuel fabrication, nuclear power operation and maintenance, and other nuclear engineering services. Radioisotope productions include ^{99}Mo, ^{131}I, ^{32}P, ^{65}Zn pip tag, and ^{192}Ir sealed source. Radiopharmaceutical products include Generator ^{99}Mo/^{99m}Tc, sodium ^{131}I (oral, injection and capsule), and sodium ^{131}I-Hippuran.

Currently, the production facility is closed for repair and clean-up of waste that has been stored in hot cells since 1988. In addition, there is contamination inside and outside of the building (see Figure 3.8). Clean-up of this contamination has been ongoing since 2014. Revitalization of equipment and facility is planned to be deployed this year using a new technology for radioisotope production that will not use FPM (Fission Product Material) as the target for ^{99}Mo production because it results in too much nuclear materials waste that would have to be stored—an economic calculation is underway. This new technology using a non-uranium target is being investigated and should be operational by the beginning of 2017. Meanwhile, ^{99}Mo target from FPM will still be used until the end of 2016.

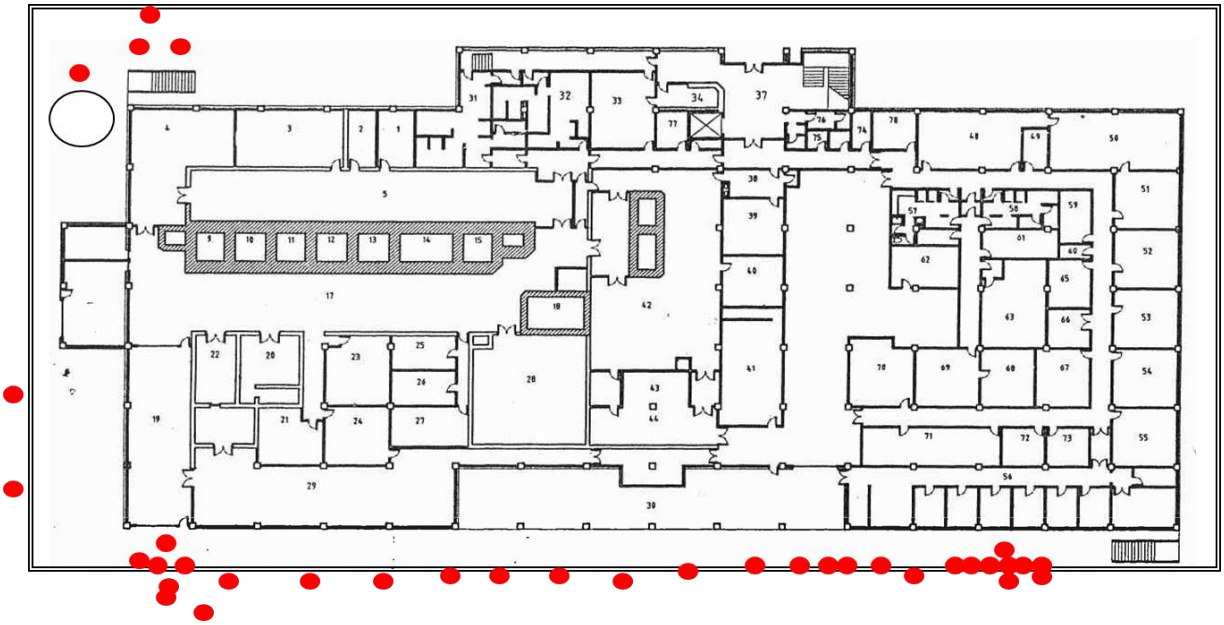


Figure 3.8. Contamination at the PT INDUSTRI NUKLIR Indonesia Is Indicated by Red Dots

3.7 NTP Update, South Africa

NTP Radioisotopes Ltd (NTP) uses the South African Fundamental Atomic Research Installation (SAFARI)-1 reactor (Oak Ridge type reactor), which went critical on 18 March 1965. This reactor operates at 20 mW, 5 days per week, 24 hours per day. NTP produces radiochemicals and Active Pharmaceutical Ingredients including ^{99}Mo, ^{131}I, and ^{177}Lu; radioactive sources including ^{192}IR, ^{137}Cs, and ^{60}Co; and radiopharmaceuticals including Novatec-P ^{99m}Tc generator, MIBG, ^{133}I capsules, FDG, and cold kits. Irradiation services provided include Neutron Transmission Doping (NTD) of silicon and target irradiations.

NTP researchers have been pioneers of change in several aspects, including the establishment of in-house expertise in reactor operation, hot cell design, construction and operation, container fleet, logistics, etc.; pioneering the introduction and use of the radiopharmaceutical FDG in South Africa; becoming the only major ^{99}Mo producer to convert to LEU/LEU based production in 2010; and the first ^{99}Mo producer to achieve true full operational cost recovery.

Some lessons from compliance HEU to LEU conversion follow. In 1987, the Reduced Enrichment for Research and Test Reactors (RERTR) program commenced at Argonne National Laboratory (ANL) with the goal "to minimize and eventually eliminate use of HEU in the civil sector." Achieving this goal took a major international effort to develop LEU fuels (containing ≥20% HEU) and convert reactors from HEU to LEU fuel. In the 2000s, ^{99}Mo production was also added in RERTR program.

Partnering with the South American Nuclear Energy Corporation, NTP performed a detailed techno-economic study into feasibility of SAFARI-1 LEU conversion in 1994/5. At that time, the decision was made not to convert to LEU at that stage. In 2000/1 the situation was reviewed again and the decision was made to convert the reactor based on techno-economic feasibility. In 2007, the ^{99}Mo production conversion project commenced, resulting in the first U.S. Food and Drug Administration (FDA)-approved full-sized commercial production run performed in late 2010. An attempt was made to transfer increased production costs resulting from LEU production to customers/patients, but market apathy was still clearly evident.

Consequences of LEU conversion at NTP are the "good," the "bad," and the "ugly." The "good" are the NTP, who are pioneers in conversion technology, achieving a world first in exceeding full compliance. The "bad" is the massive capital investment required, resulting higher reactor operational costs, lower fluxes, lower ^{99}Mo production capacity, and increased waste. The "ugly" is that there are no noticeable therapeutic benefits to LEU-produced ^{99}Mo in spite of the increased cost. Why so much bad and ugly? The RERTR had unintended consequences including the basis for HEU/LEU criteria (20%) had no sound scientific basis and the commercial generator manufacturers saw no benefit.

NTP is supportive of the principles but encourages the community to think some more about solutions. The community should apply the best rigorous scientific and systemic thinking, "putting the patient first," and commission research and studies to validate the lessons learned. The community needs to plan properly and then act swiftly.

Change is coming—let's prepare well. Establish a real scientific basis for release criteria. Explore all capital funding sources and partnerships, review the technologies employed by CTBTO radio-xenon monitoring stations, and proceed on a risk-based approach.

4.0 New and Future ^{99}Mo Production

The third session of the workshop included several presentations from new and future ^{99}Mo medical isotope producers. These talks provided an update and introduction to the status of projects to establish new ^{99}Mo production capabilities using traditional and alternate ^{99}Mo production technologies. The potential xenon releases from these various production methods and some plans for xenon mitigation were also discussed.

4.1 Radioisotope Production in Research Reactors, Jordan

The Jordan Atomic Energy Commission (JAEC) is developing radioisotope production capability using research reactors for commercial use. These radioisotopes will be used in medicine and industry and for food and safety. JAEC is currently building its first nuclear reactor, the Jordan Research and Training Reactor (JRTR), just 65 km north on Amman. This reactor project includes the reactor, a radioisotope production facility, an education and training building, a radioactive waste facility, and a cold neutron facility. JRTR will include thirteen high-flux holes in Be region, cold neutron source, four horizontal beams, three neutron activation analysis, three neutron transmutation doping, a thermal column, and many vertical irradiation holes. The reactor is 5 MW and upgradeable to 10 MW open pool reactor with a maximum flux of 1.45 x 10^{14}. JAEC plans to produce ^{99}Mo via (n,γ) of MoO_3 (^{99}Mo neutron irradiation); fission-based production was rejected because IAEA Safeguards expected determinations in the future about the availability of ^{235}U targets. When completed, JRTR will produce 1,000 Ci ^{99}Mo per year (20 Ci batch/week) and 2,000 Ci ^{131}I/year

The radioisotope production facility will contain three banks and ten hot cells for production of ^{131}I capsule and solutions, ^{192}Ir source assembly, and ^{99}Mo (for Tc generator).

4.2 Progress in Fission ^{99}Mo Project in Korea

KAERI gave an update on the progress on its Kijang Research Reactor project, KJRR, which included the general arrangement of the Fission ^{99}Mo Facility and the xenon retention mechanism. KAERI plans to meet the CTBTO voluntary release limit by using carbon delay beds and xenon decay tanks (see Figure 4.1). This system will hold the xenon fifty days in decay tanks before being released onto the carbon delay beds, which are designed to delay the xenon for an additional forty days to achieve a 4.86 GBq/day release of ^{133}Xe from the facility. This system will require a large area for the delay beds, which will contain 5751 kg of carbon and seventy-two 200-liter decay tanks.

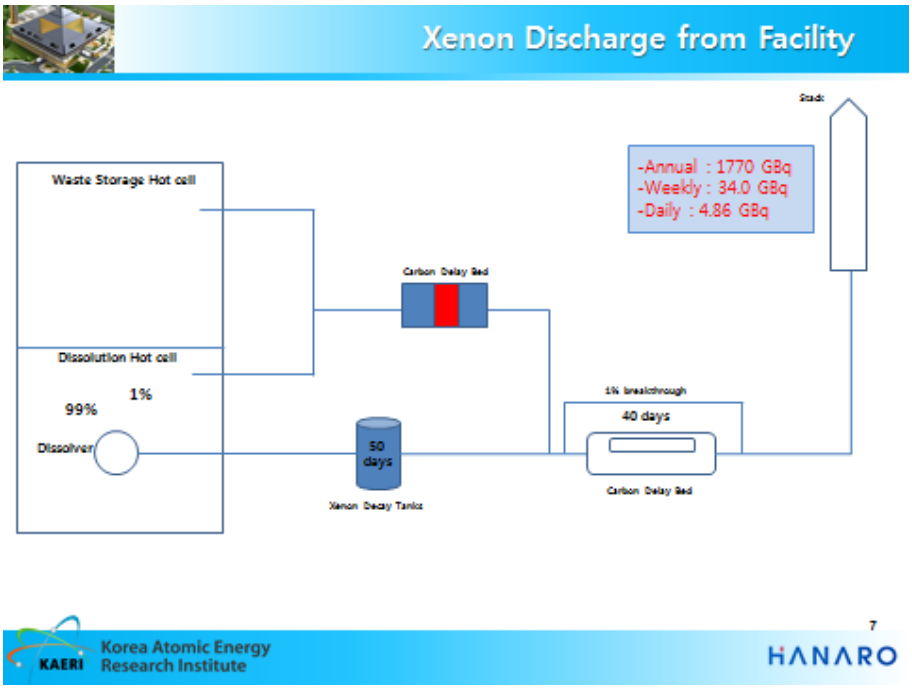


Figure 4.1. Xenon Abatement Strategy Planned at KAERI ^{99}Mo Processing Facility

Development and testing of LEU targets for the KAERI facility has begun. The fission material targets will use U-Mo or UAlx alloy powder, which allows for a simplified plate target fabrication with higher uranium density. Each target has a LEU weight of 2.95g and a total weight of 53.23g. The target assembly comprises eight targets. Irradiation testing of the targets will be completed by 2016. Processing of these targets will be performed using alkaline dissolution, with iodine removal being the first step after dissolution.

In addition to the conventional xenon abatement plan outlined above, plans to test other technologies are underway. These technologies would be used to reduce radioxenon emissions even further below the levels achieved by the conventional abatement methods.

Current studies being conducted include pilot scale test bench prototypes. A method for removing dissolved iodine from solution is being tested; this method which would incorporate a silver doped alumina step prior to ^{99}Mo separation. The use of this material was demonstrated to recover over 99.5% of iodine from solution with a 70% of the removed iodine recovered. Removal of gaseous iodine by adsorption was also investigated using a Cu/SiO_2 composite material. Iodine was sorbed and desorbed from this material with over 90% iodine removal and 95% of the removed iodine recovered. A 1/8 scale hot test module has been constructed that will allow testing of a 1 Ci ^{99}Mo target (see Figure 4.2). Finally, a compact xenon adsorption module is being tested that incorporates a low-temperature adsorption column for optimal xenon delay. KAERI is currently optimizing the design and operation conditions for this system.

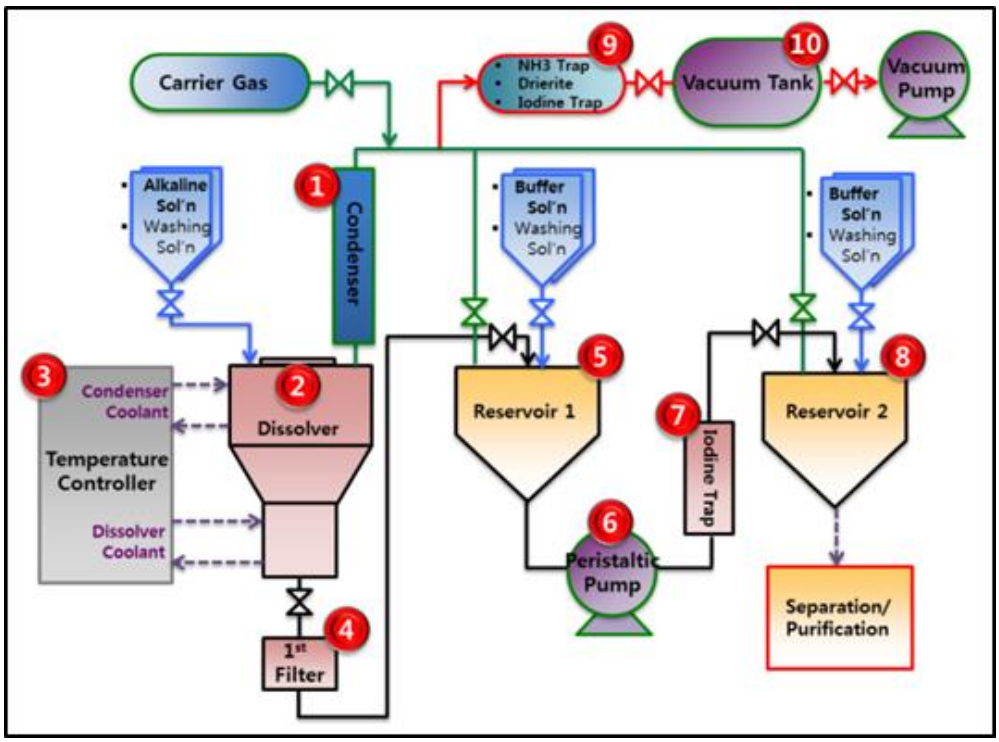


Figure 4.2. Diagram of 1/8 Scale Hot Test Module for 1 Ci ^{99}Mo Production

4.3 Medical Isotope Production Facility in Myanmar

Myanmar gave an overview of its Nuclear Medicine Center, which receives ^{99m}Tc generators from ANSTO. The first cyclotron for medical isotope production will be installed under the Ministry of Health in 2015. The cyclotron (18 MeV) is from IBA Radiopharma Solutions and will be placed in Yangon General Hospital for PET tracer medical isotope production. The Department of Atomic Energy under the Ministry of Science and Technology builds a national team for cyclotron application and has a plan to establish a cyclotron for research and other applications including isotope production. This facility will also be used as a particle accelerator training facility for the next generation of scientists and technicians.

4.4 Argonne National Laboratory Activities Directed Toward Developing SHINE Technology for Producing Molybdenum-99, United States

ANL has been involved in developing a system for producing ^{99}Mo by fissioning of LEU in an aqueous uranyl-sulfate solution, as part of the U.S. National Nuclear Security Administration (NNSA) M^3 program to assist SHINE Medical Technologies in the development of domestic U.S. ^{99}Mo production. Fission within this solution is initiated and sustained by irradiation with a fast neutron stream from a D/T generator, a deuterium-ion beam impinged on a tritium-gas target. After a five-day irradiation, the accelerator will be shut down, and after a cooling period, ^{99}Mo will be recovered from the uranyl-sulfate solution. ANL has been involved in the development and optimization of Mo recovery and purification processes; study of the thermal hydraulic effects of radiolytic gas formation during irradiation; performance of mini-SHINE experiments using an electron accelerator for neutron production; and target solution clean-up process and radiological waste assessment/treatment.

