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Pacific Northwest NATIONAL LABORATORY

Xenon International Overview

June 2018

James C. Hayes
Matthew W Cooper
Warren Harper
Mark Panisko

U.S. DEPARTMENT OF ENERGY

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Richland, Washington 99352

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1.0 Xenon International Overview

The Xenon International system is a fully automated unattended system designed to collect, separate, purify, quantify, and perform nuclear counting on radioxenon isotopes as well as transmit data using two-way communications (Figure **1**). Xenon International is designed to stringent requirements that make it a high performance next-generation-system for use in nuclear explosion monitoring networks such as the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty (CTBT).

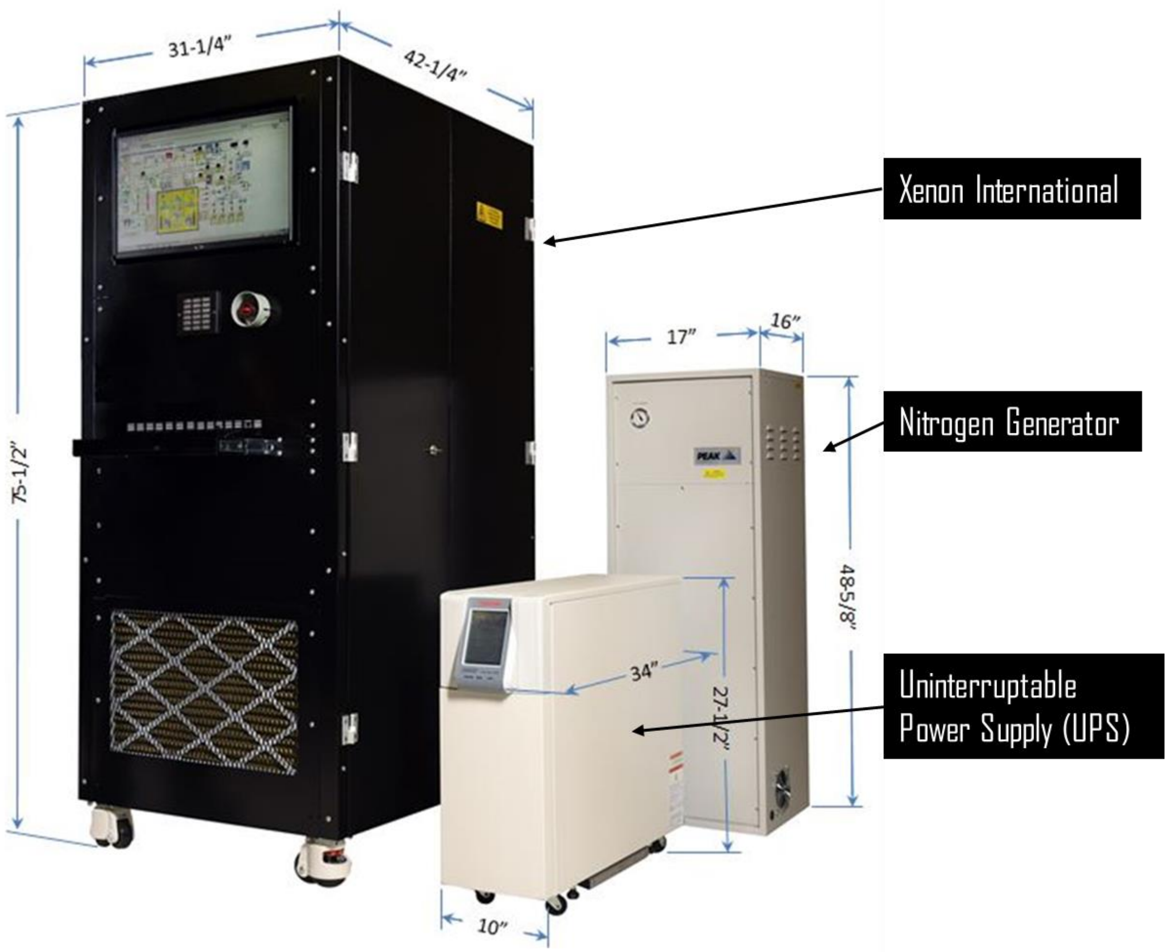

Figure 1. Xenon International shown with uninterruptable power supply and nitrogen generator.

