



PNNL-35574

The 9th Workshop on Signatures of Man-Made Isotope Production

December 4-7th, 2023 in Santiago, Chile

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The 9th Workshop on Signatures of Man-Made Isotope Production

4 -7 December 2023 in Santiago, Chile

January 2024

M P Foxe, T W Bowyer, J I Friese, L A Metz, T M Weber

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Pacific Northwest National Laboratory
Richland, WA 99354

Executive Summary

The Ninth Workshop on Signatures of Man-Made Isotope Production (WOSMIP-IX) was held December 4-7th, 2023 in Santiago Chile, co-hosted by the Chilean Nuclear Energy Commission (CCHEN). The workshop had a total of 117 participants: 88 in-person and 29 virtual attendees. The detailed agenda and presentations for the workshop and the attendance list are located at <https://www.wosmip.org/>.

WOSMIP-IX consisted of the following main topical areas: measurement and understanding of backgrounds, introduction to a list of potential sources of man-made radionuclides (aka, the “WOS-list”), emissions and sources of radionuclides, stack monitoring of facilities, Mo-99 production, and atmospheric transport modeling (ATM) and events and measurements of interest. These topical areas consisted of presentations, a poster session, and a dedicated roundtable discussion around a new repository for xenon source term data WOS-list. During the workshop, there was a tour of the RECH-1 Research Reactor, Nuclear Physics and Neutron Spectroscopy Center (CEFNE), Cyclotron and National Environmental Monitoring Stations at the Chilean Nuclear Energy Commission. While at the CCHEN, there was also a networking event that consisted of digital posters that covered topics such as: cytogenetic dosimetry (CCHEN), radionuclide dynamics in agriculture (CCHEN), international monitoring system stations for radionuclides (CCHEN/OTPCE), and source term analysis of Xenon (STAX) | (INVAP).

Acknowledgements

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Sponsors

Thank you to the following organizations who have been integral to the planning and delivery of WOSMIP IX.



Acronyms and Abbreviations

WOSMIP: Workshop on Signatures of Man-Made Isotope Production

CCHEN: Chilean Nuclear Energy Commission

ATM: Atmospheric Transport Modeling

CEFEN: Cyclotron and National Environmental Monitoring Stations

RECH-1: Research reactor

STAX: Source team analysis of Xenon

PNNL: Pacific Northwest National Laboratory

CTBT: Comprehensive Nuclear-Test-Ban Treaty

XENAH: Xenon and Environmental Nuclide Analysis at Hartlepool

IMS: International Monitoring Systems

NPP: Nuclear Power Plant

MIP: Medical Isotope Production

SNS: Spallation Neutron Source

MSRs: Molten Salt Reactors

SNF: Spent Nuclear Fuel

CRP: Cooperative Research Program

IAEA: International Atomic Energy Agency

TECDOC: Technical Documents

HEU: Highly Enriched Uranium

LEU: Low Enriched Uranium

CNEA: Argentina National Atomic Energy Commission

EDF: Électricité de France

NDC: National Data Centres

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1.0 Introduction

1.1 Overview

The 9th Workshop on Signatures of Man-Made Isotope Production (WOSMIP IX) was held December 4-7th, 2023 in Santiago Chile, hosted by the Chilean Nuclear Energy Commission (CCHEN) and supported by the Pacific Northwest National Laboratory (PNNL). WOSMIP IX provided a unique forum for technical discussions and collaborations to discuss the impact of radioisotopes released from civil and industrial sources on nuclear explosion monitoring in support of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). It aimed to unite experts from the radioisotope and nuclear explosion monitoring communities for a 4-day friendly scientific meeting with a facility tour provided at CCHEN. Recognizing the immense importance of both radioisotope production and nuclear treaty monitoring, WOSMIP IX sought to bring together both communities to better understand the challenges created by radioisotope effluents released from the peaceful uses of nuclear technology and to propose methods to mitigate these emissions.

Topical areas for WOSMIP IX focused on the measurement and understanding of backgrounds, introduction to a list of potential sources of man-made radionuclides (aka, the “WOS-list”), emissions and sources of radionuclides, stack monitoring of facilities, Mo-99 production, and atmospheric transport modeling (ATM) and events and measurements of interest. These topical areas consisted of presentations, a poster session, and a dedicated roundtable discussion around a new repository for xenon source term data WOS-list. The presentations highlighted the importance of characterizing current and new sources of radioxenon backgrounds to aid the nuclear explosion monitoring verification regime.

1.2 Background

The Workshop on Signatures of Man-Made Isotope Production (WOSMIP) has a significant background in fostering collaboration between communities involved in isotope production and monitoring. It focuses on understanding and minimizing environmental impacts from man-made processes. WOSMIP has evolved to address various challenges and solutions in this field, highlighting its dynamic nature and commitment to environmental sustainability. This initiative underscores the importance of global cooperation in managing and mitigating the effects of isotope production on the environment.

1.3 Location

WOSMIP IX was held at the Intercontinental Hotel in Santiago, Chile. Situated in a prime location, the hotel offers accessibility and a captivating setting for the workshop. Nestled in the heart of Santiago, it provided proximity to the cultural, commercial, and business hubs of the city. Notably, this venue offered convenient access to the facilities of the Chilean Nuclear Energy Commission (CCHEN).



Figure 1: InterContinental Santiago, the conference hotel and venue.

1.4 Chilean Nuclear Energy Commission

CCHEN hosted an afternoon of tours at their facility. The afternoon started with a warm welcome from the Executive Director, Luis Huerta. Conference attendees were broken into small groups touring RECH-1 Research Reactor, Nuclear Physics and Neutron Spectroscopy Center (CEFNE), and Cyclotron. After the tours, organizers held a networking session with poster presentations on the following topics: Cytogenetic Dosimetry (CCHEN), Department of Shared Technological Resources (CCHEN), Radionuclide Dynamics in Agriculture, National Radiological Monitoring Stations (CCHEN), International Monitoring System Stations for Radionuclides (CCHEN/CTBTO), Source Terms Analysis of Xenon - STAX (INVAP).