An experiment to study the effect of bubble formation in the uranyl sulfate solution is being conducted in which an electron beam from a linear accelerator is focused through the entire uranyl sulfate solution. Some of the main observations from the experiment are that no foam-layer buildup was observed; no coalescing of small bubbles into large bubbles was observed; the convection currents in the solution did not impede bubble transport to the surface; bubbles popping at the surface produced significant splatter on the walls of the chamber; and an average bubble diameter of 267±13μm and velocity of 4.7±1.6 cm/s were determined for SHINE-relevant power densities.

To investigate the effects of fission on target-solution chemistry and radiolytic off-gas generation, Mini-SHINE experiments are being conducted to demonstrate the recovery and purification of ^{99}Mo from an irradiated target solution and to sample solution off-gas for Xe, Kr and I. In this experiment, recovery of ^{99}Mo from the target solution is achieved using a titania column. Next, the alkaline molybdenum eluent is acidified using nitric acid and run through a much smaller titania column to concentrate. Finally, the concentrated solution is purified using the LEU modified Cintichem process, and the resulting purified product is pumped into a transport cask. Off-gas created during irradiation is monitored in real time by a residual gas analyzer, and off-gas samples are collected and analyzed for volatile fission products. To maintain hydrogen levels below 1 percent, oxygen is added to the system so it can recombine with hydrogen in a catalytic converter to form H_2O. Thus far, it appears that the major fraction of radioiodine stays in solution during operation. During irradiation and processing, all off-gases from the system will be collected and stored in cylinders for decay. Pumps for the off-gas recovery system are contained inside vessels to prevent leaking into the atmosphere (see Figure 4.3).

Figure 4.3. Argonne National Laboratory Off-gas Recovery System for Mini-SHINE Experiment. Pumps for the system are enclosed in vessels to prevent leaking.

4.5 Northwest Medical Isotopes Overview, United States

Northwest Medical Isotopes (NWMI) is planning construction of a ^{99}Mo processing facility in Columbia, Missouri. They have submitted Part 1 of their construction permit application and plan to submit Part 2 in

the second quarter of 2015. This facility will include a target fabrication area, target disassembly area, and hot cell processing area (for dissolution, ^{99}Mo recovery, and ^{235}U recovery). Targets will be shipped to university reactors for irradiation including MURR, Oregon State University (OSU), and one undisclosed partner. Following irradiation, the targets will be returned to the Columbia, Missouri facility where they will be dissolved and processed to recover ^{99}Mo. Proof-of-concept tests are continuing to be performed and prototypic target production has been initiated with an OSU license amendment awaiting NRC approval.

Planned off-gas treatment for the NWMI facility will include two stages of activated carbon units for Xe/Kr decay with stage 1 retaining xenon for ~10 days and stage 2 for ~60 days. Iodine removal will be accomplished by multiple units using silver-zeolite sorbent and impregnated carbon material. Other treatment unit operations include condensers and gas dryers for water vapor control, wet scrubbers for NO_x control, and a vacuum vessel for off-normal event mitigation. This preliminary design meets the WOSMIP daily release goals for ^{133}Xe.

4.6 Production of ^{99}Mo without Use of Uranium, United States

NorthStar is pursuing two approaches for ^{99}Mo production: the first approach is expected to begin late 2015 and will involve a neutron capture production method in collaboration with MURR; the second approach is expected to start in 2017 and will use a photo-nuclear reaction, ^{100}Mo (γ,n) ^{99}Mo, induced with NorthStar's linear accelerator methodology. Once up and running, both solutions will be used to produce 6,000 6-day Ci per week (3,000 6-day Ci from each method) to not only supply the U.S. market but also the rest of the world. Both approaches will use NorthStar's RadioGenix™ generating system to supply ^{99m}Tc.

The potential for xenon production from Northstar's processes has been investigated. There was no expected xenon production identified in the MURR neutron capture production method (MURR does perform sack monitoring for xenon, krypton, and iodine as part of overall operations). Impurities in the enriched Mo target material are in the sub-ppm levels (with U and Th are below 20 ppb), which would limit any potential for xenon production. Figure 4.4 shows the dissolution apparatus used at MURR. The potential for xenon production from the linear accelerator production process was also investigated as part of side reaction studies, and the xenon production is predicted to be ~2 x 10^5 Bq/day—which is well below the 5 x 10^9 Bq/day CTBTO voluntary release goal.

Currently, the neutron capture ^{99}Mo production method is pending FDA approval of the RadioGenix™ generator system. The final amendment for FDA approval is expected to be submitted early third quarter 2015 and production is expected to commence late 2015. The first building at the new facility location in Beloit, Wisconsin (Building 1) which will support ^{99}Mo production at MURR is complete and occupancy is expected by May 2015. Construction of Building 2 is planned for completion in the middle of fourth quarter 2015 and will support neutron capture production using enriched ^{98}Mo targets. Accelerator production with enriched ^{100}Mo targets will use building 3 on Beloit site and begin late 2016/early 2017.

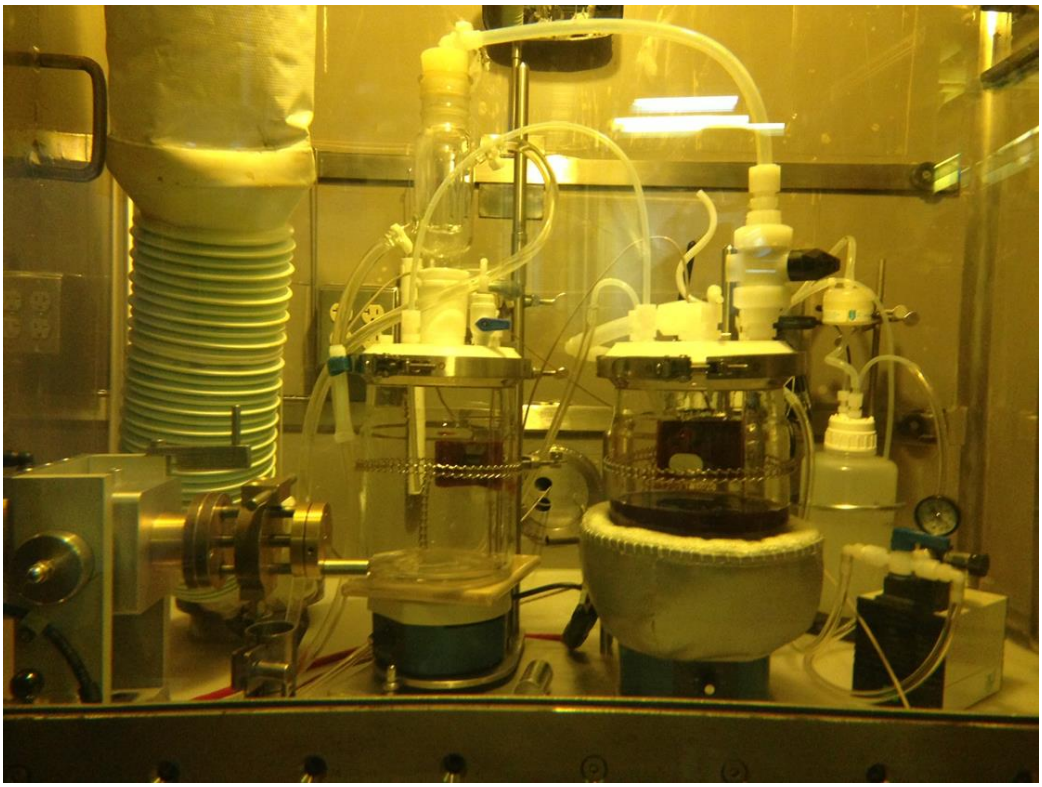
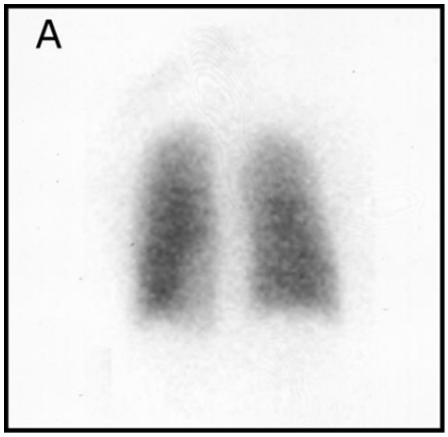


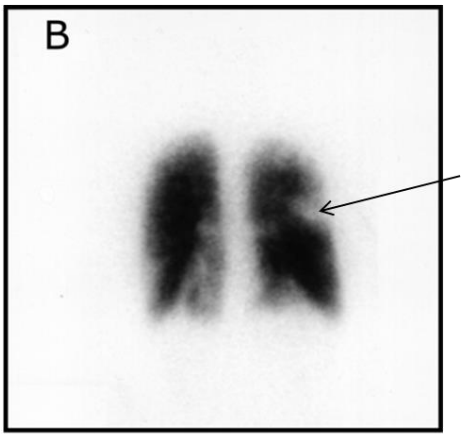
Figure 4.4. MURR/NorthStar Dissolution Apparatus

4.7 Medical Uses of Xe-133, United States

Lantheus Medical Imaging is a global company in diagnostic medical imaging agents with many products including TechneLite ^{99m}Tc generators and Xenon ^{133}Xe Gas. Two imaging methods are used to assess pulmonary embolism (PE): computed tomography pulmonary angiography and ventilation/perfusion nuclear study. Mismatch comparisons between ventilation and perfusion images provide the diagnosis of PE, (see Figure 4.5). Lung ventilation studies are performed with the patient inhaling 0.54-1.1mCi of DTPA-^{99m}TC Aerosol or 5-30mCi ^{133}Xe gas and lung images collected with a single-photon emission computed tomography (SPECT). Lung perfusion studies are performed by injecting the patient intravenously with 1-4mCi MAA-^{99m}Tc before SPECT imaging.



A) After inhalation of 20.1 mCi of Xenon-133 gas, scintigraphic images were obtained in the posterior projection, showing uniform ventilation to lungs



B) After intravenous injection of 4.1 mCi of Technetium99m- labeled macroaggregated albumin, scintigraphic images were obtained, shown here in the posterior projection.

Figure 4.5. Lung Ventilation and Perfusion Study. The mismatch between the ^{133}Xe image (left) and MAA ^{99m}Tc image (right) provide the diagnosis for PE.

There are pros and cons for each lung ventilation method. Disadvantages of ^{133}Xe imaging are that it requires an imaging room with a special exhaust system for radioactive gas, only provides planer views, and with a single breath, there is the chance of missing the image. On the positive side, the single breath allows for equilibrium and washout images to be obtained; there is a more complete characterization of ventilation; and it is more sensitive to obstructive airway disease. DTPA ^{99m}Tc disadvantages include that its use is off label for aerosol ventilation; the aerosol deposition is altered by turbulent flow; and aerosol deposition may be significant in patients with obstructive airway disease. Positives for DTPA ^{99m}Tc are that images can be obtained in multiple views or SPECT to match the perfusion image, and there are no special room requirements.

A trapping system is in place to slow the release of radioxenon from processing and other potential sources. Monitoring of ^{133}Xe releases from the Lantheus facility by an in-stack Geiger-Mueller detector indicate a decrease from ~6 to less than 1Ci/year (0.6 to 0.1 x 10^9 Bq/day average releases).

In January 2015, Lantheus announced an agreement with IRE for future supply of ^{133}Xe gas. Commercial production is expected to occur in 2016. The ^{133}Xe releases from Lantheus are very low and were ~0.5Ci released in 2014.

4.8 Running the Lagrangian Dispersion Model FLEXPART in an Operational Context at RMI

The Royal Meteorological Institute (RMI) of Belgium presented an overview of their dispersion and trajectory modeling that incorporates Lagrangian particle models. This model was originally designed for calculating the long-range and mesoscale dispersion of air pollutants from point sources. Through the years, these type of models have proven to be a very useful tool in an operational context for the protection of the population in case of NPP accidents. In the meantime, FLEXPART has evolved into a more comprehensive tool for atmospheric transport modeling and analysis.

Lagrangian particle models compute trajectories of a large number of so-called particles (not necessarily representing real particles, but infinitesimally small air parcels) to describe the transport and diffusion of tracers in the atmosphere. The main advantage of the Lagrangian models compared with Eulerian models is that there is not numerical diffusion. It can simulate the long-range and mesoscale transport, diffusion, dry and wet deposition, radioactive decay of tracers released from point, line, area, or volume sources, and the Eulerian models introduce an immediate dilution. It can be used in forward mode to simulate the dispersion of tracers from their sources or in backward mode to determine potential source contributions for given receptors. It requires only a short computation time, has a finer spatial resolution, and does not suffer numerical diffusion compared to chemistry transport models. The key tasks of RMI include providing trajectory and dispersion model output for specific hotspots; giving feedback on the output of weather forecasts and its impact for dispersion modelling; and providing dispersion output on demand.

The interface for forecasters includes an input window of three days of forecast data, the Northern Hemisphere, and hotspots and specific places that can be introduced. Output for the forecaster includes surface concentrations and the total column. Besides nuclear, other possible interests to provide a dispersion output (e.g., volcanic eruption, chemical incidents, bush fires). Several examples of the operation output were given including a simulation of ^{133}Xe from IRE's Fleurus facility (see Figure 4.6).

The dispersion model V1.0 has been operational since December 2014. The next version will include dry and wet deposition fields. Collaboration with the crisis center and on a project with SCK•CEN for uncertainty quantification of long-range atmospheric transport models is planned.

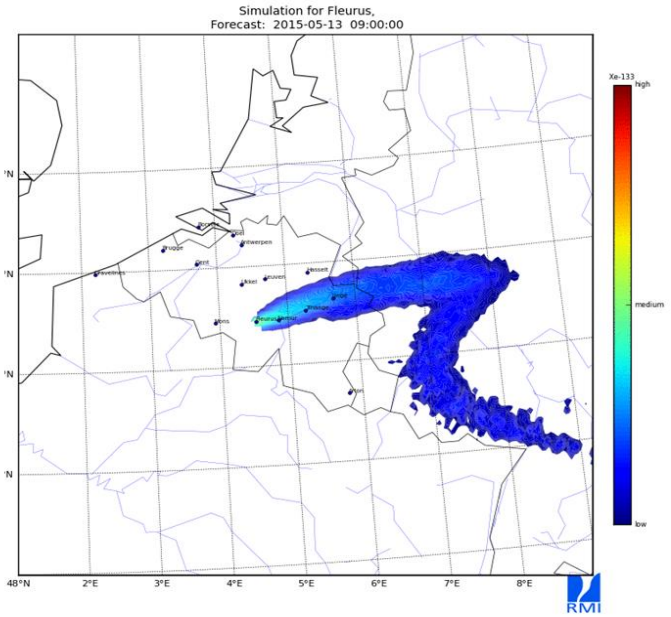


Figure 4.6. Simulation for Fleurus

5.0 Stack Monitoring Methods and Technologies

The focus of the fourth session of the workshop was stack monitoring methods and technologies. This session explored monitor requirements and issues related to sharing of stack release data with the IDC including the logistics of transferring data securely and confidentiality.

5.1 Stack Monitoring System for Gaseous Emissions in Radioisotopes Production Facilities

A new stack effluent monitor design for MIP Facilities was presented by INVAP. This new design foresees online measurement of specific isotopes (^{133}Xe, ^{133m}Xe, ^{135}Xe, ^{135m}Xe, ^{131}Xe, ^{85}Kr). An overview on this new design was presented.

The gaseous Air Effluent Monitor (AEMI) will be designed with the goals of monitoring the radioactive stack emission of aerosols, iodine, and noble gases and generation of real-time data regarding some specific isotopes (^{133}Xe, ^{135}Xe, ^{85}Kr) and determine the quantity released in the stack emission . This monitor can be used for research reactors and radioisotope production facilities. Radioisotope production facilities have higher noble gas activity concentrations than research reactors requiring the noble gases chamber volume to be reduced in comparison. Another requirement is the need to measure iodine while avoiding noble gas background. Therefore, the measuring channels used for gross beta are adapted to be used for both iodine and xenon measurement.

In the new monitor design for MIP, a CdTe detector is added to the NaI detector for better resolution in the low energy range. Aerosols and iodine samples will be accumulated continuously in filters and cartridges disposed in a two-branch sampling system (see Figure 5.1). These filters and cartridges will be measured delayed in a high-resolution spectrometer.