1.1 Design Parameters

Cycle Time: 6 hour collection, 4 samples per day, continuous sampling 24/7, 100% duty cycle

Count Time: 12 hour count, 4 nuclear detectors

Minimum Detectable Concentrations (MDC):

^{133}Xe: 0.15 mBq/m^{3}

^{135}Xe: 0.5 mBq/m^{3}

^{131m}Xe: 0.15 mBq/m^3

^{133m}Xe: 0.15 mBq/m^3

Power: 208 VAC (160-275 volt), 50/60 Hz, 30 amp circuit, 4kW (3.5 kW for Xenon International without nitrogen generator)

Backup Power: Uninterruptable Power Supply

Weight/Size: 1225 Kg. (2700 lbs.), 79 cm X 112 cm X 192 cm (31.2 inch X 44.2 inch X 75.75 inch)

Air Flow: 100 L/min (stp; 0°C, 760 torr)

Carrier gas: Nitrogen generator

Processing Efficiency: 85%, 2.5 cc Xe collected (stp; 0°C, 760 torr) and counted, per 6 hour collection cycle

Room size: 2m X 3.3m X 2.1m, (6.7' X 10.8' X 7')

Communications: IMS global communications infrastructure

Data Reporting: Every 1 – 24 hours (selectable)

1.2 Process Description

The Xenon International is designed for 100% duty cycle, which means it processes whole air without interruption for 24 hours per day to collect and measure for radioxenon from the air on a 6 hour collection cycle (Figure **2**). The Xenon International system consists of different physical subsystems built into a single compact fully integrated instrument. The Xenon International contains one compressor and one set of air dryers that operate continuously to generate a dry air flow of 100 SLPM. There are two independent collection traps (Collection Trap A and Collection Trap B) that switch between collection and elution/regeneration (Regen) every 6 hours, and there is one separation trap and one purification trap that operates during the elution/regeneration cycle of the collection trap. The system contains four nuclear detectors and one stable xenon quantification sensor. The integrated components run a process where xenon gas is collected on Collection Trap A is sent to detector 1, then the traps are cycled and xenon is collected on Collection Trap B which is sent to detector 2. The process of cycling traps is then continued where the next collection of xenon is back on Collection Trap A and is sent to detector 3. The final process in the 24 hour cycle has xenon collected on Trap B and sent to detector 4. An 11 hour gas background is collected on every detector prior to xenon being sent to the detector. Fig 1 shows the high-level processing sequence for the Xenon International system.

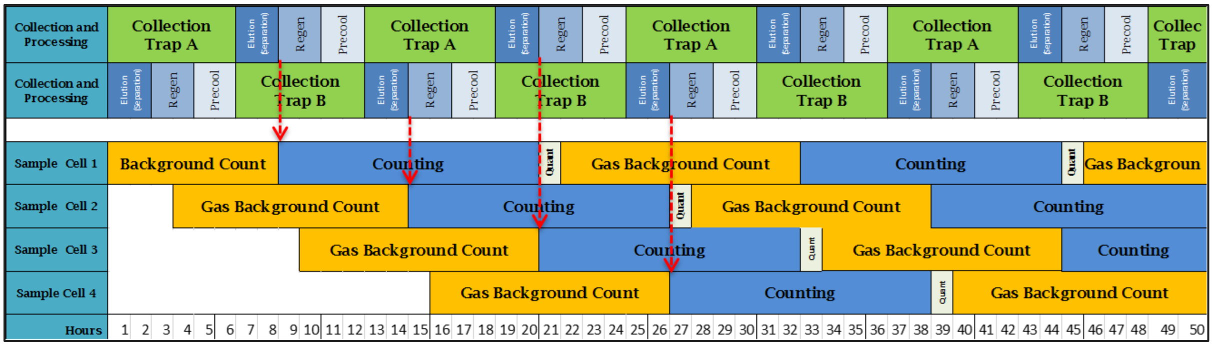

Figure 2. Xenon International processing sequence and timeline of samples through 4 separate nuclear detectors.