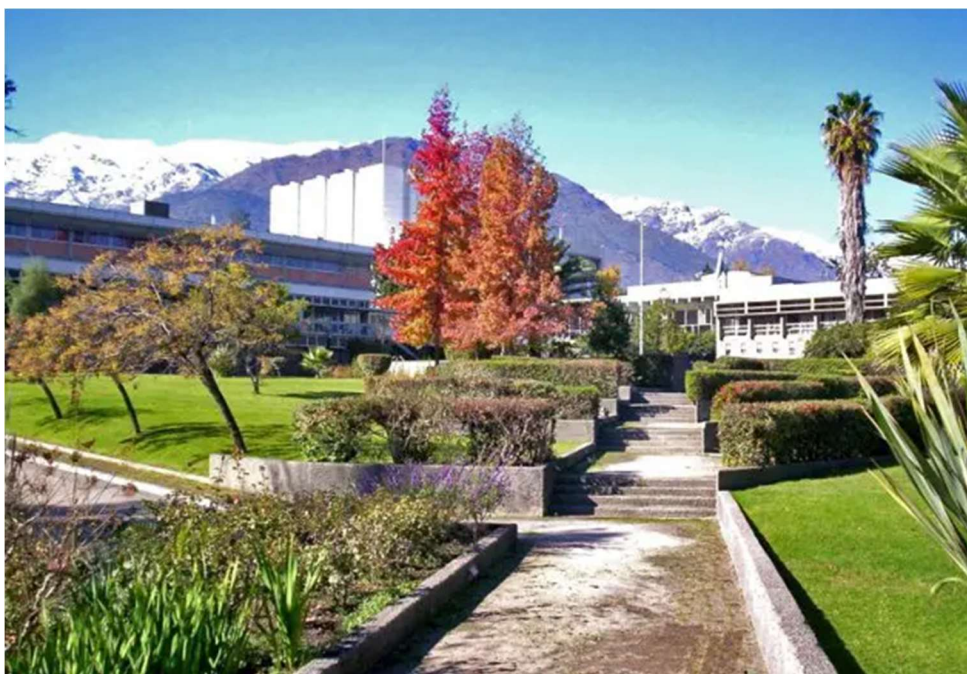


Figure 2: La Reina Nuclear Studies Center, home of the RECH-1 Reactor

1.5 Facility Tour Photographs

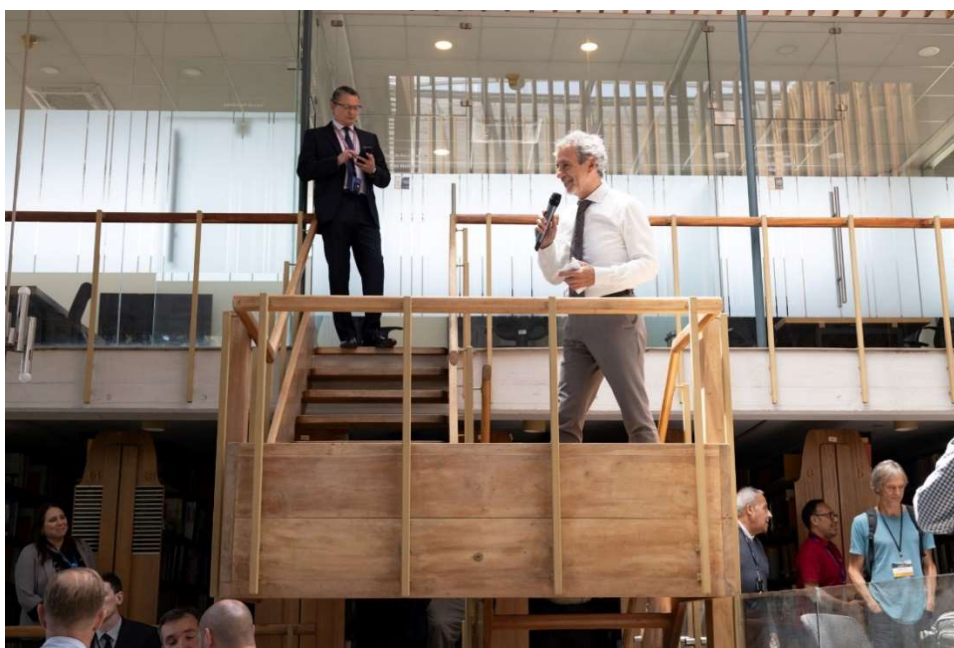


Figure 3: CCHEN Director, Luis Huerta giving a Welcome to the Facility in the library.



Figure 4: View from above the nuclear reactor at CCHEN.



Figure 5: Group outside of CCHEN, in the Patio Esplanade



Figure 6: Tour of the CCHEN nuclear reactor discussing the future medical isotope production irradiations.



Figure 7: Demonstration at the CCHEN neutron spectroscopy laboratory.

2.0 Session 1: Background sources

Martin Kalinowski gave a presentation "The Problems of Backgrounds at the CTBTO Prepcom" delved into the challenges faced by the Comprehensive Nuclear-Test-Ban Treaty Organization in discerning

man-made radioxenon emissions from natural backgrounds. Kalinowski's work highlighted the complexities in differentiating between natural and anthropogenic sources of radioxenon, which is crucial for effective global nuclear monitoring.

Ted W. Bowyer presented "XENAH: Xenon and Environmental Nuclide Analysis at Hartlepool," Bowyer focused on the analysis of environmental xenon and other nuclides in Hartlepool. His research provided key insights into the regional variations of background levels, stressing the importance of regional data for global monitoring efforts.

Sofia Brander presented "Evaluation of the Phase II test of Xenon International on Mount Schauinsland" offered an in-depth analysis of radioxenon background levels at Mount Schauinsland. This study contributed unique insights into the variations of background levels from anthropogenic sources in specific geographical settings, emphasizing the need for tailored monitoring approaches.

Ibrahim Abdulmajeed discussed "Xenon Background Measurements in the Equatorial Region of Africa," Abdulmajeed explored the background levels of radioxenon in Africa's equatorial region. His work highlighted the regional differences in background radiation levels, underscoring the diversity of environmental factors influencing noble gas measurements.

The Background source session, along with the broader discussions, emphasized the criticality of understanding and analyzing regional background levels of xenon and other noble gases for effective global non-proliferation monitoring. This theme intersected with the evolving impact of backgrounds from anthropogenic sources, notably due to the increased demand for medical isotopes and the deployment of new, sensitive radioxenon systems like Xenon International. The integration of these systems into the IMS, the need for timely installations, and the emergence of "Level C" samples underline the necessity for advanced, location-specific detection methods. Additionally, the capability to measure non-traditional radioxenon isotopes and the use of stack monitoring data for source identification were highlighted. These developments point towards a nuanced approach to non-proliferation efforts, requiring a balance between technological advancements and the evolving nature of environmental and anthropogenic factors.

2.1 WOS-list

Charles Doll's presentation, "WOS-list: A Repository for Xenon Source Term Data," introduced the WOS-list as a crucial database for compiling and accessing radioxenon release data from diverse sources. This information is instrumental in Atmospheric Transport Modeling (ATM) calculations, crucial for distinguishing industrial radioxenon backgrounds from detections at International Monitoring System stations. The WOS-list, evolving from prior WOSMIP discussions, encompasses data on medical isotope production, nuclear power reactors, and hospital releases, providing a comprehensive resource for researchers and National Data Centers in nuclear non-proliferation and monitoring.