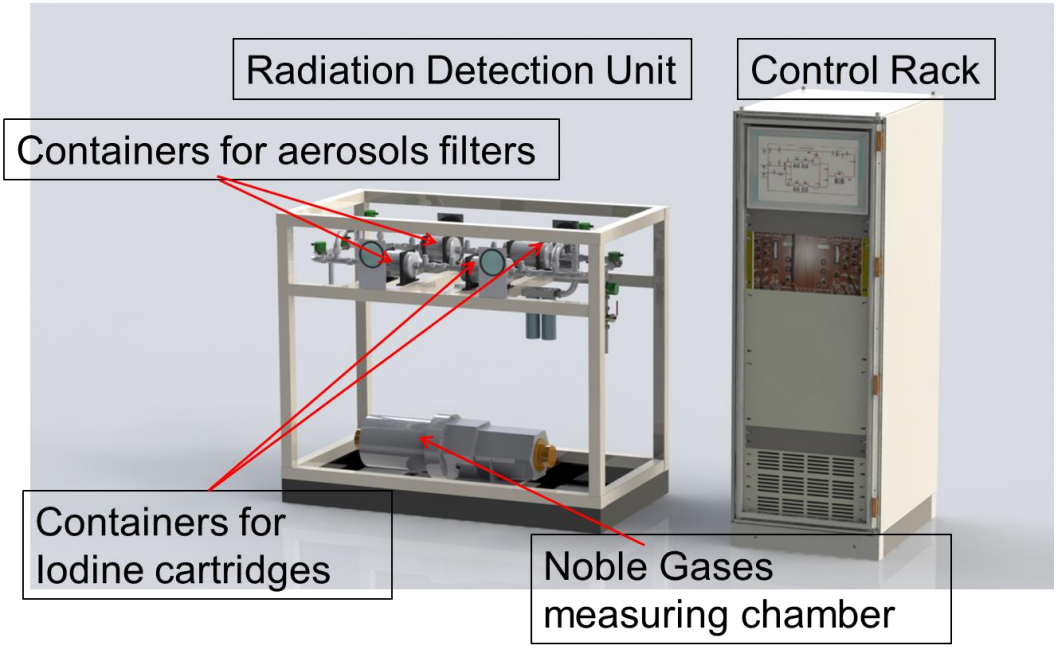


Figure 5.1. New Stack Monitor Design the Gaseous Effluent Monitor for Radioisotope Production Facilities

Monte Carlo simulations for the NaI detector with the new stack inventory have been completed for the determination of lead shielding requirements, and the CdTe efficiency calibration simulations are in progress; these simulations were put on hold due to background interference from the Calbuco volcano eruptions in April.

The previous design used single-channel analyzers to determine the lower and upper channels of each peak. The number of counts between these two channels was assigned to the activity of the peak. No background subtraction was performed for these analyses. The new software interface for the new AEMi design will allow for all the spectra to be stored; the evolution of each peak to be followed in time; the number of counts in peaks to be calculated with spectroscopy software *with* background subtraction; and historical spectra will be stored for future analysis if needed.

In conclusion, the online measurement of specific isotopes (^{133}Xe, ^{135}Xe, ^{85}Kr) in gaseous effluent is possible with the new AEMi. The addition of a CdTe detector along with the NaI detector allows for better resolution in the low energy range. Continuous accumulation of aerosol and iodine data is possible with the two-branch system. Filters and cartridges are measured (delayed) in a high-resolution spectrometer. Monte Carlo simulations for the NaI detector with new stack inventory provide lead shielding dimensions. With the new software, all the spectra will be stored; evolution of each peak will be followed in time; number of counts in peaks will be calculated with spectroscopy software with background subtraction; and historical spectra will be stored for future analysis if needed.

5.2 Local Monitoring of Noble Gas Released from Nuclear Facilities

Northwest Institute of Nuclear Technology in China gave a presentation on development of a local monitoring system to study xenon backgrounds near a nuclear facility. The development of this monitoring system will provide the ability to set more systems in real time in a limited area. Data from this system would be used to provide the foundation to validate the model of atmospheric transportation.

The consumption of ^{99m}Tc in China is increasing much faster than the worldwide demand (see Figure 5.2). With increased demand for ^{99}Mo comes an increase in global background of radioxenon from nuclear facilities that release noble gases during ^{99}Mo processing.

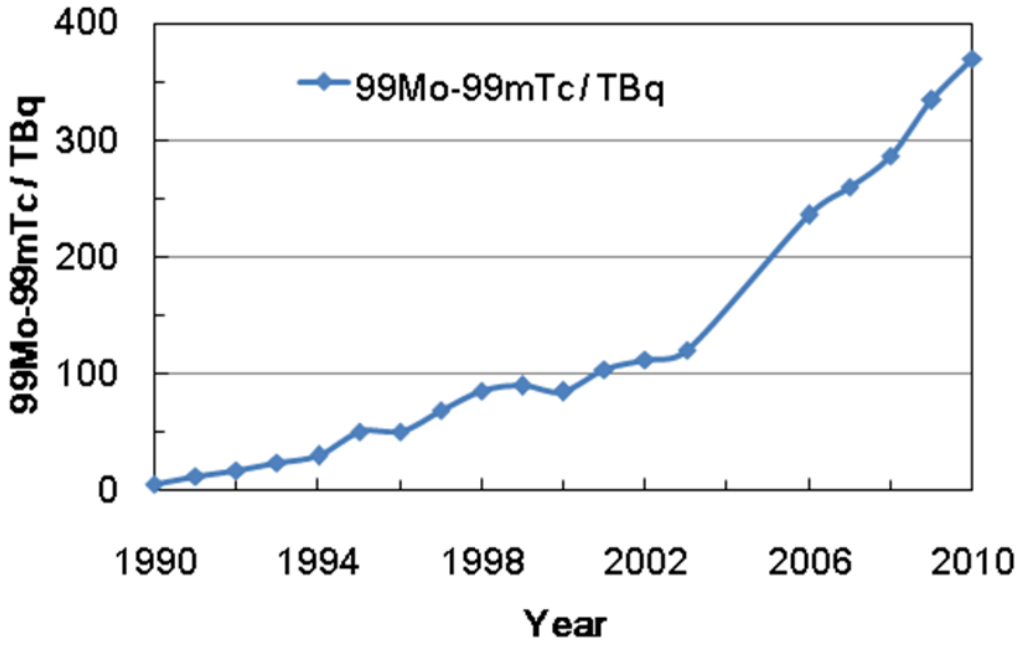


Figure 5.2. Consumption of ^{99m}Tc in China

Local monitoring of radioxenon concentrations in real time and at the different sites near a nuclear facility can provide data to validate the model of atmospheric transportation. The difficulty with this monitoring is that the xenon monitoring systems employed by the IMS and OSI are very complex. Therefore, it is not feasible for setting too many monitoring systems in real time in a limited area near a nuclear facility. Thus, it is necessary to set up a model (ATM) to deduce the process of transportation of xenon emitted from a nuclear facility in the near zone and evaluate the specification for the monitoring ability of the xenon monitoring system.

Portable monitoring systems could be used to deduce the process of transportation of xenon emitted from a nuclear facility in the near zone using ATM to evaluate the specification for the monitoring ability of the xenon monitoring system. Therefore, development of a simple portable monitoring system is of interest. This local monitoring system should be a simpler device with a higher MDC and shorter monitoring period (than those used for the IMS). The development of a local monitoring system will provide the ability to deploy more monitoring systems in real time in a limited area near a nuclear facility.

5.3 Requirements for Stack Monitoring

A presentation introducing stack release data collection requirements at MIP facilities in order to share data with the monitoring community was given by PNNL. In an ideal world, emissions from MIP would be below the voluntary release limit and stack release data would not be necessary for monitoring. However, the estimated cost to retrofit a MIP facility to meet the 5 x 10^9 Bq/day voluntary ^{133}Xe release limit is ~$7-14 million U.S. dollars (not including the cost of down time) and may not be feasible for all facilities. The lower estimated cost to install stack monitoring equipment, ~$150-200K US dollars, makes this another possible tool for understanding the global radioxenon background.

MIP facilities already collect stack release data for health and safety purposes, but there are different needs for the monitoring community. Monitoring community detector requirements for a system to collect stack release data would include the ability to detect and quantify ^{131m}Xe, ^{133m}Xe, ^{133}Xe and ^{135}Xe;

to adjust to a large dynamic range between 1 x 10^9 to 1 x 10^{13} Bq/day; to collect data in three-hour increments; and to deliver spectral data.

A number of questions have been raised at previous WOSMIPs. Some of these ongoing conversations with producers and monitoring communities include what are real stack monitoring requirements (needs vs. wants); how is data used in an analysis; and how is the data secured and stored and who has access. Dialogue on this topic within the WOSMIP community was encouraged as we continue to move forward through dialogue and understanding. Xenon monitoring can only be improved by working together.

5.4 IDC Views on the Use and Security of Stack Data

The IDC spoke on their views for the use and security of stack release data. They began by stressing that there are currently six MIP companies that have signed the CTBTO radioxenon emissions pledge (ANSTO, IRE, INUKI, KAERI, Coqui, and NorthStar). This pledge states that the signee voluntarily agrees to:

> Explore means to share xenon monitoring (i.e., "stack" or facility monitoring) data with the CTBTO/PTS for use in screening out xenon detections from the IMS that result from isotope production, the modalities of this communication will address the timing, the processing of the data and confidentiality issues; and, Further support the CTBTO/PTS, upon request, with information regarding radioxenon emissions in order to improve the interpretation or clarification of IMS radioxenon data.

The scientific potential of combining MIP radioxenon release data with atmospheric observations was discussed. The audience was asked to consider the potential offered by combining release data with observations at IMS stations. These data would go significantly beyond the inert tracer data (point source releases and related observations) that are already available to the global community of ATM experts. Groundbreaking new science can be achieved that will help understand the impact of MIP facility releases on the IMS and to address various CTBT related questions—it will have a significant scientific impact beyond this objective. Applications of this data include understanding the impact of MIP facility releases on IMS with respect to network performance, atmospheric background characterization, and station response optimized parameters and contribution to concentrations in air samples; and advancement of the scientific methods based on ATM by validating models, testing different algorithms, studying the impact of model parameters (such as resolution on the output), and possible source region attribution from network calculation including non-detections.

The type of data required for stack release data to be useful was also discussed. Possible data discussed include the location of the MIP facility, operational status (off/on), absolute release data (time resolution—annual, monthly, daily, hourly—and isotopes—whether only ^{133}Xe or all four isotopes would be needed, and raw data collected from a stack detector (including time spectral resolution).

An experimental stack release detection system was installed at PT INUIK (formerly Batek) in 2012. The data collected in this study include the MIP location, operational status (on/off), and raw data from a LaBr3 spectral detector. These data can be analyzed for all xenon isotopes.

Several aspects of data security were discussed. It was stated that methods for data surety by authentication will need to be determined. Additionally, rules need to be established for confidentiality and transparency of data. Security should be ensured through access restrictions based on classes of users and access methods. Finally, levels of disclosure for raw data, release values (isotopic activities or

concentrations), the resulting concentration predations at IMS stations broken down by source, and resulting overall predicted background at IMS stations need to be determined.

A roadmap of steps to be taken in order to use noble gas release data was outlined. The first step of analyzing the situation has been completed by published information based on scientific studies to understand the impact of MIP releases on IMS stations. Step two is an exploratory phase in which methodologies will be developed and tested. The third step is the method and development phase, which will use systematic historic data for scientific research into sound algorithms for network performance, contribution to sample concentrations, impact assessment, and source attribution. The final step is the demonstration/operationalization phases in which continuous near-real-time data would be collected to demonstrate operational readiness.

A possible operational implementation would incorporate a flagging system similar to the scheme shown in Figure 5.3. The use of such a system would not be implemented until research to determine a meaningful and scientifically sound approach is completed.

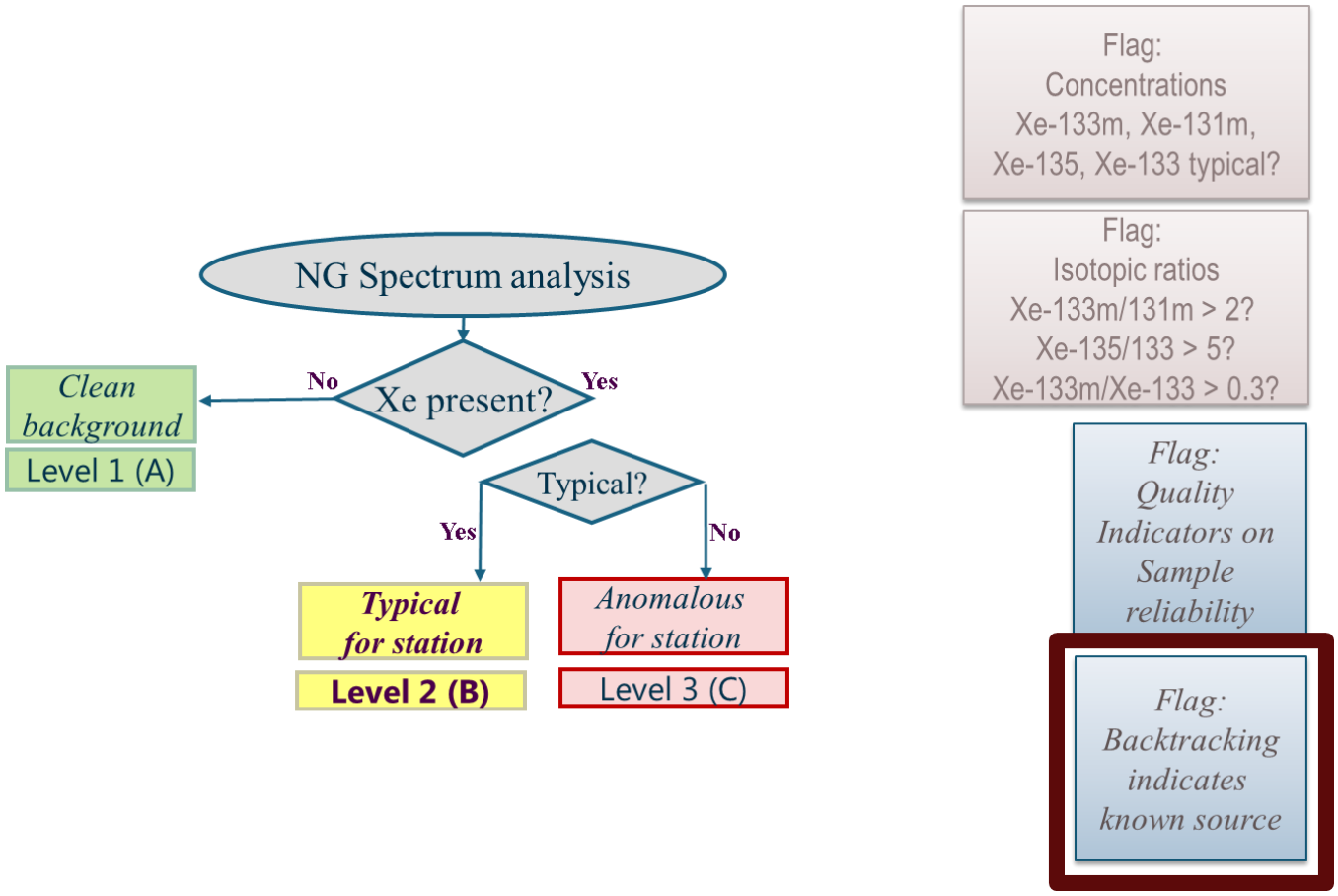


Figure 5.3. Scheme for the current three-level activity-concentration-based categorization system and event screening flags. One of the agreed event screening flags is currently not implemented: The flag for a known source being indicated by ATM backtracking (highlighted in the lower right corner). This flag will not be implemented until research to determine a meaningful and scientifically sound approach is completed.

5.5 Confidentiality of Stack Monitoring Data

An overview of the transfer of stack data confidentiality was provided by PNNL. At WOMIP IV (2013), participants began to discuss the logistics of delivery and use of stack data. Several aspects of stack release data sharing were discussed, including security of data transfer, security of data storage, and sharing of or access to data once provided to CTBTO. Concerns expressed at WOSMIP IV focused on stack release data being accessed by unauthorized/unintended parties (e.g., producers, regulators, public).

The secure transfer and storage of data are important aspects of a stack data-sharing system. Collected data should be transmitted securely, in a timely manner, and in a format useful to the IDC. Secure transfer of data is not a new problem for the CTBTO; the IDC currently uses a Global Communications Infrastructure to securely transmit data from 337 worldwide IMS stations and labs to the IDC. Global Communications Infrastructure exists for the IMS and could be used for stack release data transfer. The IDC also uses Virtual Private Network for transfer of IMS data. In addition to secure transfer, data must be stored securely and for the period of time necessary to ensure that analysis of delayed detections can be supported. Like data transfer, data storage is not a new issue for the CTBTO. The IDC houses one of the largest nuclear explosion monitoring databases in the world; this database can hold large amounts of data for extended periods.