1.3 Flow Schematic

The Xenon International system uses graphical user interfaces (GUI) to monitor the system operation and to access system functions. The GUI shown in Figure **3** highlights the subsystems displayed relative to the functions of the full system.

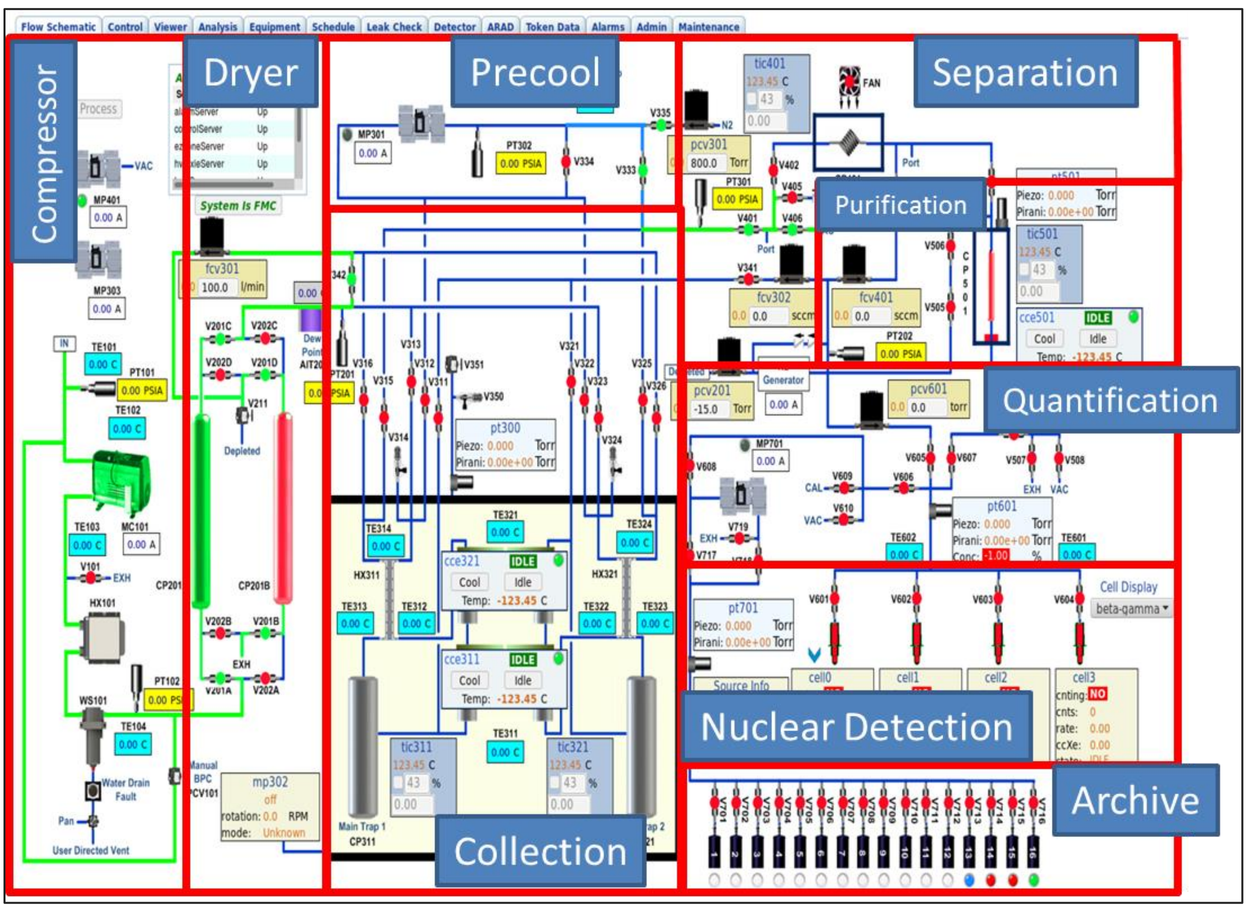

Figure 3. Xenon International flow sheet showing the processing and measurement functions of the system.

The Xenon International subsystems shown in Figure **3** include the following:

1.4 Compressor (Air Intake)

The Xenon International system intakes air through a high volume compressor at 100 SLPM, through a heat exchanger to remove the heat of compression, and then through a phase separator to remove condensable water. The air then passes into the dryer subsystem but also can pass through a bypass line that recirculates excess air (over the 100 SLPM) back into the input of the compressor so there is no loss of sample.

1.5 Dryer

The air dryer consists of a set of two pressure swing adsorption (PSA) columns containing aluminum oxide to remove remaining water vapor and carbon dioxide. During the pressure swing cycle, one column is under high pressure where water and carbon dioxide are adsorbed onto the aluminum oxide and are removed from the air stream. When one column is at high pressure, the other column is at low pressure to regenerate the column using a stream of dry air from the exit of the collection traps. During regeneration, water and carbon dioxide are removed from the low-pressure column and passed to waste. The columns switch every 20 minutes from high-pressure collection to low-pressure regeneration. The air from the high-pressure column is passed into the xenon collection traps.

1.6 Collection and Pre-cool Recirculation Loop

The collection subsystem contains two activated charcoal collection traps that are used for the first xenon enrichment step. The collection traps are cooled using two Stirling mechanical coolers. While one column is cold and collects xenon from the air for six hours, the second column is heated to release the collected xenon (elution) to a separation column.