Following the introduction of the WOS-list and a subsequent roundtable discussion, key outcomes were identified to enhance this crucial nuclear monitoring tool. The current focus of the WOS-list on IMS stations, NPP, and MIP could be expanded to include more diverse sources. Proposed additions include stack altitude, major operational changes, criteria for hospital inclusion based on release levels, differentiation between accidental and standard operations, and the presence of STAX detectors. Additionally, incorporating data on other sources like SNS, expected release ranges (maximum, average, minimum), radioiodine levels, types of nuclear reactors, and planned facilities was discussed. Finalizing

source locations, understanding release frequencies, and normal operating hours of facilities were also emphasized as essential elements to improve the WOS-list's efficacy in global nuclear monitoring and non-proliferation efforts.

2.2 Session Photographs



Figure 8: Opening Welcomes by the Executive Director of the CCHEN (Chilean Nuclear Energy Commission), Luis Huerta



Figure 9: Sofia Brander presenting "Evaluation of the Phase II test of Xenon International on Mount Schauinsland"



Figure 10: Ibrahim Abdulmajeed discussing background levels of xenon in Africa's equatorial region.

2.3 POSTER Session

A poster session was kicked off by each presenter by providing an overview of their poster which moved into a full display held at the InterContinental prior to dinner hosted by CCHEN. Posters were presented on a range of topics including the experiments performed to better understand the transport of radionuclides and the impact of new radioxenon emissions (traditional and non-traditional isotopes) on the IMS, all listed in Appendix.

3.0 Session 2: Emissions and Sources

This session discussed the potential impact of radioxenon sources around the world to backgrounds for nuclear explosion monitoring systems. While Medical Isotope Production Facilities have been a major source in recent years, there are a wide range of current and future sources being evaluated by the community.

Martin Kalinowski and his team's "Review of Xe-135 observations, specifically in Japan, and possible sources that might explain high Xe-135/Xe-133 ratios." examined the elevated levels of the $^{135}\text{Xe}/^{133}\text{Xe}$ activity ratio, which is a crucial indicator in detecting underground nuclear explosions. Kalinowski research focused on understanding the various sources of ^{135}Xe , including nuclear explosions and facilities. They took a comprehensive approach, analyzing observations at various International

Monitoring System (IMS) noble gas systems and background campaigns, comparing these observations with different sources to assess the usefulness of the $^{135}\text{Xe}/^{133}\text{Xe}$ ratio for nuclear explosion monitoring. The team found that there is no unique explanation for all occurrences of elevated $^{135}\text{Xe}/^{133}\text{Xe}$ ratios, and that for most locations, the sources are still unclear. Suggesting the need for further investigation, particularly regarding Light Water Reactor (LWR) start-up and activation sources, possibly including High Enriched Uranium (HEU) reactors.

Clayton Hudson with colleagues explored "Retention of Molten Salt Reactor Off-Gas." Hudson shared how they focused on the challenges and potential strategies for managing off-gas from Molten Salt Reactors (MSRs), an emerging nuclear reactor technology. Their research emphasized the importance of effectively capturing and retaining noble gases byproducts from within the MSRs. The team proposed innovative approaches for noble gas retention, highlighting the necessity for advancements in this area to ensure a minimized impact of MSRs are IMS systems. Their findings are significant for the nuclear industry, particularly in the context of deploying new reactor technologies with minimal environmental impact.

Andrew Petts, on behalf of the XENAH collaboration presented "XENAH: Current Status, Results and Challenges Faced." This research focused on the Xenon Environmental Nuclide Analysis at Hartlepool (XENAH), involving a collaboration of scientists from the UK, US, and Sweden. They conducted measurements at Hartlepool Power Station to better understand radionuclide emissions from a nuclear power reactor and their impact on the International Monitoring System (IMS) used for Comprehensive Nuclear-Test-Ban Treaty (CTBT) monitoring. The presentation addressed the challenges of working in a highly regulated nuclear facility and shared preliminary results of their analysis, including the identification of trace levels of various isotopes and insights into radionuclide activities during fuel handling.

Tatiana Boitsova presented "Impact on IMS of Radioiodine and Radioxenon emission by spontaneous fission of Cm-244 and Pu-240 during Spent Nuclear Fuel (SNF) Reprocessing Plants." Boitsova and collaborators investigated the effects of radioxenon and radioiodine emissions from SNF reprocessing plants on the International Monitoring System (IMS) for nuclear explosion monitoring. The study focused on emissions resulting from the spontaneous fission of Cm-244 and Pu-240 in SNF. It emphasized the relevance of such facilities in nuclear explosion monitoring, despite being previously considered of lesser importance. The team used two methods for estimating radioxenon emissions from these plants and validated their approach by comparing results from both methods.

Lori Metz presented on the "IAEA Cooperative Research Program (CRP)." Metz provided an update on the IAEA's efforts to minimize radioactive gaseous releases in the production of medical radioisotopes. This project began in 2015, focusing on developing protocols for reducing emissions while maintaining good manufacturing practices. The CRP involved multiple research coordination meetings and a consultants' meeting, leading to a draft TECDOC publication with major recommendations. These recommendations aimed to enhance collaboration between isotope producers and nuclear explosion monitoring communities, optimize isotope production processes, share stack data technology for treaty verification, and develop methods for distinguishing emissions from nuclear explosions.

Christophe Gueibe shared research on "Radiation Resistance and Thermal Durability of Silver-Exchanged Zeolites for Trapping Radioxenon." The study concentrated on the effectiveness of silver-exchanged zeolites (AgZs) in trapping radioxenon. They investigated the durability of these zeolites under thermal

regeneration and radiation exposure. The team's findings indicate that AgZs show promising potential for use in radionuclide abatement systems due to their resistance to degradation, thereby contributing to lower global backgrounds for monitoring systems.

Individually these studies emphasized distinct facets, from examining isotopes' emissions in reactor functions and reprocessing plants to exploring new materials for trapping radioactive gases. The collective aim is to improve the detection and management of nuclear activities, ensuring safety and compliance with international treaties. The presentations in this session showed that through better identification, quantification and reduction of these sources, the robustness of the verification regime can be improved.

3.1 Session Photographs





Figure 11: Group Photo at the conference venue.

4.0 Session 3: Stack Monitoring

The Stack Monitoring session demonstrated the capabilities of the STAX project and how the community can collectively leverage the information provided by the STAX team to better understand backgrounds observed at IMS stations.

Judah Frieze updated colleagues with "The STAX Project Progress," which focused on the Source Term Analysis of Xenon project (STAX). This project aims to improve the detection and analysis of xenon in the atmosphere, particularly for nuclear test monitoring. The presentation discussed the progress made in understanding xenon backgrounds and the use of STAX data in removing these backgrounds to better identify signals of nuclear tests. The project's contributions to scientific understanding and future directions were highlighted, emphasizing the importance of continued research and collaboration in the field.