Confidentiality concerns were also expressed at WOSMIP IV and focused on the potential of stack data being accessed by unauthorized parties. There were concerns that proprietary information related to a producer's regular production cycle could be inferred from shared stack data. In the hands of a regulator, stack monitoring data could be used as justification for stricter regulation. Finally, if released to the public, stack monitoring data could be misconstrued to suggest a threat to health and safety.

Confidentiality is a difficult issue to address. There are likely policy barriers to withholding stack release data from State Signatories to the CTBT. Additionally, the State Signatories would require access to all data for reconstruction of IDC event analysis; however, that data must only be used for Treaty-relevant purposes. There are parallels to this issue in waveform data, including signals from mining explosions and wind farms.

In a best-case scenario, producers would agree to share stack release data with the CTBTO with the understanding that CTBT national authorities would have access and national authorities would agree to use stack data only for Treaty purposes. Where possible, the existing CTBT infrastructure would be used for data transfer and storage. Lingering questions include how much proprietary information can be gleaned from stack release data; what length of delay would eliminate proprietary information concerns; how can the CTBT community ease concerns of regulators' increased access to stack release data; and could the CTBT community incentivize producers to provide stack release data?

6.0 Other Aspects of Medical Isotope Production

The fifth session of the workshop included several presentations covering other aspects of MIP.

6.1 NNSA's Efforts to Establish Reliable Supplies of Molybdnum-99 Produced without Highly Enriched Uranium

The NNSA presented an overview of their objective of accelerating the establishment of reliable supplies of ^{99}Mo produced without HEU. This mission provides a dual approach by providing assistance to existing MIP facilities to convert to from HEU to LEU targets in addition to supporting the establishment of a reliable U.S. domestic supply of ^{99}Mo produced without the use of HEU.

NNSA's strategy seeks to address the vulnerability in the current ^{99}Mo supply chain, including using HEU, implementing full-cost recovery at all facilities, developing reserve production capacity, developing new infrastructure to replace aging facilities, and introducing new "technology-neutral" methods to diversify the ^{99}Mo production technologies.

Since 2009, the NNSA has partnered with U.S. commercial entities to accelerate domestic ^{99}Mo production. In these agreements, a 50%-50% cost-share cooperative agreement with a $25M limit in NNSA contributions per project is awarded to develop new technologies. Currently, NNSA has awarded $16.1 million and $4 million to NorthStar Medical Radioisotopes to develop neutron capture technology and accelerator technology respectively and $14 million to the Morgridge Institute and SHINE Medical Technologies to develop its accelerator with LEU fission technology. In support of this technical development, the U.S. national laboratories' expertise is available for technical development of non-proprietary, non-critical path activities.

Other government efforts supporting establishing a supply of LEU produced ^{99}Mo include The Medical Isotopes Production Act, which was enacted on January 2, 2013 to help establish a reliable domestic (U.S.) supply of ^{99}Mo without HEU, and the White House Fact Sheet (June 7, 2012) encouraging the use of ^{99}Mo produced without HEU. Additionally, thirteen countries including the United States have joined the Organization for Economic and Co-operative Development-Nuclear Energy Agency Joint Declaration on the Security of Supply of Medical Radioisotopes, which was established to support development of new infrastructure and full-cost recovery and to accept the principles set forth in the policy to ensure the long-term secure supply of medical radioisotopes. From the Organization for Economic and Co-operative Development-Nuclear Energy Agency, a study was used to forecast the global processing capacity for ^{99}Mo from 2015-2020 and was published in 2014.

Additional actions are required to ensure a reliable supply of U.S. ^{99}Mo. These actions include investment and continued development of non-HEU-based full-cost recovery production of ^{99}Mo capacity in the United States, education of customers and hospitals, an end of government subsidies in this commercial industry, and continued support for the expedient implementation of the American Isotopes Production Act by all stakeholders.

6.2 Considerations on the Ethical Aspects of the Societal Application of Nuclear Technology

An overview of ethical considerations associated with issues related to MIP and the CTBTO was presented by SCK•CEN, which considered the beneficial impact of MIP on human health and how this

peaceful use of nuclear technology affects non-proliferation policies. An exploration of the possible meaningful notions of ethics in relation to the societal use of nuclear technology led to the determination that the practical "problem" is that MIP produces radioxenon emissions, which are identical isotopes to those released from a nuclear explosion. These emissions present a challenge for the CTBTO, which wants to monitor for nuclear explosions but faces interference by the isotope producers that "legally" emit radioxenon. On the other hand, the isotope producers want to contribute to health care but face the fact that they would need to mitigate their emissions for other reasons and the fact that mitigation is not evident in technical and economic terms. Taking into account each party's good intentions, the problem can be approached as a simple problem of co-existence while each party continues to engage in contributing to a different, unquestionable higher good (peace and health).

In general, the problem was analyzed in order to provide an ethical perspective and to raise awareness for the importance of the ethical perspective. This is important because it provides ideas and a language as tools to improve the mutual understanding between the CTBTO and the isotope producers (reference to opening speech of the CTBTO executive secretary Mr. Zerbo) and to reflect on the issue of accountability towards society. During this presentation, issues related to the problem were explored, including problems with co-existence, co-governance as pragmatic, accommodation, the problem of societal justification, and co-governance as ethical commitment.

7.0 Atmospheric Transport Modeling

The sixth session of the workshop included several presentations on employing ATM to better understand and predict the effect of radioxenon releases from MIP on the IMS and to backtrack detections from IMS noble gas stations to their source.

7.1 Simulation Software for Impact of MIPF Radioxenon Release on IMS Observations Based on Hypothetical Stack Monitoring Data

A software application has been prototyped for the CTBTO to provide interactive and real-time simulation of MIP facilities' xenon emissions and their impact on detections at noble gas systems of the IMS radionuclide monitoring network. This software was used for a case study to assess the potential influence of xenon emissions from the KAERI MIP facilities on CTBTO noble gas stations of the IMS. ATM simulations were performed in the forward mode (and SRS as generated automatically in the IDC pipeline). The detection sensitivity of the current and upcoming generation of noble gas systems (0.1 mBq/m^3 and 0.01 mBq/m^3) were compared for emission scenarios of 2 TBq/day and 5 GB/day. The software was used to determine which IMS stations would be influenced by MIP xenon emissions; the frequency of detections; quantified impact on background levels in terms of activity concentration; and how the impact on IMS stations will be significantly mitigated due to a reduced emission rate of 5 GBq/day.

It was determined that the potential impact of xenon emissions from KAERI of ~2 TBq/day would affect three IMS stations with the current detection limit and eight stations with the upcoming generation of noble gas systems (0.01 mBq/m^3 detection limit). Therefore, the number of affected samplers would be two to ten times higher with the improved systems (see Figure 7.1). When a reduced emissions level of 5 GBq/day ^{133}Xe was assumed, no IMS station would be affected—even with the improved detection sensitivity of the upcoming noble gas monitoring systems (see Figure 7.2).

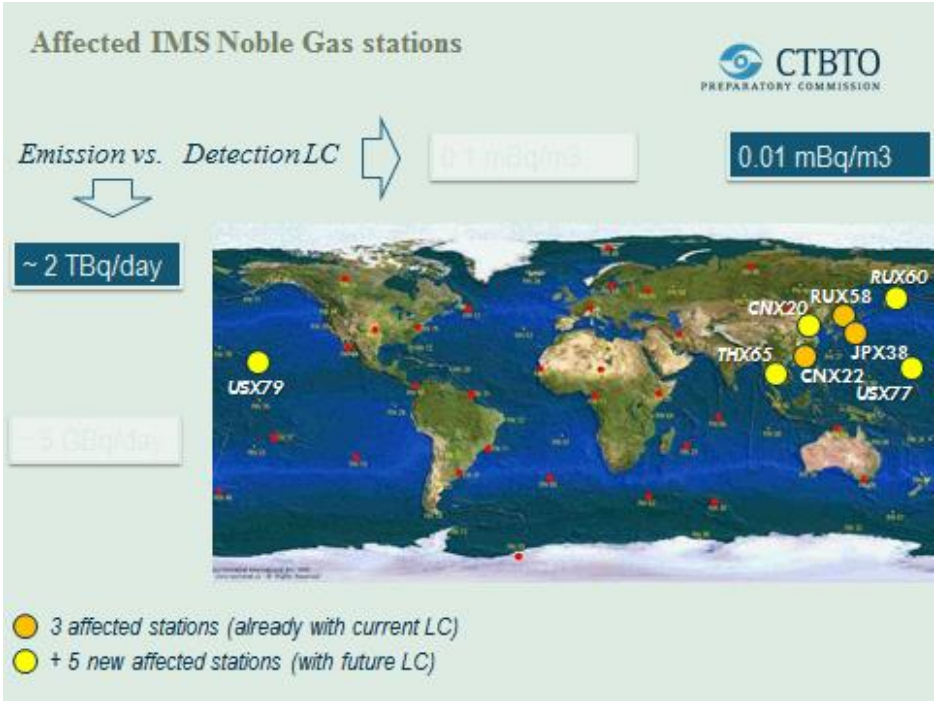


Figure 7.1. Affected IMS Noble Gas Stations Assuming a ~2 TBq/day Release from KAERI and a 0.01 mBq/m^3 ^{133}Xe Detection Limit. According to this model, the lower detection limit of 0.01 mBq/m^3 would be expected to increase the number of affected stations from three to eight. Note: the abbreviation for Limit Concentration (LC) is used in the figure.

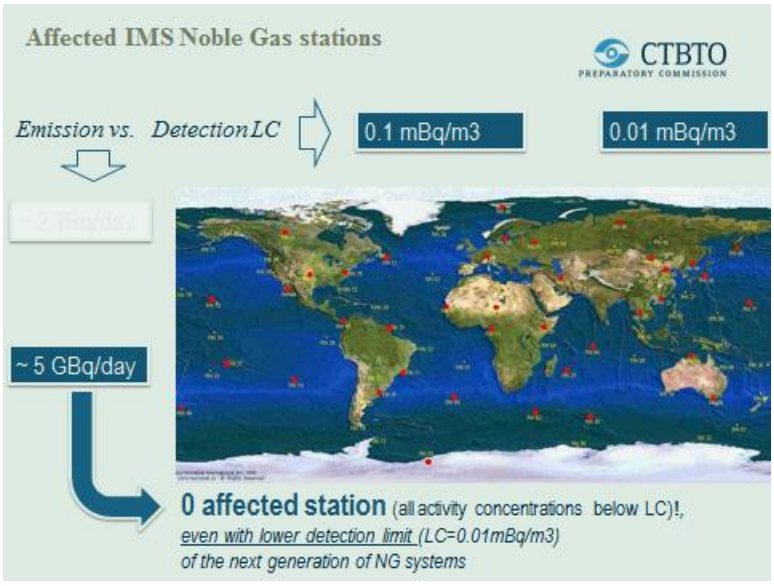


Figure 7.2. When a ~5 GBq/day Release Was Assumed for the KAERI facility and a 0.01 mBq/m^3 1^{33}Xe Detection Limit for IMS Noble Gas Stations, No Stations Are Expected to Be Affected

A software tool was investigated with the goal of providing interactive and real-time simulation of MIP facilities' xenon emissions and their impact on detections at noble gas systems of the IMS radionuclide monitoring network. The main functionality of the software is to assess the impact in terms of affected

stations, frequency of detections, and activity levels. Moving forward, tests using actual emission data form MIP facilities will be performed with this tool.

7.2 Detection of Radioxenon Released from Medical Isotope Production in Subsurface Gases

Under the CTBT, an OSI may be conducted to clarify whether a nuclear explosion has been carried out in violation of Article I of the Treaty. A major component of an OSI is the measurement of subsurface gases to detect radioactive noble gases that are produced in a nuclear explosion, particularly radioxenon and radioargon. To better understand potential backgrounds, a sampling campaign was performed near Chalk River Laboratories in the Ottawa River Valley. The work used current OSI techniques to measure atmospheric radioxenon intruding into the local geology. The goals of this project were to determine whether the releases from Chalk River will imprint gases into the subsurface (Xe, Ar and Rn); to correlate possible releases and soil-gas measurements with ATM modeling; to potentially consider distance from source implications; to consider potentially depth profiling; and to potentially consider geology variation and sensitivity.

An OSI can be used for verification of the CTBT as requested by State parties to clarify whether a violation of the Treaty has occurred. Inspections look for a "smoking gun" (^{37}Ar, ^{131}I, and radioxenon isotopes including ^{131m}Xe, ^{133m}Xe, ^{133}Xe and ^{135}Xe). This is the most invasive component of the verification regime and involves up to 40 inspectors for up to 130 days with broad access rights.

While background interference has the potential to complicate the inspections, background sources are not well understood. MIP is a major contributor to the radioxenon background measured by IMS, but little is known about backgrounds that could be encountered in an OSI. Sampling and analysis methods are under development with only a cursory understanding of these issues.

This experiment was the first ever to measure radioxenon imprinting into subsurface gas. The experiment conducted soil-gas sampling in an area near Chalk River that is known to have consistently high concentrations of atmospheric radioxenon in order to look for evidence of imprinting of gas into the ground. Eight subsurface samples were acquired from September 10, 2014 through September 19, 2014 (seven corresponding to atmospheric gas samples); see Figure 7.3. ATM was used to model the expected ^{133}Xe plume from Chalk River (see Figure 7.4). The average atmospheric ^{133}Xe concentration during sample collection was 30 Bq/m^3 with the largest plume of 400 Bq/m^3. Preliminary results indicate that the subsurface^{133}Xe levels were elevated after plume passage. Pending further analysis, it was concluded that subsurface sampling could result in detected levels of radioxenon on the order of 1% of the average atmospheric radioxenon concentrations. Future work is planned to focus on broadening these conclusions to other sites, depths, and conditions.

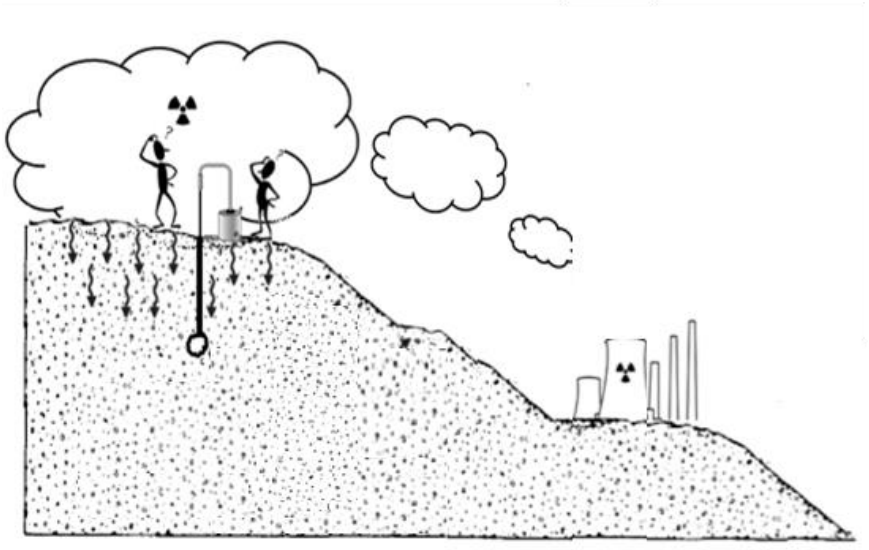


Figure 7.3. The Experimental Objective Was to Perform Sampling for Determination of Imprinting of Gases into the Subsurface, such as Xe, Ar, and Rn

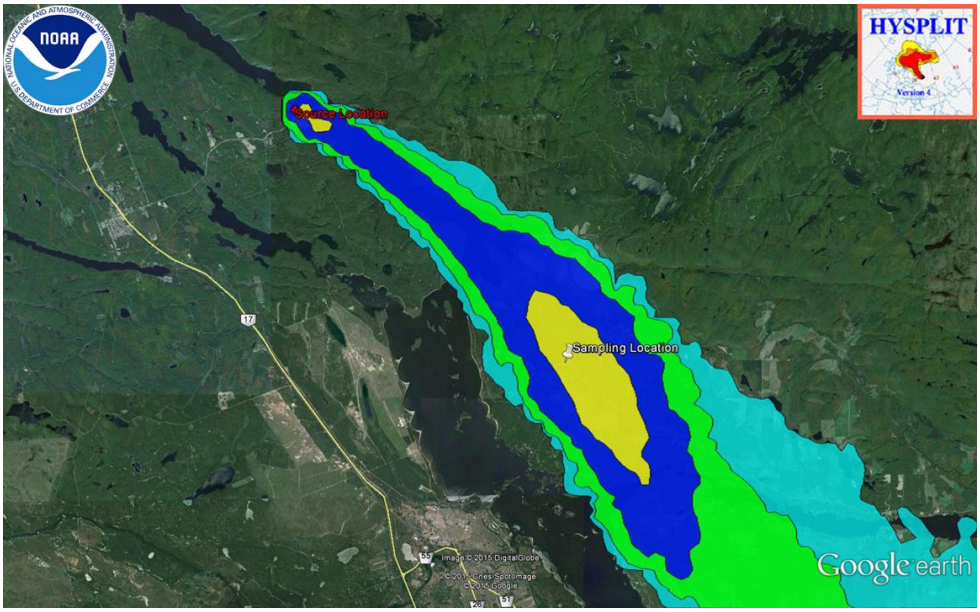


Figure 7.4. Model of the ^{133}Xe Plume Released from Chalk River on 16 September 2014. The sampling location was located in the center of the plume at this time.

7.3 Radioxenon Monitoring in the Ottawa Valley

CNL has been producing ^{99}Mo since the 1970s and currently supplies 30-40% of the world supply. Emissions of radioxenon from the CNL medical isotope facility in Chalk River, Ontario (formerly Atomic Energy of Canada Limited), although harmless, dominate the total releases of radioxenon to the global environment. Since 2001, Health Canada has used these emissions as the basis of a real-world measurement and "modeling laboratory" employing its radiation monitoring equipment throughout the Ottawa valley and its access to data from more sensitive equipment operated in the global international monitoring system of the CTBTO. Recently, Health Canada and CNL co-developed improved software to

analyze time series data from the existing emissions monitoring systems at the CNL facility. As a consequence, Health Canada has had access to detailed emissions from this facility every 30 seconds from a four-channel NaI stack monitor, greatly enhancing a correlation between the approximately 1TBq/hr of stack emissions and network surveillance measurements. This report characterizes correlations of time series of both the stack emissions and NaI data from the regional environmental monitoring network. Health Canada has been monitoring in the vicinity of CNL using a SPALAX radioxenon analyzer for over fourteen years and using a NaI detectors for over thirteen years. This network consists of seven detectors within a 47 km radius of the facility (see Figure 7.5).

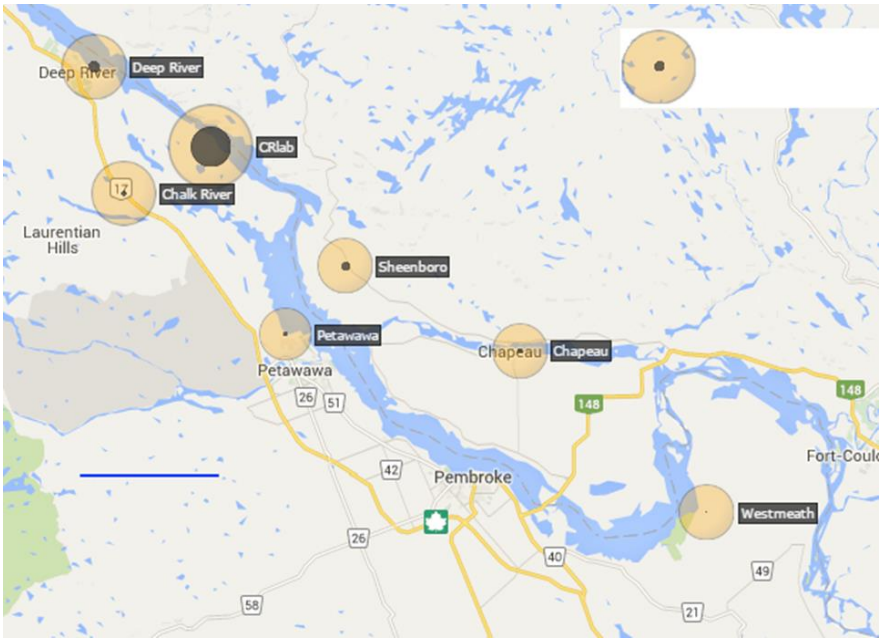


Figure 7.5. The CNL Monitoring Network, Which Consists of Seven Detectors

Processing of ^{99}Mo at CNL begins by allowing targets to decay fourteen hours after irradiation. After decay, dissolver off-gas containing radioxenon is collected from dissolution, which lasts ~one hour, and is passed through underground delay columns. To delay radioxenon released during vacuum transfer of liquids between vessels, molecular sieve delay columns at atmospheric pressure are used in the ^{99}Mo hot cells. The combined exhaust from the ^{99}Mo hot cells, the underground delay columns, and the isolation room flows underground to the building stack through two parallel sets of high-efficiency particulate air and 50mm bed charcoal filters. The ^{99}Mo hot cell building exhaust is combined with exhaust from other buildings and discharged to the stack. Radioxenon releases are monitored prior to the stack by a recently upgraded four-channel NaI detector (monitoring ^{135m}Xe, ^{135}Xe, and ^{133}Xe); example data is shown in Figure 7.6.

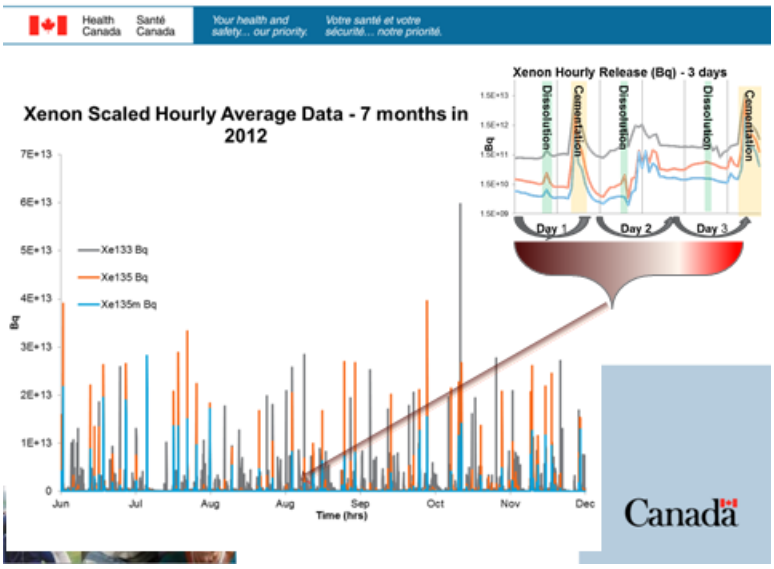


Figure 7.6. Xenon Releases from CNL. Drilling down into the data, related release can be tied to individual events.

The ^{133}Xe detected at the fixed point monitors trends upward with stack data (average emissions of 28 TBq/day), but short time periods like a week do not correspond as well. This lack of short time correlation is hypothesized to be due to a persistent cloud of ^{133}Xe that floats up and down the valley. Monthly trends correlate very well between stack monitor and network measurements. The shorter-lived ^{135}Xe trends correspond almost daily with a possible time off set. Possible back mixing of past ^{133}Xe would increase the network ratio in detectors nearest to CNL. The measured concentration ratios agree with estimates from those with the dose detections further from CNL. The median ratio compared to CNL stack suggests about a twenty-hour transit from CNL to Ottawa—about three to four times longer than typically estimated by other means.

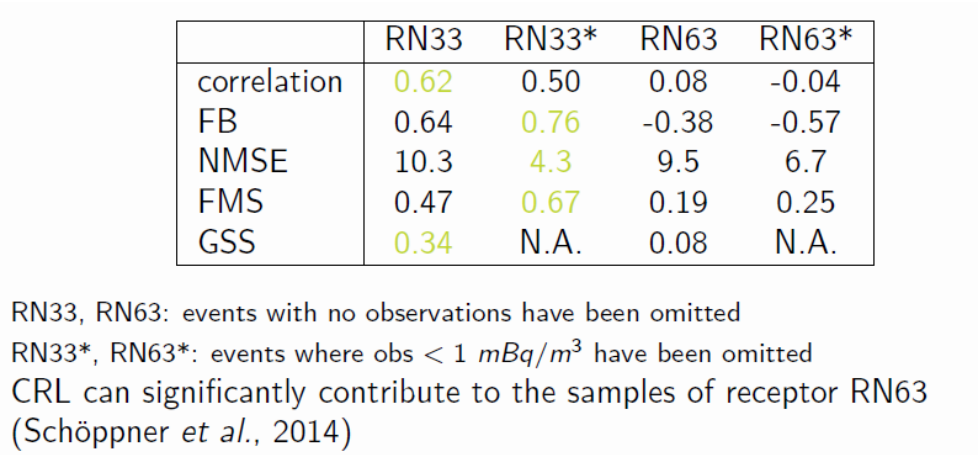
The CNL facility and available environmental monitoring systems provide a good basis to understand the radiological and CTBT verification impacts of fission-based MIP. An additional detailed study would be beneficial.

7.4 Uncertainty Quantification of Long-range Atmospheric Transport Models

An overview of the ongoing collaboration between SCK•CEN and RMI of Belgium, which tries to quantify the uncertainty of long-range radioactive xenon background forecasts in the context of the CTBT, was presented by SCK•CEN. Accurate ATM forecasts can help detect violations of the CTBT and are important for decision support in case of nuclear incidents. Therefore, an as accurate as possible forecast is desired, but unfortunately the forecast is prone to errors that are difficult to quantify. The determination of uncertainty in ATMs is a difficult task but can be determined by comparing data.

Sources of uncertainty in ATM are associated with data or parameter, model or structural, and stochastic. The focus of this study was meteorological uncertainty, which is most important. The atmosphere is a chaotic system. To access the uncertainty of meteorological data, an ensemble prediction system can be used.

The initial results of this study used ATM FLEXPART simulation roughly corresponding to Europe for 2014. The source used was IRE assuming a constant release of 1.3 TBq ^{133}Xe and three-hour weather data. This fairly simple setup produced good results for IMS radionuclide station RN33 but poor results for RN63 and an overestimation of activity for RN33 (see Figure 7.7). Work on this project is ongoing.



	RN33	RN33*	RN63	RN63*
correlation	0.62	0.50	0.08	-0.04
FB	0.64	0.76	-0.38	-0.57
NMSE	10.3	4.3	9.5	6.7
FMS	0.47	0.67	0.19	0.25
GSS	0.34	N.A.	0.08	N.A.

Figure 7.7. Results from Initial FLEXPART Results for IMS Radionuclide Stations RN33 and RN63

7.5 ATM Challenge

PNNL presented the results of the ATM Challenge, which was held to investigate the feasibility of using stack release data and ATM as a tool to help mitigate the effects of emissions from MIP on the global radioxenon background. The basic idea is that it may be possible to either "flag" an IMS measurement that has been influenced by MIP emissions and using the accompanying stack data or subtract the effect of the emissions at a particular location based on stack release data.

There are pros and cons to each sample flagging and effect subtraction. While it is relatively easy to compute whether a measurement is affected by emission from a known source and "flag" this measurement, doing so generally does not allow an understanding of the effect of a sample; it only flags an event and therefore has limited uses in some areas of the world. This technique could lead to the loss of events due to ambiguity of the data. Effect subtraction is the most scientifically defensible technique currently available and can theoretically be used to retrieve events that have an admixture of MIP effect and nuclear explosion. However, the fidelity of stack data required is unclear and there is a perceived issue with sharing of stack release data.

The challenge was issued to determine the fidelity of stack data required for effect subtraction. Therefore, a test was conceived to challenge the community to reproduce the concentrations of xenon measured at IMS xenon monitoring facility (DEX33, Shauinsland, Germany), based on IRE stack monitoring data. Each group would decide on which model and atmospheric data to use (using DEX33 data was not allowed). The idea was to look for trends in the data and inform the community on gaps in the technique in a real-world scenario. Optimally, one would like to calculate the contribution of MIP to a peak or set of peaks.

The challenge was announced at the 2014 ATM workshop. Twelve groups responded, and there were twenty-three results (several groups gave more than one answer).

At the inception of the exercise, there was a desire to provide a simple statistic to show which model performed best. However, due to the extreme variability of the results as shown in Figure 7.8, a statistic that explains the results in a single set of values has not been found. Several statistics have been applied to compare models and determine which describes the best peak shape and amplitude including overall peak shape, Pearson R-value, and Pearson auto-correlation.

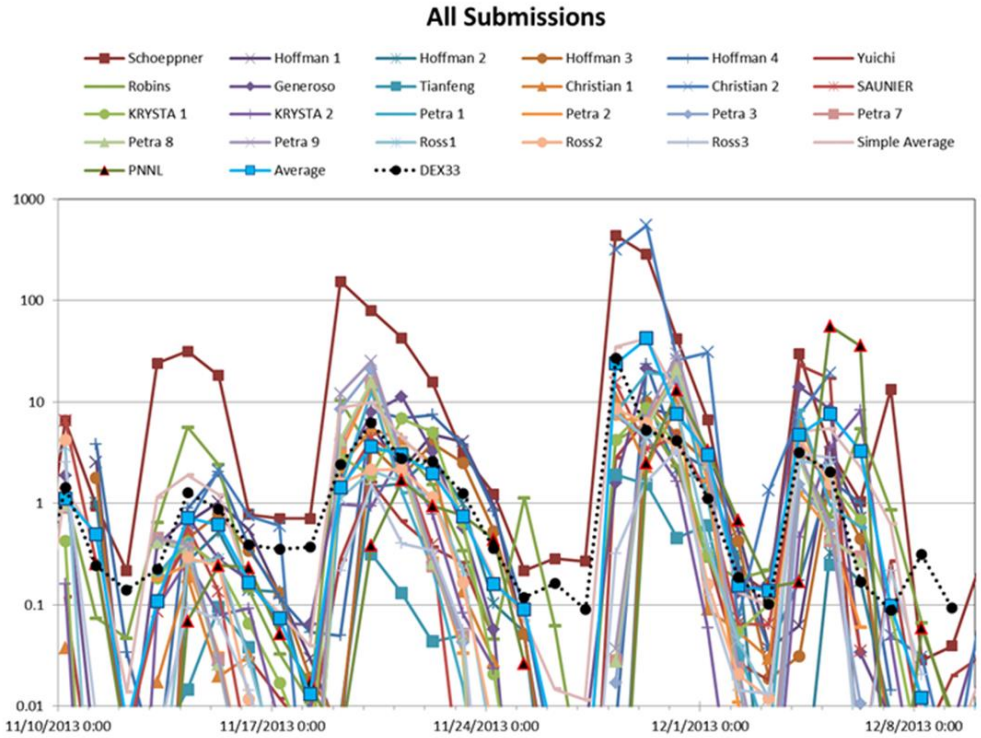


Figure 7.8. All Results from the ATM Challenge

From these comparisons, the best overall fitting data was found to be "Hoffmann4" model—although it had a twenty-four-hour shift in time compared with the data from DEX33. Few results predicted the peak location in time. Of the two best modeled results, one was low by 14% and the other was high by 11% compared with the actual peak values. About half of the participants reproduced the shape of the concentrations for most of the peaks; this reproduction of peak shape seems to correlate with the choice of weather data. The best results for concentration are within 10-15% for the main peak but further off (times two or greater) for most results submitted.

Several factors could affect the results. The station at Mount Schauinsland is 1200 meters above sea level, and the Freiberg station is located 280 meters above sea level in the Rhine valley. This orology could result in different activity concentration during stationary temperature inversion at the stations—this effect has been observed in ^{85}Kr data from the Bundesamt für Strahlenschutz station in Trier, Germany. In weekly samples from December 2 through December 16, 2013, the ^{85}Kr activity concentrations are different at the two stations, indicating an inversion layer. Although there may have been an inversion, this finding does not invalidate the test in any way. In fact, this is a real-world scenario that could occur at any time. In addition, the inversion appeared to occur after the large peak on November 28.

7.5.1 Implications on the Use of Stack Monitoring Data

Using the best models we have today, our predictions of concentrations caused from a MIP facility are not better than about 10-15%. Sub-twenty-four-hour stack data appears to be critical, although the required timeframe was not evaluated in this exercise. There appears to be an offset for much of the data, which could be a problem for determining the effect of MIP on a particular measurement. This offset leads to questions of whether we can design an experiment to test for this offset and if there is something wrong with our input data.