Mattias Auer delivered a presentation titled "Update on the STAX Data Viewing Software." This talk focused on the latest developments and features of the STAX software, a key tool for analyzing and visualizing data related to xenon releases. The presentation covered enhancements to the software's user interface and functionality, aiming to improve the experience and efficiency for users.

Mihaela Rizescu presented "Interacting with STAX – Data Access and Processing." Rizescu focused on the STAX project software capabilities. The demonstration highlighted how users can access and process

data from the STAX systems, which monitors radioxenon isotopes released from medical isotope production facilities. The presentation also outlined various data products generated by STAX, including automatic time series, emissions time series, state of health reports, high-resolution gamma spectra, and alerts. It emphasized the secure transfer and processing of data, ensuring user-friendly access and comprehensive data analysis capabilities.

These presentations collectively underscored the advancements and challenges in radioxenon source detection and analysis. They highlighted the collaborative efforts and technological innovations in collection, processing, and visualization of the data.

4.1 Session Photographs



Figure 12: Judah Friese updating attendees of the progress of the STAX Project.



Figure 13: Mattias Auer giving an update on STAX data viewing software.

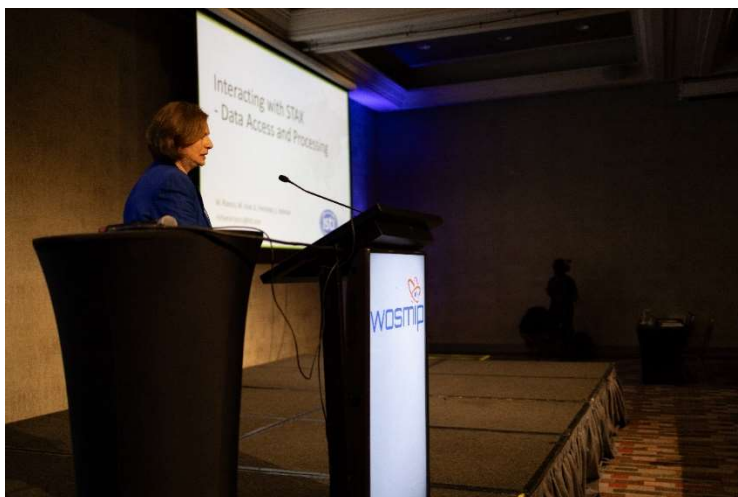


Figure 14: Mihaela Rizescu presenting on STAX data access and processing.

5.0 Session 4 and 5: Production

The sessions on production highlighted the various companies involved in medical isotope production and detailed the progress being made in the production of medical isotopes and reduction of radioxenon releases.

Roy W. Brown's "Curium Briefing on Mo-99 & Xe-133 Production" covered the company's operations in producing Molybdenum-99 (Mo-99) and Xenon-133 (Xe-133), vital isotopes in nuclear medicine. Brown discussed Curium's history, global presence, and the importance of Mo-99 in medical diagnostics. A significant focus was on the efficient and environmentally responsible production processes, particularly highlighting the measures taken to minimize Xe-133 effluent releases. The presentation also touched on the medical applications of Xe-133, underscoring its role in diagnosing pulmonary embolism.

Frédéric Brabant outlined within "Full Conversion of IRE Mo-99 Production Process to LEU: Impact on Radioxenon Emissions." the details concerning the transition of the Institut des Radioéléments from Highly Enriched Uranium (HEU) to Low Enriched Uranium (LEU) in the production of Molybdenum-99 (Mo-99), Iodine-131, and Xenon-133. The conversion, completed in March 2023, had a significant impact on reducing radioxenon emissions, a critical factor in environmental and treaty compliance considerations. The process changes led to a notable decrease in ^{133}Xe emissions, promoting the monitoring benefits of using LEU in isotope production.

Daniel Cestau gave a detailed history and current state of fission radioisotope production in Argentina, focusing on the new production plant project, in "Project of a New Fission Radioisotope Production Plant in Argentina and the Planned Noble Gas Emission Mitigation System." The plant aims to produce Mo-99 and I-131, with significant attention given to noble gas emission mitigation. The team considered several engineered abatement methods, including containment, adsorption, hydrogen oxidation/reduction, and innovative methods developed by CNEA.

John N. Dewes presented "IAEA Activities in Support of Mo-99 Production with LEU." Dewes focused on the IAEA's efforts to minimize the use of Highly Enriched Uranium (HEU) in the production of Molybdenum-99 (Mo-99) and Technetium-99m (Tc-99m). He discussed various initiatives, including the

promotion of Low Enriched Uranium (LEU) technology for isotope production, support for the development of alternative production methods, and collaborative projects aimed at reducing radioactive emissions. The presentation highlighted the IAEA's role in facilitating global transition towards more environmentally sustainable and non-proliferation friendly production methods.

Jakub Ośko provided a presentation on "Environmental Radiation Monitoring on the Territory of the National Centre for Nuclear Research, Poland." Ośko focused on the radiation monitoring activities at the Świerk Nuclear Centre, Poland's main nuclear research facility. The presentation detailed the monitoring strategies, including both online and offline methods, for various environmental samples like air, water, and soil. Highlighted the importance of comprehensive radiation monitoring in ensuring environmental safety around nuclear facilities and meeting regulatory requirements.

Max Postman's "NNSA Support to Mo-99 Production." focused on the NNSA's efforts in promoting the transition from Highly Enriched Uranium (HEU) to Low Enriched Uranium (LEU) in the production of Molybdenum-99 (Mo-99). This initiative has successfully led to all major international Mo-99 producers using LEU targets. Additionally, the presentation highlighted the U.S. government's support for emissions monitoring and control, developments in new Mo-99 production facilities, and technical accomplishments of various national laboratories in the U.S. in relation to Mo-99 production.

These presentations collectively underscore the dynamic nature of the nuclear research and isotope production fields. An emphasis is on the evolution of practices towards environmental sustainability, the adoption of innovative production and abatement techniques in medical isotope production. They also underscored the significant role of governmental efforts, particularly by the NNSA, in facilitating the transition to more sustainable production processes and advancing the global standards in nuclear safety and non-proliferation.

5.1 WOSTER Award

The poster titled "Estimation of Radioxenon Release Trajectory Plots Based on the Recent Development of the Molten Salt Reactor" was voted best poster and Sri Sundari Retnoasih of the National Research and Innovation Agency (BRIN) of the Republic of Indonesia was acknowledged and presented the WOSTER award.



Figure 15: Sri Sundari Retnoasih with her WOSTER award

6.0 Session 6: Atmospheric Transport Modeling (ATM) & Events

This session discussed different atmospheric transport models and methods of utilizing the data for event analysis. While the new radioxenon monitoring systems are becoming more sensitive and the understanding of backgrounds is improving, the atmospheric transport modeling is important to be able to link observations with background releases.