Moving forward, a better exercise could be designed to narrow down issues, identify gaps, and determine how to address uncertainties. Questions that could be answered include what can we do to decrease the uncertainty in the calculation of concentrations at the IMS stations; is stack data a significant source of uncertainty; what is the overall uncertainty in our result; and can the flagger concept be improved so that NDCs can use it and calculate the effect by themselves.

In conclusion, a rudimentary but realistic and applicable atmospheric transport modeling challenge that directly tests ideas about the use of MIP stack data was conducted. The results from the challenge found that some solutions are much better than others and can, in a few cases, determine concentrations at a station to within about 15%; however, in many cases, the agreement is poorer. Many calculations were able to predict peak shape but require temporal offsets.

8.0 R&D for Emission Reduction

The seventh session of the workshop covered topics related to engineered reduction of radioxenon releases from MIP facilities. Presentations were shared covering topics such as incorporation of current methods and development of new technologies to reduce radioxenon emissions, which are vital to achieving the low release levels required to eliminate interfering emissions.

8.1 Results and Conclusions from the Two First Phases of the Xenon Mitigation Project

SCK•CEN has undertaken a mitigation project for the development and testing of a mobile pilot system at IRE for reduction of xenon emissions from MIP. The aim of this project is to design a mobile system for the reduction of radioxenon emissions from Radiopharmaceutical Production Facilities. Xenon mitigation by this system will be accomplished using physical adsorption. The project is subdivided into three phases: In the first phase, xenon adsorption materials will be selected and studied with an emphasis on new types of silver zeolites; the second phase will consist of a study on operational conditions of a xenon trap and trap design; and the final construction and testing of a mobile trap will be conducted in phase 3 at the IRE facility. Phases 1 and 2 have been completed and phase 3 is in progress.

Several adsorbents were studied, and the most promising activated carbon and silver zeolite were found to be Nusorb GXK and Ag-ETS-10 respectively—based on xenon retention time. Figure 2.16 compares xenon retention time for the tested sorbents. It is worth noting that due to the large retention time for the Ag-ETS-10, the adsorbent volume is considerably less than for the other tested sorbents. The Ag-ETS-10 silver zeolite was used for fourteen successive regenerations of the same batch with no reduction in the retention. High concentrations of radioxenon on the sorbent may cause degradation and temperature increase. Solutions to this potential problem include mixing Ag-ETS-10 with activated carbon to increase volume and replacing one column with two to four smaller columns. The durability of Ag-ETS-10 against irradiation was also tested with no degradation of the material observed after applying a 20 kGy/h for 50h, see Figure 8.1.

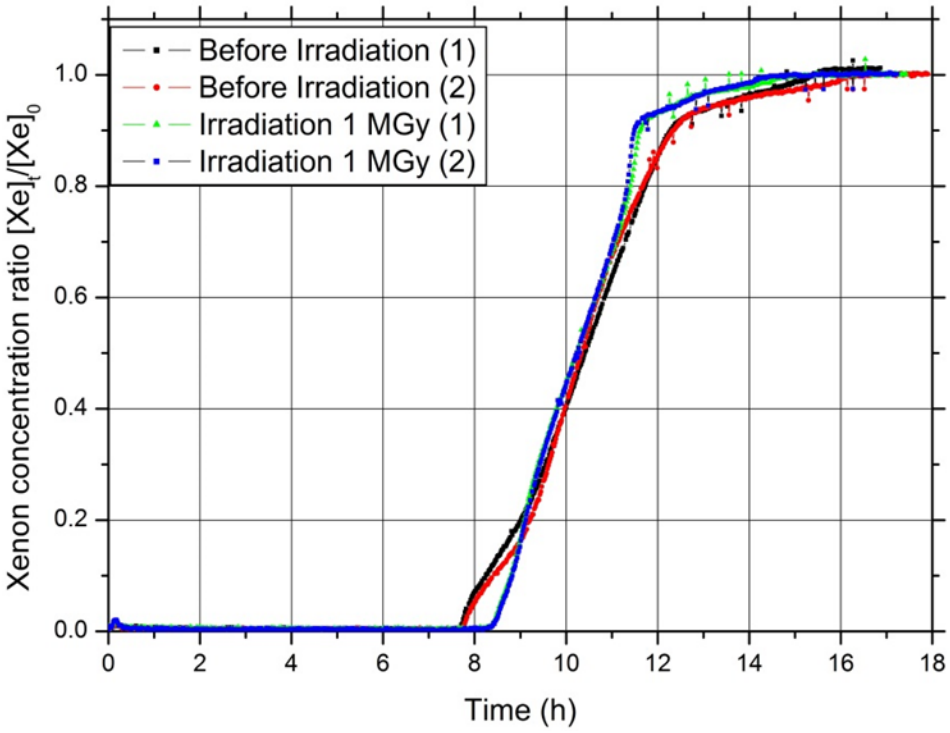


Figure 8.1. No degradation of the Ag-ETS-10 material was observed after exposing to 20 kGy/h for 50h.

Several radioxenon trap geometries were tested, and it was determined that a length/diameter ratio of 10 was the optimal geometry based on breakthrough curves. Trap regeneration was optimized to be 160-170º C for three hours. To reduce temperature due to concentrating large amounts of radioxenon activity, multiple oversized columns will be used (less activity per column). Based on these criteria, a prototype was designed that will be tested at SCK•CEN initially and at IRE to test operational conditions.

8.2 Effort on Xenon Release Reduction in the Framework of the IRE LEU Conversion Program

IRE spoke about using conversation from HEU to LEU as an opportunity introduce process and equipment modifications to reduce radioxenon releases. IRE plans to be fully converted to LEU in several years. During this time, they expect to increase safety, decrease releases, and maintain production. This effort creates several technical challenges that have to be overcome, such as installation of a new radioxenon trapping system in the existing building.

For LEU production, a new target is being developed and qualified in the BR2 reactor that will ultimately be irradiated in reactors (BR2, HFR, MARIA, LWR-15, FRM-II, JHR, and Osiris). To accommodate the larger targets, modifications of the target transport container were performed and application for a new transport license was completed. Additionally, process and plant modifications for dissolution, U filtration and ^{99}Mo/131I separation will be required.

Objectives of the project are to maximize the ^{99}Mo yield while minimizing waste during purification and to improve xenon trapping. Hot cell refurbishment and modifications will be performed to keep the current service level on the HEU line and for management of both HEU and LEU batches. The xenon management system is being converted from liquid nitrogen trapping to holding tanks that will incorporate fifty-six decay tanks to achieve a nine-week delay. In the new system, Xe will be trapped

passively during dissolution and iodine will be trapped in a solid support (unique source of xenon decay) (see Figure 8.2). Xenon trapping will be done during other hot cell operations; and liquid transfers will be under reduced pressure to trap xenon from iodine decay. The expected reduction in for xenon releases is by a factor of ~20.

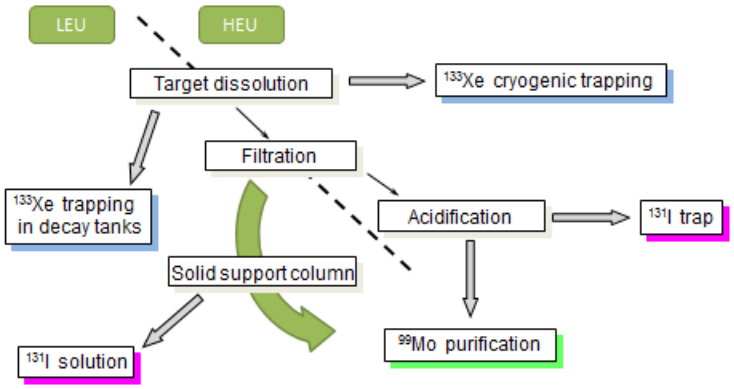


Figure 8.2. Comparison of Current HEU Xenon and Iodine Trapping with the New LEU Trapping. These new strategies are expected to reduce xenon releases by a factor of ~20.

8.3 Research on New Adsorbents Aimed at Increasing the Xenon Retention Capacity for the Adsorption Bed

The Chinese NDC presented information on their research on adsorption material for xenon retention. Adsorption on solid materials is a well-known technique that can be applied to treat a gaseous effluent and to monitor radioxenon. Activated carbons and carbon molecular sieves are two types of porous materials that have a high adsorption coefficient for xenon. In this talk, an investigation of activated carbon and two carbon molecular sieves to determine the efficiency for the stable xenon retention was discussed.

The carbon molecular sieves were characterized for pore size by static adsorption and tested using dynamic adsorption (see Figure 8.3). Commercial activated carbon (from coconut) CF-1450 and manufactured carbon molecular sieves (Phenolic resin) CMS-1, CMS-2, and CMS-3 were analyzed. This study found that the CMS-2 had the best adsorption, which was ~2.5 times greater than the CF-1450 activated carbon.

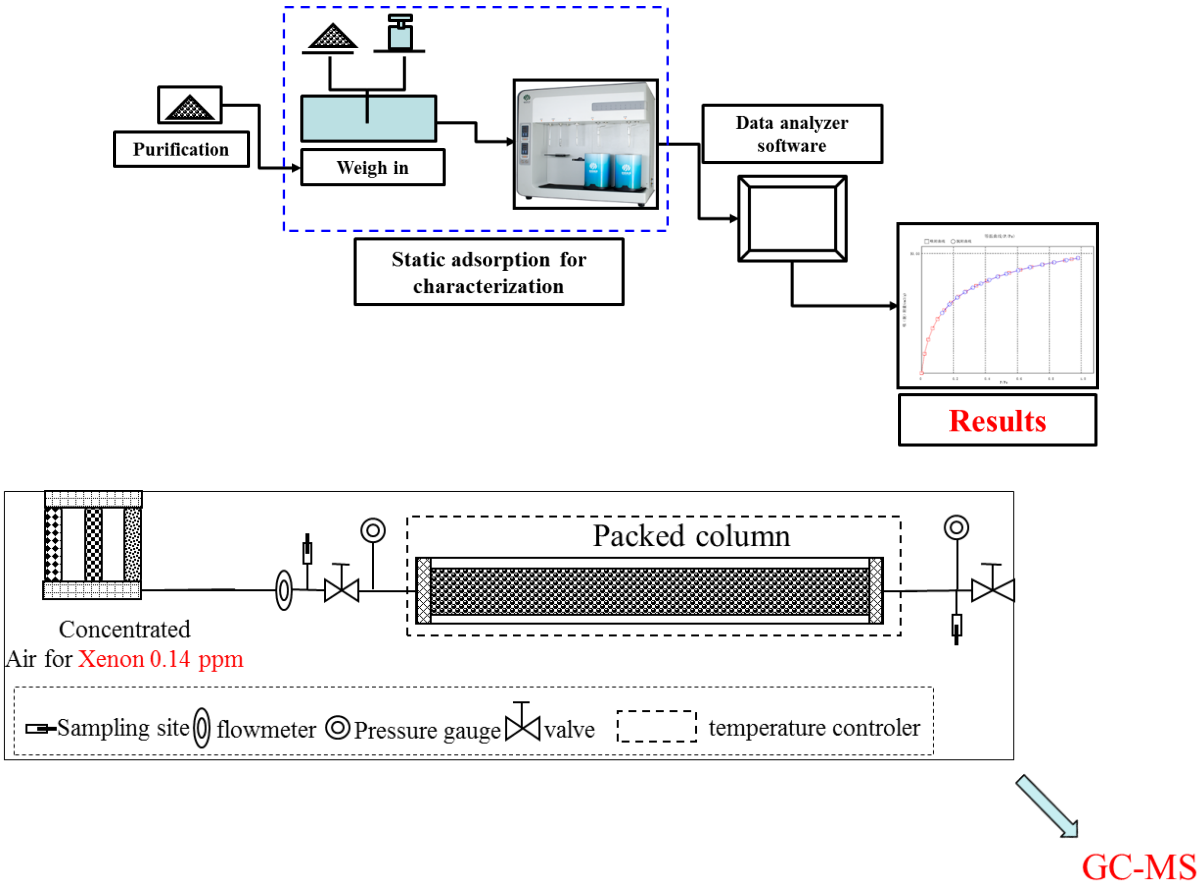


Figure 8.3. Systems to Test the Pore Structure and the Dynamic Adsorption of Different Materials

8.4 Evaluation of the Gas Trap Assembly Used in the Acid Dissolving Process of the LEU Target

The Institute of Nuclear Research in Romania shared information on the use and design of their gas trap assembly that is used to capture waste gases during dissolution and foil and processing via the modified Cintichem process. First, the expected grams of gas isotopes (iodine, xenon and krypton) produced from a five-day irradiation of a 9.2g LEU target were calculated in ORIGEN based on neutronics calculations (see Figure 8.4). Next, a gas trap assembly was built that is attached to the LEU foil dissolver and consists of an iodine trap and a cold finger to capture the noble gases (see Figure 8.5). The iodine trap consists of a copper assembly filled with 26g of copper wire to initiate the reaction:

$$Cu + 0.5\ I_2 \leftrightarrow CuI$$

The cold trap contains a mixture of 10cc calcium oxide, 30cc molecular sieve and 30cc calcium sulfate to increase the retaining capacity of the cold finger. To cool the trap, liquid nitrogen is pumped from outside of the hot cell to the cold finger trap.

Grams of gas isotopes obtained after 5 days irradiation of a 9 g LEU foil

ISOTOPE	CHARGE	DISCHARGE	24H
i135	0.000E+00	1,341E-04	1,066E-05
i134	0.000E+00	2,212E-05	5,623E-13
i133	0.000E+00	4,332E-04	2,007E-04
i132	0.000E+00	2,103E-05	1,705E-05
i131	0.000E+00	5,857E-04	5,578E-04
i130	0.000E+00	2,750E-08	7,199E-09
i129	0.000E+00	1,162E-04	1,243E-04
i128	0.000E+00	3,223E-11	1,454E-28
Total I		1,312E-03	9,105E-04

ISOTOPE	CHARGE	DISCHARGE	24H
xe128	0,000E+00	2,325E-09	2,355E-09
xe129	0,000E+00	1,468E-13	1,683E-13
xe129m	0,000E+00	8,986E-14	8,312E-14
xe130	0,000E+00	1,675E-07	1,880E-07
xe131	0,000E+00	1,306E-04	1,798E-04
xe131m	0,000E+00	1,302E-06	1,751E-06
xe132	0,000E+00	4,375E-04	5,758E-04
xe133m	0,000E+00	2,196E-05	2,194E-05
xe134	0,000E+00	2,085E-03	2,123E-03
xe135	0,000E+00	1,098E-05	4,130E-05
xe135m	0,000E+00	9,666E-07	6,755E-08
xe136	0,000E+00	3,307E-03	3,307E-03
Total Xe		5,995E-03	6,251E-03

ISOTOPE	CHARGE	DISCHARGE	24H
kr81	0,000E+00	1,973E-13	1,973E-13
kr82	0,000E+00	7,935E-09	1,016E-08
kr83	0,000E+00	9,436E-05	9,906E-05
kr83m	0,000E+00	1,959E-06	7,939E-09
kr84	0,000E+00	1,803E-04	1,815E-04
kr85	0,000E+00	4,767E-05	5,007E-05
kr85m	0,000E+00	1,159E-05	2,862E-07
kr86	0,000E+00	3,290E-04	3,290E-04
kr87	0,000E+00	6,794E-06	1,435E-11
kr88	0,000E+00	2,131E-05	6,095E-08
Total Kr		6,930E-04	6,600E-04

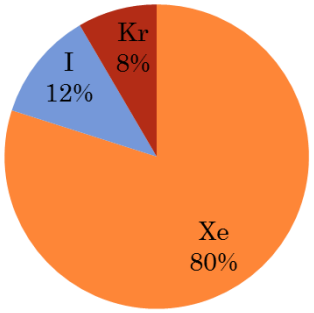


Figure 8.4. Neutronics Calculations for the Grams of Gas Isotopes Present after Irradiation of a 9.2g LEU Foil Target

To determine the efficiency of the gas trap assembly (shown in Figure 8.5), a few experiments using tracers were conducted in the post-irradiation examination laboratory. The pressure of the trap was monitored during the acid dissolving process, the gas draining process, and after heating the cold trap at room temperature. From these tests, it was determined that most of the radioactive iodine was retained by the iodine trap The iodine trap can be used for at least two target dissolutions but, due to irreversible changes of the adsorbents, the cold finger is only good for one process. After some delay time, the radioactive waste can be treated as low active solid waste.

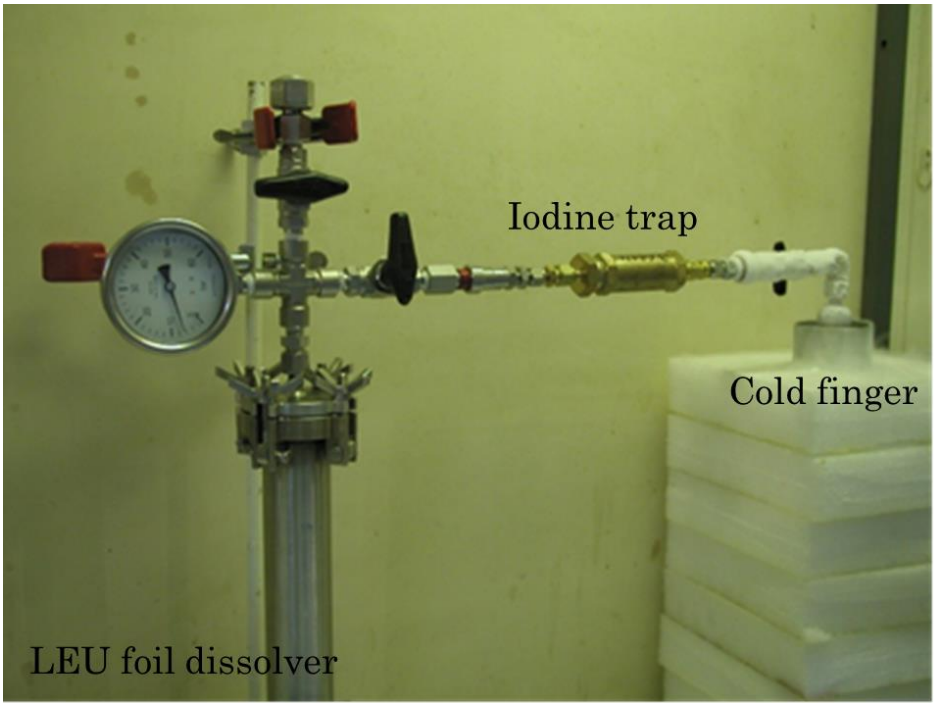


Figure 8.5. Gas Trap Assembly

8.5 Development of Compact Xenon Delay Bed System for Fission Mo-99 Process and Facility

KAREI expects to produce 2,000 Ci ^{99}Mo/week when the Kijang Research Reactor, KJRR, and adjacent fission ^{99}Mo production facility are completed. KAREI is committed to meeting or exceeding the 5 GBq/day voluntary release limit for this facility, which is expected to produce about 13,000 Ci of radioxenon and 16,000 Ci of radioiodine. Conventional strategies for treatment of radioxenon gas in MIP facilities requires installation of large-scale facilities to treat the xenon gas due to the large volume of ventilation air from the hot cell. Therefore, KAERI is researching the potential for a compact xenon delay bed to reduce the huge equipment and space requirements associated with meeting the 5 GBq/day voluntary CTBTO radioxenon release limit by conventional methods. This strategy will reduce the amount of radioxenon off-gas released from the hot cell to the ventilation air and therefore the number of delay beds and decay tanks. The strategy that they are developing would use two modules to capture off gas, an off-gas treatment module inside the hot cell, and a pre-processing module outside the hot cell prior to the hot cell ventilation system (see Figure 8.6).

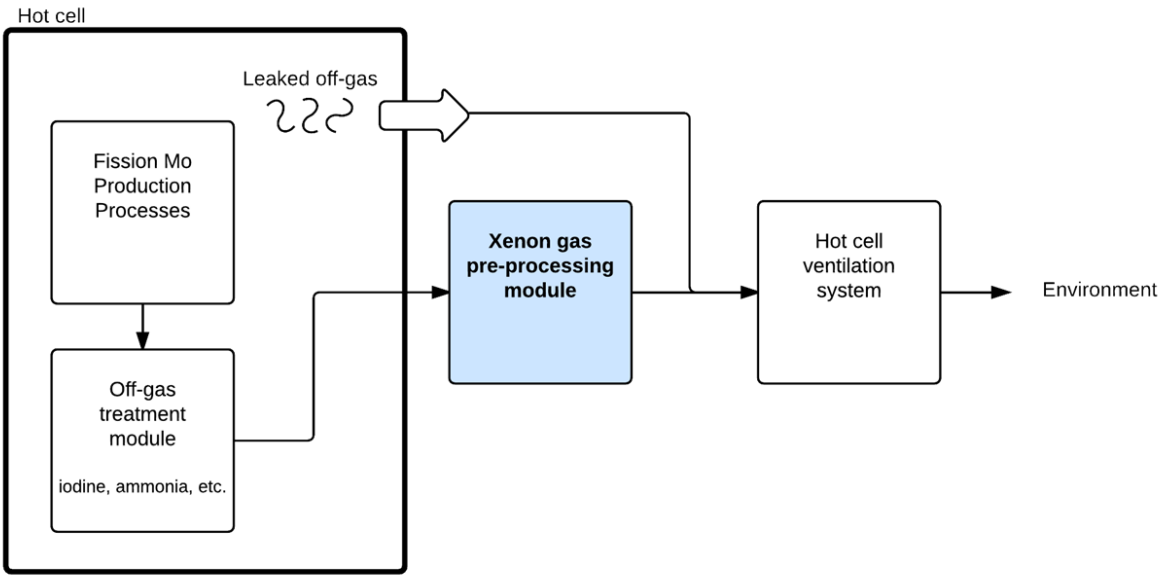


Figure 8.6. Conceptual Design of Off-gas Treatment System at KAERI

A lab scale test of the xenon pre-processing module that uses a cooled charcoal delay bed is being tested. Performance of the charcoal delay bed can be exponentially increased by decreasing the system temperature. To achieve this, a high-performance heat exchanger was designed to efficiently cool the temperature of incoming airflow before the delay bed system and a jacketed column were employed to chill the packed charcoal in the adsorption tower. This experimental test module is composed of a gas mixture chamber, pre heat-exchanger for gas cooling of the gas stream in the mixing chamber and the charcoal delay bed (water bath -26ºC), a charcoal delay bed, and a xenon analyzer, as shown in Figure 8.7. To determine optimized design parameters and operating conditions of the delay bed, process modeling was established based on the experimental data.

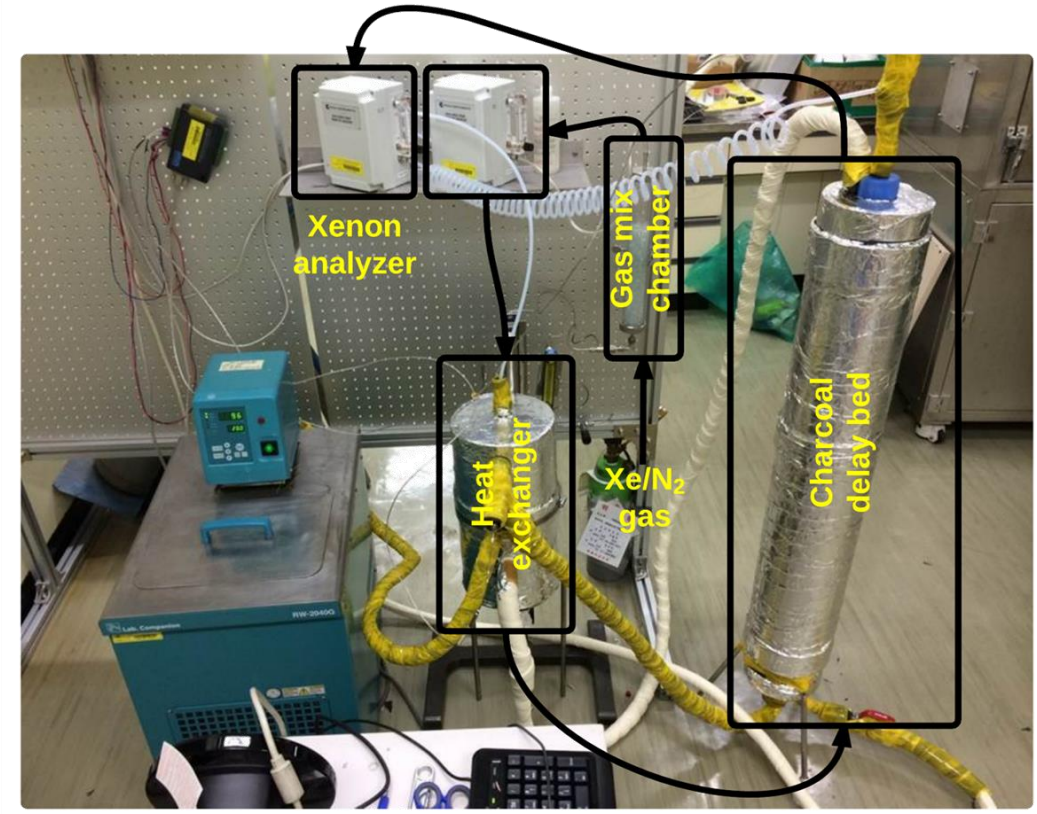


Figure 8.7. Lab Scale Xenon Gas Pre-processing Module

This system could be replaced with the huge conventional xenon treatment facilities (if not successful).

8.6 Noble Gases Treatment Impact on the ^{99}Mo Production Facilities

A presentation by INVAP covered basic concepts relating to noble gas generation sources, alternatives for their treatment, and the impact on the ^{99}Mo production facility. During the last decade, INVAP has designed and constructed facilities for the production of ^{99}Mo from LEU. Current MIP facilities release between 3 x 10^{11} and 8 x 10^{13} Bq/day radioxenon. The source of this radioxenon is from target processing and iodine decay. The majority of radioxenon released from target processing is liberated during dissolution (~2.5x10^{11} Bq ^{133}Xe and 2.1x10^{11} Bq ^{135}Xe per 6 day Ci ^{99}Mo produced). Iodine decay also accounts for a significant amount of radioxenon released from MIP as ^{133}I and ^{135}I decay to ^{133}Xe and ^{135}Xe. The decay time for radioxenon required to meet the 5 x 10^{9} Bq/day voluntary limit assuming a 200 Ci ^{99}Mo 6-day Ci production is ~70 days (compared to 31 days to achieve 8 x 10^{11}). To achieve this delay time, xenon leaks during target processing need to be reduced to 0.1% for xenon and 1% for iodine (see Figure 8.8).

Source	Case	Decay time	
		for 5 x 10^9 Bq/day	for 8 x 10^{11} Bq/day
Target processing	-	70 days	31 days
Iodine decay	5 min I decay	15 days	No decay
	3 hrs I decay	42 days	3 days
	12 hrs I decay	51 days	13 days
Leaks	Target processing	0,1 % leak, 17 days	1 % leak acceptable
	Iodine decay 12 hrs I decay	1% leak, 16 days	15% leak acceptable

Figure 8.8. Comparison of the Decay Time Required to Achieve 5x10^9 and 8x10^{11} Bq/day ^{133}Xe Released from a MIP Facility Producing 200 6-day Ci of ^{99}Mo

To efficiently capture radioxenon from dissolution and processing, several considerations need to be taken into account during system design. Some processes that have potential for radioxenon release are target management (cutting, opening, etc.); leaks as a result of design construction; dissolution process selection; hydrogen generation (or nitrates); storage, treatment, and venting of hydrogen; and storage, treatment, and venting of flushing gases.

In addition to radioxenon from dissolution, iodine decay must also be considered when designing a system to limit the release of radioxenon. Considerations for process and system design for iodine treatment include temperature and pressure, design and construction (leaks), control of vents, and storage and treatment of gases.

The release of radioxenon into hot cells from dissolution and iodine decay must also be considered. The delay time for noble gas in a bed of activated carbon is determined by the carbon weight, the gas flow rate, and the dynamic coefficient (K) for the specific carbon that is installed, according to the following formula.

$$T=MK/F$$

Where T=delay time (seconds), M=carbon weight (g), K=dynamic coefficient (cm3/g), and F=flow (cm3/sec).

Treatment of noble gas is influenced by many factors in a MIP facility. These factors include the facility operation and maintenance, processing system design and construction, gas storage and treatment systems, and the hot cell ventilation system.

9.0 Roundtable Discussions

To promote the exchange of ideas and conversation on topics of interest four roundtable discussion sessions were held during the workshop on Stack Monitoring and Data Confidentiality, Other Issues Related to MIP, Atmospheric Transport Modeling, and Emission Reduction R&D. New for this workshop, flash talks – short 3-5 minute presentations – were presented at the beginning of several roundtable sessions to help cultivate questions and encourage discussion.

9.1 Stack Monitoring and Data Confidentiality

The first roundtable session covered issues relating to the sharing of stack release data. The session began with a flash talk by ANSTO in which it was stated that they have shared stack release data with the community and that it wouldn't be difficult to automate the process of data sharing. They suggested that it may possible to have a tiered system for different producers (making an agreement prior to sharing data). ANSTO suggested that in order to ensure data quality, the flow rate is important for accurate calibration (±20% without calibration) – and suggested installation of a relatively inexpensive digital meter for collection of flow rate data. Regarding worries about regulators using shared release data, it was stated that regulators can already look at the IMS data, which may be good depending on perspective.

In a flash talk by IRE, it was stated that they have also previously shared stack release data and that they would only want to share release data with the CTBTO. Additionally, an overview of IRE's stack monitoring system was shared. The stack releases from IRE are continuously monitored at their main stack on-line with a high resolution HPGe detector and off-line monitoring of iodine is achieved by counting weekly cartridges.

The final flash talk of the stack monitoring session was given by the Swedish NDC. They stated that the use of release data could be used to screen out IMS measurements; however, the system would still be partly blind from MIP releases. Some requirements for collection of useful stack release data for the NDC would be a minimum of one hour time resolution and measurements of ^{133}Xe, ^{131m}Xe, ^{133m}Xe, ^{135}Xe, ^{135}Xe, ^{131}I and ^{133}I (either activities or upper limits). Preferably, the data should be in a well-defined format which could be used for both IMS measurements and release data. In addition, calculations for activities, activity concentrations, and associated uncertainties should be clearly defined. With respect to confidentiality, it would be possible to produce analysis reports without publishing any details on the release data.

Discussions following the flash talks covered topics such as: what stack monitoring system is best, whether the CTBTO can agree to receive data without first establishing a standard format, standard isotopes, and receiving hourly input in a format suitable for ATM. An idea for the establishment of a group to determine format and move work forward was also deliberated.

9.2 Other Issues Related to MIP

In the roundtable session covering other issues, the IAEA gave a flash talk introducing other "crazy ideas" such as looking for other signals or signatures from a MIP facility that could be used to identify the source, subtraction of simulated nuclear weapons explosion from the IMS network with and without MIP emissions, research on a new disposable plastic scrubber/filter to filter out gases like xenon (under development in Sandia), changing the IMS sampling time resolution if the NaI detector at a station indicates a high xenon level, studying the deconvolution of circulated air in which an older emission is

combined with a newer emission and thus makes the signal above the MDC (even though each separate emission may be below MDC).

The NNSA flash talk covered ethics related to MIP. They stated that producers provide great value to the medical and industrial communities and that a reliable supply of ^{99}Mo is essential. Ideally, emissions from fission-based MIP should be low enough to not interfere with nuclear explosion monitoring. Therefore, reducing radioxenon emissions is the right thing to do. Once we are aware of an issue that has a feasible remedy, we should take action and work towards the goal. Attending WOSMIP shows that you want to be a part of the solution.

S. Korea spoke about their countries perspective. There are five radioisotope/radiation technology clusters in South Korea supported by central and local governments. Radiation is a very sensitive issue for S. Koreans, after Fukushima, there has been more fear for radiation release. The xenon issue is important not only because of interference to detection of bomb testing, but also environmental protection in Korea, no matter what the quantity is.

9.3 Atmospheric Transport Modeling

No flash talks were given during this session. However, a discussion on pros and cons of using stack release data to identify potential background interference from MIP emissions (flaggers) verses subtraction of the background from IMS detections ensued. It was suggested that using flaggers with no additional information could lead to more confusion. The uncertainty of the subtraction method (large errors and time shifts) seen in the ATM Challenge was also seen a disadvantage. Both options allow for a quick look at the situation but in an actual event, more data would be needed to thoroughly analyze the event. In the future, a stack monitoring system can be envisioned which would supply real time stack release data from each MIP facility for ATM analysis.