Yuichi Kijima investigated "Using a Monte Carlo Approach to Determine the Radioxenon Probability Density Function at an IMS Station for Background Estimation." Kijima focused on a novel method to estimate the background levels of radioxenon at International Monitoring System (IMS) stations. The team used a Monte Carlo approach to model the probability density functions of radioxenon concentrations, considering emissions from known nuclear facilities. This method aims to improve the accuracy of background estimation, which is critical for the effective monitoring of nuclear explosions.

Donald D. Lucas focused on "Top-down Estimates of Daily Global Emissions of Anthropogenic Radioxenon during 2013-2022." Lucas introduced a new method for estimating global radioxenon emissions using top-down analysis, combining atmospheric transport simulations with inverse methods. This approach, contrasting with traditional bottom-up methods, utilized machine learning to infer daily Xe-133 emissions and provided insights into the global trend of these emissions over a decade. The findings revealed a downward trend in global Xe-133 emissions despite increasing demand for radioisotopes.

Robin Schoemaker presented "A Software Tool for Exploring Scientific Methods to Estimate the Radioxenon Background with More Confidence." Schoemaker outlined a software tool designed to improve the estimation of the radioxenon background in the atmosphere. The tool utilizes advanced scientific methods, including Monte Carlo simulations, to enhance the confidence in background estimations, crucial for accurate nuclear test monitoring. The team's work is part of ongoing efforts to optimize the detection capabilities of the International Monitoring System.

Klas Elmgren's "The Swedish Noble Gas Array – Experience and Future" dove into the SAUNA QB system, a network of radioxenon detection systems installed across Sweden, along with his team. This highlighted the effectiveness of this array in identifying radioxenon sources and the use of machine learning to analyze data. The array's ability to detect multiple plumes of xenon per week in Sweden was emphasized, showcasing its potential in monitoring atmospheric radioxenon levels.

Boxue Liu presented "Updating Screening Thresholds." On behalf of his team, Liu focused on sharing improving the screening of nuclear explosion events by updating algorithms for estimating isotopic activity ratios and associated thresholds. The team suggested using a second-order polynomial model for estimation and setting thresholds based on nuclear explosion scenarios. They emphasized the importance of accurate event screening in the context of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) and the need for further research in this area.

Alex Jonko studied and outlined in "Investigation of the Joint Influences of Background RN Sources and Topography on Plume Characteristics at Monitoring Sites using the Weather Research." Jonko explored how background radioactive noble gas sources and local topography influence plume characteristics at monitoring sites. Using WRF-Chem simulations, the team analyzed how these factors affect the detection and interpretation of radioxenon emissions. This research is significant for improving the accuracy of monitoring and interpreting data from nuclear test detection systems.

These presentations highlight significant advancements in nuclear monitoring capabilities. They collectively emphasize the importance of uncertainty reduction in the atmospheric transport modeling. The use of Monte Carlo methods, global emission analysis, software tools for estimating radioxenon background, and the study of topography and background sources on plume characteristics, together provides a comprehensive insight into the ability to model the propagation of radioxenon signals.

6.1 WOZZIE Award

The WOZZIE award went to Dr. Andrew Petts of EDF Energy of the United Kingdom for his pioneering work to understand emissions from nuclear reactors. Andrew has helped to highlight the potential range of radioxenon isotopic ratios from nuclear reactors and the dependence on reactor design and operation.



Figure 16: Andrew Petts with WOZZIE award, along with conference organizers.

6.2 Session Photographs



7.0 Conclusion

Two awards were given at WOSMIP-IX (WOSTER/WOZZIE), the WOSTER for best poster and the WOZZIE for overall contribution to the community. The WOSTER was awarded to Sri Sundari Retnoasih of the National Research and Innovation Agency (BRIN) of the Republic of Indonesia for “Estimation of Radioxenon Release Trajectory Plots Based on the Recent Development of the Molten Salt Reactor.” The WOZZIE award went to Dr. Andrew Petts of EDF Energy of the United Kingdom was awarded the “WOZZIE” for his pioneering work to understand emissions from nuclear reactors.

The partnership between CCHEN and PNNL is a major accomplishment in the field of nuclear explosion monitoring and showcases the dedication of both organizations to advancing this critical effort. The STAX project and WOSMIP represent significant steps towards a safer and more secure world.

Experts at WOSMIP had a few recommendations for further work in this area including:

- 1) The monitoring community agreed that the efforts to create and maintain a list of potential sources of airborne radioactivity continues to be an important task for WOSMIP. Current fields and additional fields were discussed, including emission location, emission type, expected hits and many more.
- 2) Participants were extremely excited about the use of STAX data and agreed that continued use within the analysis and leveraging by NDCs will help to better understand how the data can be leveraged by the community.
- 3) Participants were very grateful for the efforts by the medical isotope producers to reduce emissions and provide stack monitoring data. It was agreed that continued collaboration will be important to the success of the background minimization efforts for the monitoring community.
- 4) Participants highlighted the importance potential sources of “non-traditional” radioxenon isotopes throughout the workshop. The usual sources of radioactivity include new types of nuclear reactors and medical isotope production facilities, hospitals, and spallation neutron sources. These other sources should continue to be studied and should also be added to future iterations of the WOS-list.

Appendix A - Workshop Program

Monday, December 04, 2023 | Day 1

TIME	SESSION TITLE SPEAKERS
10:00 a.m. – 12:00 p.m.	Conference Registration InterContinental Santiago Las Americas Foyer Level 1
1:00 p.m. – 5:00 p.m.	Facility Tour CCHEN La Reina Facility
1:00 p.m.	Gather in InterContinental Hotel lobby to depart
1:30 p.m.	Load Buses to depart for CCHEN La Reina Facility
2:00 p.m.	Arrive and processing at CCHEN
2:20 p.m. – 2:30 p.m.	Welcome by the Executive Director of CCHEN, Luis Huerta CCHEN Library
2:35 p.m. – 2:45 p.m.	Group Photo Events Patio Esplanade
2:45 p.m. – 3:00 p.m.	Designation of groups to access the facilities
3:00 p.m. – 4:30 p.m.	Facility Visits: <ul style="list-style-type: none"> ▪ RECH-1 Research Reactor ▪ Nuclear Physics and Neutron Spectroscopy Center (CEFNE) ▪ Cyclotron Once each group finishes the tour, they will join the networking session in the Library.
3:00 p.m. – 4:45 p.m.	Workshop Networking Coffee Break Digital Poster Session CCHEN Library <ul style="list-style-type: none"> ▪ Cytogenetic Dosimetry CCHEN ▪ Department of Shared Technological Resources CCHEN ▪ Radionuclide Dynamics in Agriculture CCHEN ▪ National Radiological Monitoring Stations CCHEN ▪ International Monitoring System Stations for Radionuclides CCHEN/OTPC ▪ Source Term Analysis of Xenon (STAX) INVAP
4:45 p.m. – 5:00 p.m.	Conclusion of event and bus departure to InterContinental Hotel
7:00 – 9:00 p.m.	Workshop Networking Happy Hour Pullman Santiago El Bosque Hosted by ISTI

Tuesday, December 05, 2023 | Day 2

TIME	SESSION TITLE SPEAKERS
8:30 a.m.	Conference Registration InterContinental Santiago Norte América Ballroom
9:00 a.m. – 11:00 a.m.	Welcome and Workshop Overview Session Chair: Ted Bowyer (PNNL)
9:00 a.m.	Welcome to WOSMIP IX Opening Remarks
9:30 a.m.	WOSMIP IX Overview Ted Bowyer PNNL
9:45 a.m.	Evolution of WOSMIP: A Journey Through Time Paul Saey TU Wien
10:00 a.m.	The International Monitoring System Radionuclide Network Richard Britton CTBTO
10:30 a.m.	<i>Workshop Networking Coffee Break / Group Photo</i>
11:00 a.m. – 3:00 p.m.	SESSION I: Backgrounds Session Chair: Lori Metz (PNNL)
11:00 a.m.	The Problems of Backgrounds at the CTBTO Prepcom Martin Kalinowski CTBTO Virtual
11:30 a.m.	XENAH: Xenon and Environmental Nuclide Analysis at Hartlepool Matthew Goodwin AWE <i>Presented by Ted Bowyer, PNNL</i>
12:00 p.m.	Evaluation of the Phase II test of Xenon International on Mount Schauinsland – Identifying detections of interest Sofia Brander BfS
12:25 p.m.	Xenon Background Measurements and Analysis in Nigeria in the Equatorial Region of Africa Abdulmajeed Ibrahim Nigerian Nuclear Regulatory Authority
12:50 p.m.	<i>Working Lunch</i>
2:00 p.m. – 3:00 p.m.	WOS-list Session Chair: Ian Cameron (PNNL)
2:00 p.m.	WOS-list: A repository for xenon source term data Charlie Doll PNNL
2:15 p.m.	Roundtable WOS-list Facilitator: Ian Cameron PNNL
3:00 p.m. – 3:30 p.m.	<i>Workshop Networking Coffee Break</i>

TIME	SESSION TITLE SPEAKERS
3:30 p.m. – 4:15 p.m.	POSTER SESSION Session Chair: Tami Weber (PNNL)
3:30 p.m. – 3:35 p.m.	Poster Session Introduction Stanislav Kočvara VF Nuclear
3:35 p.m. – 4:15 p.m.	<p>Poster Session Flash Talks</p> <p>Posters:</p> <ol style="list-style-type: none"> 1. <i>Andrés Cárdenas Ceballos: Title TBD</i> 2. <i>Eduardo Carlos Carranza, Eduardo Nassif, Mauro Nuñez, Román Pino, Andrés Zapata, and Ricardo Sagarzazu: The EZEIZA MIPF STAX</i> 3. <i>Benoît Deconninck: Mo-99 production using a high-power accelerator - The story of a challenging project</i> 4. <i>Charlie Doll: STAX-2 investigation into the impact of nuclear power plants on nuclear explosion monitoring</i> 5. <i>Michael Foxe: Utilizing the Man-Made Isotope Transport and IMS Data to Evaluate Climate Change Indicators</i> 6. <i>Lee Glascoe: Improving Sensor Siting for Plume Detectability with Multiscale Atmospheric Transport Modeling</i> 7. <i>Anas Hamdouchi: STAX system at IRE</i> 8. <i>Claus Johannsen: Recovery and performance of the Noble Gas system at CLX19, Easter Island, during and after the COVID-19 pandemic lock-down</i> 9. <i>Martin Kalinowski: Exploring the use of radioxenon to radioiodine isotopic ratios as additional screening method regarding possible CTBT-relevant events</i> 10. <i>Joshua Kunkle: Evaluation of methodologies for forming a global view of radionuclide release events and their application to the data fusion pipeline at the CTBTO</i> 11. <i>Jolanta Kusmierczyk-Michulec: The interhemispheric transport of anthropogenic emissions: additional challenge for source localization</i> 12. <i>Boxue Liu: Impacts on Characterization of CTBT-relevant Nuclear Events using Isotopic Activity Ratios caused by the Radioxenon Background at IMS Stations</i> 13. <i>Ahmad Malkawi: Radioisotope Production in Jordan Research reactor update</i> 14. <i>Christian Maurer: Final results of the 1st Nuclear Explosion Signal Screening Open Inter-Comparison Exercise 2021</i> 15. <i>Sri Sundari Retnoasih: Estimation of Radioxenon Release Trajectory Plots Based on The Recent Development of the Molten Salt Reactor</i> 16. <i>Antoinetta Rizzo: Title TBD</i> 17. <i>Troy Robinson: An Analysis of Potential Sources of Non-fission Product Xenon Radionuclides</i> 18. <i>Cari Seifert: Lessons learned from an atmospheric radiotracer experiment</i> 19. <i>Ana Valdés Durán: Potential studies of radioactive elements in soils and sediments, Chile</i> 20. <i>Jim Zickenfoose: Predictive Maintenance of HPGe-based Systems with Lab-Pulse Services</i>

TIME	SESSION TITLE SPEAKERS
5:15 p.m. – 9:30 p.m.	EVENING EVENTS
<i>5:15 p.m.</i>	Gather in InterContinental Hotel lobby to depart
<i>5:30 p.m.</i>	Load Buses to depart for Club de Campo de Oficiales Quinchamali Fach
<i>6:00 p.m. – 7:30 p.m.</i>	WOSMIP Poster Session Happy Hour Club de Campo de Oficiales Quinchamali Fach Hosted by VF Nuclear
<i>7:30 p.m. – 9:30 p.m.</i>	Offsite Dinner Club de Campo de Oficiales Quinchamali Fach Hosted by CCHEN