9.4 Emission Reduction R&D

Mr. Abdel-Hadi Ali Sameh (an expert on production cycles of irradiated nuclear fuels for medical isotopes) from Germany opened this session with a flash talk stating that increasing the number of delay tanks alone will not reduce emissions. In addition to having adequate tanks for storage of radioxenon, the system will need to be thoughtfully engineered. Several methods to reduce xenon loss were discussed including: having two valves on each tank to efficiently capture xenon, incorporation of and extra (lung) tank, as at Petten, one tank for operation and one for reserve (redundancy), the use of helium rather than air for flow over charcoal beds to increases the charcoal efficiency. Other solutions include: using 200 L waste tubs, cooling charcoal beds to 15º C, incorporating slow flow hot cells to reduce exhaust air flow and volume, and the importance of quality operations.

A flash talk by SCK•CEN asked the question of how xenon abatement efforts can be optimized? In this talk, the effect of different release pathways on the outcome of an abatement solution was discussed. The goal is to understand whether there is a way to assist MIP's to better identify the relative importance of each pathway. Some ideas posed were the study of new adsorption materials and creating an adsorption material database. Some questions asked of the community included: Which material characteristics should be tested before industrial implementation of a new material and how should they be tested? Is there an optimal design? Are there ways to convert peak releases to continuous releases?

The discussion following these flash talks covered topics such as the human factor and training, taking responsibility for quality work, developing and using best practices, and the sharing of new technologies as "open source."

10.0 Conclusion, Next Steps, and Reporting for WOSMIP

At the conclusion of the workshop, the positive outcomes from WOSMIP V were discussed with the participants, which are listed below.

-
- WOSMIP V had the largest representation of producers of any WOSMIP to date. These producers provided detailed information on current and future production. Additionally, several of these producers indicated that they plan to work toward meeting the voluntary $5x10^9$ Bq/day ^{133}Xe release limit.
- Several additional producers have offered to share their stack data with the CTBTO in addition to those who have previously shared stack release data. The CTBTO will take necessary steps to ensure that shared data is protected and announced that they will begin collecting stack data on an experimental basis.
- Methods for novel software technology for modeling were introduced.
- Lessons learned from HEU to LEU conversion were shared and thoughts on how these lessons relate to xenon emissions were discussed.
- The value of sharing outside ideas from other workshops and conferences that could benefit WOSMIP was discussed.
- South Korea mentioned their country's unique situation and how radioxenon emission affects their country and the global community.
- It was shown that $5x10^9$ Bq/day release limit released from MIP did not significantly interfere with monitoring when investigated using ATM.
- Discussions of various methods for using stack monitoring data were held and it was agreed that further development is needed.
- It was agreed that stack data is absolutely vital for the development and validation of ATM methods.
- The uncertainty associated with ATM was discussed and it was agreed that further development is required.
- It was shown that MIP affects OSIs (underground detection).
- New technology for abatement was shared with the community. Included in this is equipment that is being developed by SCK•CEN that will soon be tested at IRE and potentially other facilities.
- The IAEA CRP on sharing and developing of protocols to further minimize radioactive gaseous emissions to the environment in MIP was introduced and interested parties were encouraged to participate.
- It was agreed that abatement remains the ideal solution to the xenon background problem, but other approaches such as stack release data sharing are also important and have potential for significant impact.

The contributions from both the producers and monitoring communities allowed for a very successful and productive WOSMIP hosted by the CTBTO, SCK•CEN and PNNL. Looking forward, the community agreed that the next WOSMIP should take place roughly 1 ½ years after WOSMIP V.

11.0 Bibliography

Matthews M and TW Bowyer. 2013. *WOSMIP III - Workshop on Signatures of Medical and Industrial Isotope Production*. PNNL-22721, Pacific Northwest National Laboratory, Richland, WA.

Matthews M et al. 2010. *Workshop on Signatures of Medical and Industrial Isotope Production - A Review*. PNNL-19294, Pacific Northwest National Laboratory, Richland, WA.

Metz, L. et al. 2014. WOSMIP IV – Workshop on Signatures of Medical and Industrial Isotope Production. PNNL-23165, Pacific Northwest National Laboratory, Richland, WA.

World Nuclear Association. 2015. Radioisotopes in Medicine. World Nuclear Association, London, UK. Accessed November 25, 2015 at http://www.world-nuclear.org/info/non-power-nuclear-applications/radioisotopes/radioisotopes-in-medicine/

Appendix A

WOSMIP 2015 Agenda

Appendix A

Workshop on the Signatures of Medical and Industrial Isotope Production (WOSMIP) 2015

Hosted by the Prepatory Committee for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), the Belgian Nuclear Research Centre (SCK•CEN) and Pacific Northwest National Laboratory (PNNL).

12-14 May 2015

Egmont Palace, Brussels, Belgium

Agenda

Monday 11-May-15

16:00 - 18:00 Registration and Reception

Tuesday 12-May-15

08:00 - 09:00 Badging/Registration

09:00 - 09:10 Welcome
SCK•CEN

09:10 - 09:25 Welcoming Remarks by the Belgian Minister of Energy and the Environment
N. Mahieu on behalf of H.E. Marie Christine Marghem

09:25 - 09:40 Introductory Remarks by the CTBTO Executive Secretary
L. Zerbo—CTBTO

09:40 - 09:50 WOSMIP Group Picture

Session 1—Introduction to the Problem
Chair: J. Friese, M. Kalinowski

09:50 - 10:05 Workshop Overview
T. Bowyer—PNNL

10:05 - 10:20 International Monitoring System Overview
M. Auer—PTS

10:20 - 10:40 Background of CTBT Relevant Xenon Isotopes at IMS Stations Based on Reviewed Results in IDC Operations
H. Gheddou, J. Kusmierczyk-Michulec, M. Krysta—CTBTO

10:40 - 11:00 Simulation of Worldwide Xe-133 Atmospheric Background

P. Achim, S. Generoso, M. Morin, P. Gross, G. Le Petit—CEA

11:00 - 11:20 Impact of Radioxenon Emissions from IPFs on the Global Coverage of the IMS noble gas Component
M. Schoeppner—Princeton University

11:20 - 11:40 **Coffee Break/Poster Session 1**

11:40 - 12:05 The Way Forward in Xenon Emission Mitigation Research
J. Camps, C. Gueibe, J. Rutten, K. Van Der Meer—SCK•CEN

12:05 - 12:30 IAEA Coordinated Research Project (CRP) Overview
J. Dix—IAEA

12:30 - 14:00 Lunch

Session 2—Current ^{99}Mo Production Overview
Chairs: J. Dix, M. Auer

14:00 - 14:15 New Radioisotopes Production Plant in Argentine
E. Carranza—CNEA

14:15 - 14:30 ANSTO Update
E. Hoffman—ANSTO

14:30 - 14:40 IRE Update
B. Deconninck—IRE

14:40 - 14:50 Nordion Update
R. DeCaire—Nordion

14:50 - 15:00 Mallinckrodt Update
R. Brown—Mallinckrodt

15:00 - 15:15 Batan Update
Y. Imardjoko—PT INUKI (Indonesia)

15:15 - 15:30 NTP Update
G. Ball—NTP

15:30 - 16:00 **Coffee Break/Poster Session 2**

Session 3—New and Future ^{99}Mo Production
Chair: L. Metz, J. Gintner

16:00 - 16:15 Radioisotope Production in Research Reactors
A. Malkawi—JAEC

16:15 - 16:35 Progress in Fission Mo-99 Project in Korea
J. Lee, S. Lee, S. Lee, U. Park, E. Cho, S. Hong, S. Jung, W. Cho—KAERI

16:35 - 16:50 Medical Isotope Production Facility in Myanmar

C. Zaw

16:50 - 17:05 Argonne National Laboratory Activities Directed Toward Developing SHINE Technology for Producing Molybdenum-99
G. Vandegrift—ANL

17:05 - 17:20 Northwest Medical Isotopes Overview
C. Haass—NWMI

17:20 - 17:35 Production of Mo-99 Without Use of Uranium
J. Harvey—Northstar Medical Technologies

17:35 - 19:00 Break

19:00 - 22:00 Workshop Dinner

22:00 **End of Day 1**

Wednesday 13-May-15

Session 3—New and Future ^{99}Mo Production (continued)
Chairs: L. Metz, J. Gintner

09:00 - 09:15 Medical Use of Xe-133
I. Goldman—Lantheus

09:15 - 09:30 Running the Lagrangian Dispersion Model FLEXPART in an Operational Context at RMI
A. Delcloo—Royal Meteorological Institute of Belgium

Session 4—Stack Monitoring Methods and Technologies
Chairs: E. Hoffman, A. Gheddou

09:30 - 09:45 Stack Monitoring System for Gaseous Emissions in Radioisotopes Production Facilities
M. Di Tada, E. Nassif, M. Nuñez, R. Pino—INVAP

09:45 - 10:00 Local Monitoring of Noble Gas Released from Nuclear Facilities
S. Wu, L. Liu, Z. Li—Northwest Institute of Nuclear Technology

10:00 - 10:10 Requirements for Stack Monitoring
J. Friese—PNNL

10:10 - 10:30 IDC Views on the Use and Security of Stack Data
M. Kalinowski, A. Gheddou, W.R. Bell—CTBTO

10:30 - 10:45 Confidentiality of Stack Monitoring Data
I. Cameron—PNNL

10:45 - 11:20 **Coffee Break/Poster Session 3**

11:20 - 12:30 **Round Table Discussion: Stack Monitoring and Data Confidentiality**
Moderator: A. Gheddou
Panel: A. Ringbom, M. Kalinowski, E. Hoffman, B. Deconninck

12:30 - 14:00 **Lunch**

Session 5—Other Aspects of Medical Isotope Production
Chairs: T. Evans

14:00 - 14:20 NNSA's Efforts to Establish Reliable Supplies of Molybdenum-99 Produced without Highly Enriched Uranium
R. Hamilton, R. Howell, T. Hanlon, J. Gintner, S. Fitzwater—NNSA

14:20 - 14:35 Dose Calculation at MIPF
L. Piola, M. Alessi, M. Brizuela, J. Weigandt—INVAP

14:35 - 14:50 Considerations on the ethical aspects of the societal application of nuclear technology
G. Meskens – SCK•CEN

14:50 - 15:10 **Round Table Discussion: Other Issues Related to MIP**
Moderator:
Panel: T. Evans, G. Meskens, Paul Saey, J. Lee

15:10 - 18:30 **Tours of Brussels**

Thursday 14-May-15

Session 6—Atmospheric Transport Modelling
Chairs: M. Krysta, T. Bowyer

09:00 - 09:15 Simulation Software for Impact of MIPF Radioxenon Release on IMS Observations Based on Hypothetical Stack Monitoring Data
H. Gheddou, M. Krysta, J. Kusmierczyk-Michulec, L. Terzi—CTBTO

09:15 - 09:30 The Influence of Local and Global Noble Gas Releases on On-Site Inspections in Support of CTBT
M. Auer, E. Wieslander—CTBTO

09:30 - 9:45 Detection of Radioxenon Released from Medical Isotope Production in Subsurface Gases
C. Johnson, S. Biegalski, J. Lowrey, D. Haas—University of Texas

9:45 - 10:00 Radioxenon Monitoring in the Ottawa Valley
R. Berg, K. Ungar, I. Hoffman, G. Dolinar—Health Canada

10:00 - 10:15 Uncertainty Quantification of Long-Range Atmospheric Transport Models
P. de Meutter, J. Camps, A. Delcloo, P. Termonia—SCK•CEN

10:15 - 10:40 ATM Challenge
T. Bowyer—PNNL

10:40 - 11:15 **Coffee Break/Poster Session 4**

11:15 - 12:30 **Round Table Discussion: Atmospheric Transport Modelling**
Moderators: T. Bowyer, M. Krysta

12:30 - 14:00 **Lunch**

Session 7—R&D for Emission Reduction
Chairs: A. Sameh, J. Camps

14:00 - 14:15 Results and Conclusions from the Two First Phases of the Xenon Mitigation Project
C. Gueibe, J. Camps, K. Van Der Meer, D. Moyaux, B. Deconninck, M. Auer, A. Gheddou—SCK•CEN

14:15 - 14:30 Effort on Xenon Release Reduction in the Framework of the IRE LEU Conversion Program
V. Host, D. Moyaux, B. Deconninck—IRE

14:30 - 14:45 Research on New Adsorbents Aimed at Increasing the Xenon Retention Capacity for the Adsorption Bed
Z. Chen, S. Liu, Y. Chang—Chinese NDC

14:45 - 15:00 Evaluation of the Gas Trap Assembly Used in the Acid Dissolving Process of the LEU Target
A. Ivan, P. Busuioc, S. Dulugeac—RATEN-ICN Pitesti

15:00 - 15:15 Development of Compact Xenon Delay Bed System for Fission Mo-99 Process and Facility
S. Lee, S. Lee, J. Lee, U. Park, K. Jang, K. Yoo, W. Cho—KAERI

15:15 - 15:30 Noble Gases Treatment Impact on the Mo-99 Production Facilities
D. Amaya, V. Wilkinson, C. Maneiro, D. Andreossi—INVAP

15:30 - 16:00 **Coffee Break /Poster Session 5**

16:00 - 17:00 **Round Table Discussion: Emissions Reduction R&D**
Moderator: J. Friese
Panel members: J. Camps, A. Sameh, J. Lee, D. Moyaux

17:00 - 17:45 **Conclusion and Next Steps and Reporting for WOSMIP**
Awarding of the Wozzie for Demonstrated Commitment Towards Mitigating the Effects of Emissions from Medical and Industrial Isotope Production

Posters

Note: All posters will be on display throughout the workshop. Authors will be present to discuss their poster during the assigned sessions (below).

Poster Session 1: Tuesday 12-May-15, 11:10-11:40

Challenges in the Establishment & Operation of the PNRI Mo99/Tc99m Generator Production Facility A. Bulos, G. Ciocson, M. Rommel, I. Nunez, A. Dela Rosa—Philippine Nuclear Research Institute

Treatment of Hyperthyroidism with Iodine-131: Experience of Nuclear Medicine Department at the Salah Azaiez Institute in Tunis
I. El Bez[1], A. Mhiri[2], I. Slim[2], D. Ben Sellem[2], I. Yeddes[2], I. Meddeb[2], L. Zaabar[2], B. Letaief[2], M. Ben Slimene[2]
[1]Consultant in the Department of Nuclear Medicine, [2]Salah Azaiez Institute

Poster Session 2: Tuesday 12-May-15, 15:30-16:00

The Update Status of Current Medical Isotope at PT INUKI Company
Y. Imardjoko—PT INUKI

Sterile Production of Technetium-99m (Tc-99m) Generator under Good Manufacturing Practice (GMP) Environment
A. Kasbollah[1], W. Wan Awang[1], R. Dahalan[1], Z. Ibrahim[2], S. Kasim[2]
[1]Senior Research Officer, [2]Assistant Science Officer

SAUNA—Equipment for Low Level Measurement of Radioactive Xenon
H. Berglund, U. Sundstrom—Scienta SAUNA Systems

Poster Session 3: Wednesday 13-May-15, 11:05-11:40

Radioxenon Monitoring in the Canadian Arctic in Resolute Bay NU at the CTBT Aerosol Monitoring Station, RN15
R. Berg, M. Bean, I. Hoffman, K. Ungar—Health Canada

New development in Ruggedized HPGe Detectors for Outdoor Gamma Spectroscopy
F. Jeremy, P. Benoit, C. Jean, Z. Milan, M. Vlad, Q. Pascal, L. Marie Odile—Canberra

Production of Radioxenon Standards for Calibration at the Idaho National Laboratory
R. Hague[1], T. Houghton[1], M. Watrous[1], D. Jenson1, J. Pfeiffer[1], C. Mcgrath[2], S. Biegalski[3]
[1]Idaho National Laboratory, [2]Idaho State University,[3]University of Texas

Development and Application of a Web-based Spatio-temporal Database platform for an early warning system - From Field Monitoring and Data Storage to Database Management and Local Spatial Analysis to Data Visualization
B. Ayoniyi—University of Vienna, Department of Geography and Regional Research

Poster Session 4: Thursday 14-May-15, 11:10-11:40

Backtracking the Holuhraun Exceptional SO_2 Event in September 2014
C. Maurer, G. Wotawa—Zentralanstalt fuer Meteorologie und Geodynamik (ZAMG)

Some Thoughts about Atmospheric Transport Modelling Needs for the Assessment of Network Sensitivity under the Presence of Civil Radioxenon Sources
P. Seibert—Department of Meteorology and Geophysics, University of Vienna

Poster Session 5: Thursday 14-May-15, 15:30-16:00

Design of a Xenon Mitigation Prototype; C. Gueibe—SCK•CEN

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

U.S. DEPARTMENT OF
ENERGY

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)

www.pnnl.gov