Wednesday, December 06, 2023 | Day 3

TIME	SESSION TITLE SPEAKERS
9:00 a.m. – 1:50 p.m.	SESSION II: Emissions & Sources Session Chair: Paul Saey (TU Wien)
9:00 a.m.	Review of Xe-135 observations, specifically in Japan, and possible sources that might explain high Xe-135/Xe-133 ratios Martin Kalinowski CTBTO Virtual
9:25 a.m.	Retention of molten salt reactor off-gas Clayton Hudson University of Texas, Austin Virtual
9:50 a.m.	<i>Workshop Networking Coffee Break</i>
10:35 a.m.	XENAH: Current status, results and challenges faced Andrew Petts EDF Energy
11:00 a.m.	Possible impact on IMS observations of radioiodine and radioxenon emission produced by spontaneous fission of Cm-244 and Pu-240 and released during spent nuclear fuel (SNF) reprocessing plants Tatiana Boitsova CTBTO
11:25 a.m.	IAEA Cooperative Research Program (CRP) Lori Metz PNNL
11:50 a.m.	Radiation resistance and thermal durability of silver-exchanged zeolites for trapping radioxenon Christophe Gueibe SK CEN
12:10 p.m.	<i>Working Lunch</i>
1:50 p.m. – 4:00 p.m.	SESSION III: Stack Monitoring Session Chair: Christopher Celis (CCHEN)
1:50 p.m.	STAX Judah Friese PNNL
2:15 p.m.	Update on the STAX data viewing software Mattias Auer ISTI
2:40 p.m.	Interacting with STAX – Data access and processing Mihaela Rizescu ISTI
3:05 p.m.	<i>Workshop Networking Coffee Break</i>
3:35 p.m.	Stack Monitoring Q&A Ted Bowyer PNNL
4:00 p.m. – 4:25 p.m.	SESSION IV: Production Session Chair: Judah Friese (PNNL)
4:00 p.m.	NNSA Support to Mo-99 Production Max Postman NA-23 Virtual
4:25 p.m.	Woster Award Session Chair: Ted Bowyer (PNNL)
4:40 p.m.	Session Concludes
7:00 p.m.	Offsite Dinner Divertimento Chileno Hosted by CTBTO

Thursday, December 07, 2023 | Day 4

TIME	TITLE SPEAKER ORGANIZATION
9:00 a.m. – 11:30 a.m.	SESSION V: Production, <i>cont.</i> Session Chair: Judah Friese (PNNL)
9:00 a.m.	Curium Briefing on Mo-99 & Xe-133 Production Roy Brown Curium
9:25 a.m.	Full conversion of IRE Mo-99 production process to LEU : Impact on radio-xenon emissions Frédéric Brabant IRE
9:50 a.m.	Project of a new Fission Radioisotope Production Plant in Argentina and the planned noble gas emission mitigation system Daniel Cestau CNEA
10:15 a.m.	IAEA Activities in support of Mo-99 Production with LEU John Dewes IAEA
10:35 a.m.	<i>Workshop Networking Coffee Break</i>
11:05 a.m.	Environmental radiation monitoring on the territory and vicinity of the National Centre for Nuclear Research, Poland Grzegorz Krzysztozek & Jakub Ośko NCBJ
11:30 a.m. – 3:30 p.m.	SESSION VI: ATM & Events Session Chair: Christian Maurer (GeoSphere Austria)
11:30 a.m.	Using a Monte Carlo Approach to Determine the Radioxenon Probability Density Function at an IMS Station for Background Estimation Yuichi Kijima CTBTO Virtual
11:50 a.m.	Investigation of the joint influences of background RN sources and topography on plume characteristics at monitoring sites using the Weather Research and Forecasting model with inline chemistry (WRF-Chem) Alex Jonko LLNL
12:15 p.m.	Top-down estimates of daily global emissions of anthropogenic radioxenon during 2013-2022 Don Lucas LLNL
12:35 p.m.	<i>Working Lunch</i>
1:45 p.m.	A Software Tool for Exploring Scientific Methods to Estimate the Radioxenon Background with more Confidence Robin Schoemaker CTBTO
2:10 p.m.	The Swedish Noble Gas Array – experience and future Elmgren FOI
2:35 p.m.	Updating Algorithms of Isotopic Activity Ratios and the associated Thresholds for screening CTBT-relevant Nuclear Events Boxue Liu CTBTO
3:00 p.m.	<i>Workshop Networking Coffee Break</i>
3:30 p.m. – 4:15 p.m.	CONCLUSION & SUMMARY Session Chair: Michael Foxe (PNNL)
3:30 p.m.	WOSMIP IX Summary Michael Foxe PNNL
4:00 p.m.	The Wozzie Ted Bowyer PNNL
4:15 p.m.	Conference Concludes

Appendix B – Conference Posters

1	Christian Maurer	1 st Nuclear Explosion Signal Screening Open Inter-Comparison Exercise 2021
2	Troy Robinson	An Analysis of Potential Sources of Non-fission Product Xenon Radionuclides
3	Sri Sundari Retnoasih	Estimation of Radioxenon Release Trajectory Plots Based on The Recent Development of the Molten Salt Reactor
4	Joshua Kunkle	Evaluation of Methodologies for Forming a Global View of Radionuclide Release Events and their Application to the Data Fusion Pipeline at the CTBTO
5	Martin Kalinowski	Exploring the use of Radioxenon to Radioiodine Isotopic Ratios as Additional Screening Method Regarding Possible CTBT-Relevant Events
6	Jim Zickenfoose	HPGe CP5 Predictive Maintenance
7	Boxue Liu	Impacts on Characterization of CTBT-relevant Nuclear Events using Isotopic Activity Ratios caused by the Radioxenon Background at IMS Stations
8	Lee Glascoe	Improving Sensor Siting for Plume Detectability with Multiscale Atmospheric Transport Modeling
9	Cari Seifert	Lessons Learned from an Atmospheric Radiotracer Experiment
10	Jim Zickenfoose	Mirion Spectroscopic Stack Monitor – System Overview, Data, and Analysis
11	Benoît Deconninck	Mo-99 Production Using a High-Power Accelerator – The Story of a Challenging Project
12	Ana Valdés Durán	Potential studies of radioactive elements in soils and sediments, Chile
13	Claus Johannsen	Recovery and Performance of the Noble Gas System at CLX19, Easter Island, during and after the COVID-19 Pandemic Lock-Down
14	Anas Hamdouchi	STAX System at IRE
15	Charlie Doll	STAX-2 Investigation into the Impact of Nuclear Power Plants on Nuclear Explosion Monitoring
16	Eduardo Luis Nassif	The Ezeiza MIPF STAX
17	Jolanta Kusmierczyk-Michulec	The Interhemispheric Transport of Anthropogenic Emissions Additional Challenge for Source Localization

Appendix C – Workshop Participants

Last Name	First Name	Organization
Chester	Daniel	Atomic Weapons Establishment (AWE)
Goodwin	Matthew	Atomic Weapons Establishment (AWE)
Orr	Blake	Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)
Hoffmann	Emmy	Australia's Nuclear Science and Technology Organisation (ANSTO)
Guelbe	Christophe	Belgian Nuclear Research Centre (SCK CEN)
Hiromoto	Goro	Brazilian Nuclear Energy Commission
Retnoasih	Sri Sundari	BRIN of Indonesia
Cestau	Daniel	Central Nuclear en Atucha (CNEA)
Bonfim	Carlos Eduardo	Chemical, Biological, Radiological and Nuclear Defense Institute
Zamora	Marcelo	Comisión Chilena de Energía Nuclear (CCHEN)
Crispieri	Renzo	Comisión Chilena de Energía Nuclear (CCHEN)
Valdés Durán	Ana	Comisión Chilena de Energía Nuclear (CCHEN)
Romero-Barrientos	Jaime	Comisión Chilena de Energía Nuclear (CCHEN)
Ly	Doris	Comisión Chilena de Energía Nuclear (CCHEN)
Villegas	Daniel	Comisión Chilena de Energía Nuclear (CCHEN)
Medina	Luis	Comisión Chilena de Energía Nuclear (CCHEN)
Yáñez	María	Comisión Chilena de Energía Nuclear (CCHEN)
Sylvester	Gustavo	Comisión Chilena de Energía Nuclear (CCHEN)
Morales Herrera	María Jesús	Comisión Chilena de Energía Nuclear (CCHEN)
Blanc	Poulette	Comisión Chilena de Energía Nuclear (CCHEN)
Vila	Francisca	Comisión Chilena de Energía Nuclear (CCHEN)
Henriquez	Patricio	Comisión Chilena de Energía Nuclear (CCHEN)
Valdés	Ana	Comisión Chilena de Energía Nuclear (CCHEN)
Molina	Francisco	Comisión Chilena de Energía Nuclear (CCHEN)
Manriquez	Luis	Comisión Chilena de Energía Nuclear (CCHEN)
Casanueva	Rommy	Comisión Chilena de Energía Nuclear (CCHEN)
Nagel	Barbara	Comisión Chilena de Energía Nuclear (CCHEN)
Rios	Mirtha	Comisión Chilena de Energía Nuclear (CCHEN)
Rojas	Valeria	Comisión Chilena de Energía Nuclear (CCHEN)
Celis	Christopher	Comisión Chilena de Energía Nuclear (CCHEN)
García	Paola	Comisión Chilena de Energía Nuclear (CCHEN)
Brown	Roy	Curium Pharma
Ewasjuk	Keith	Defense Threat Reduction Agency (DTRA)
Bloch	Lindsay	Department of Defense (DOD)
Petts	Andrew	EDF Energy
Telloli	Chiara	Energia Nucleare ed Energie Alternative (ENEA)
Telloli	Chiara	Energia Nucleare ed Energie Alternative (ENEA)
Nava	Elisabetta	Energia Nucleare ed Energie Alternative (ENEA)
Rizzo	Antoinetta	Energia Nucleare ed Energie Alternative (ENEA)
Brander	Sofia	Federal Office for Radiation Protection / Bundesamt für Strahlenschutz (BFS)
Bernadib	Yudiutomo Imardjoko	Gadjah Mada University
Maurer	Christian	GeoSphere Austria (former ZAMG)
Robinson	Troy	Idaho National Laboratory (INL)
Hamdouchi	Anas	Institute for Radioelements (IRE)
Deconninck	Benoît	Institute for Radioelements (IRE)
Brabant	Frédéric	Institute for Radioelements (IRE)
Auer	Matthias	Instrumental Software Technologies, Inc.
Rizescu	Mihaela	Instrumental Software Technologies, Inc. (ISTI)
Cooke	Andrew	Instrumental Software Technologies, Inc. (ISTI)
Hellman	Sid	Instrumental Software Technologies, Inc. (ISTI)
Dewes	John	International Atomic Energy Agency (IAEA)
Peñaloza	Samuel	INTERNATIONAL NUCLEAR INDUSTRY
Cárdenas Ceballos	Andrés	International Nuclear Industry
Maneiro	María Cecilia	INVAP S.E.
D'Anna	Emiliano	INVAP S.E.
Sagarzazu	Ricardo	INVAP S.E.
Núñez	Mauro Andres	INVAP S.E.
Nassif	Eduardo Luis	INVAP S.E.
Piola	Lucas	INVAP SE
Furuno	Akiko	Japan Atomic Energy Agency
Malkawi	Ahmad	Jordan Atomic Energy Commission(JAEC)
Lucas	Donald	Lawrence Livermore National Laboratory (LLNL)
Waters	Amy	Lawrence Livermore National Laboratory (LLNL)
Glascoe	Lee	Lawrence Livermore National Laboratory (LLNL)
Jonko	Alex	Los Alamos National Laboratory (LANL)
Zickefoose	Jim	Mirion Technologies (Canberra) Inc
Stankevicius	Natalia	National Atomic Energy Commission
Ośko	Jakub	National Centre for Nuclear Research
Krzysztof	Grzegorz	National Centre for Nuclear Research

Evans	Timothy	National Nuclear Security Administration (NNSA)
Kros	Charles	Necsa
Mohammed	Hadiza	Nigerian Nuclear Regulatory Authority
Ibrahim	Abdulmajeed	Nigerian Nuclear Regulatory Authority
Stephens	Daniel	Pacific Northwest National Laboratory (PNNL)
Doll	Charlie	Pacific Northwest National Laboratory (PNNL)
Nelson	Dennis	Pacific Northwest National Laboratory (PNNL)
Metz	Lori	Pacific Northwest National Laboratory (PNNL)
Bowyer	Theodore	Pacific Northwest National Laboratory (PNNL)
Friese	Judah	Pacific Northwest National Laboratory (PNNL)
Weber	Tami	Pacific Northwest National Laboratory (PNNL)
Seifert	Carolyn	Pacific Northwest National Laboratory (PNNL)
Foxe	Michael	Pacific Northwest National Laboratory (PNNL)
Cameron	Ian	Pacific Northwest National Laboratory (PNNL)
Dufault	Gaby	Pacific Northwest National Laboratory (PNNL)
Garcia	Hidalia	Pacific Northwest National Laboratory (PNNL)
Thorén	Viktor	Scienta Ervinet
Breitkreutz	Harald	
Persson	Tobias	Scienta Ervinet
Elmgren	Klas	Swedish Defence Research Agency (FOI)
Aldener	Mattias	Swedish Defence Research Agency (FOI)
Bare	Jonathan	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Salgueiro Pires Wint Carla Maria		The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Kunkle	Joshua	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Schoemaker	Robin	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Shashkin	Aleksandr	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Beziat	Guillaume	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Liu	Boxue	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Tipka	Anne	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Kalinowski	Martin	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Johannsen	Claus	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Britton	Richard	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Riedmann	Robin	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Kijima	Yuichi	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Boltsova	Tatiana	The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
Hudson	Clayton	The University of Texas at Austin
Garrido	Daniela	Universidad de Chile
Salgado	Javiera	Universidad de Chile
Aránguiz	Fernanda	Universidad de Concepción
Truax	Kelly	University of Hawaii at Manoa, SOEST, Department of Earth Sciences - PNNL as of Nov. 6th
O'Donnell	Gregory	US Air Force
Roberts	John	US National Data Center
Kocvara	Stanislav	VF, a.s.
Saey	Paul	Vienna University of Technology
Carranza	Eduardo Carlos	