During collection of xenon on the collection trap, the majority of nitrogen, oxygen, argon, and other minor gases pass through the trap to waste. A small amount of radon, water, and carbon dioxide are collected with the xenon during the 6 hour collection. While one trap is collecting xenon, the second trap is heated to elute xenon from the trap until all of the xenon is off of the trap and passed to a separation column. After elution, the collection trap continues to be heated for regeneration of the trap. During regeneration, any water, carbon dioxide, and radon that collected on the trap are removed to waste. After elution and regeneration, the trap is cooled to near collection temperature through a precool process. The precool process passes high-purity nitrogen gas through the mechanical coolers, cooling the nitrogen gas that passes through the regenerated trap to cool the collection trap in preparation for the next collection cycle. After the trap is cold and six hours have passed, the process switches and the cold regenerated trap begins the collection process and the trap used for collection goes through elution and regeneration.

1.7 Separation

Xenon is separated from any contaminants in the separation process. The separation process contains a separation column (molecular sieve) that is designed to separate xenon from trace amounts of radon and carbon dioxide that eluted with xenon from the collection traps. A nitrogen gas flow from a nitrogen generator is used as a carrier gas to push xenon through the column. As the xenon elutes from the separation column, it passes through a purification trap. The separation column is then heated at which time nitrogen flow is also started and used to remove the separated radon and carbon dioxide to waste.

1.8 Purification

Xenon is mostly pure as it exits the separation column and is carried to the purification trap with a nitrogen carrier gas. The purification trap contains a small amount of activated charcoal and is cooled using a Stirling mechanical cooler to an optimal temperature to collect almost all of the xenon but very little nitrogen. At the end of the purification process, the high-purity xenon is eluted from the purification trap by heating the trap and expanding it into an evacuated beta cell. To complete the xenon transfer process, a small amount of high-purity nitrogen is used to push the remaining xenon from the activated charcoal into the nuclear detector.

1.9 Nuclear Detection (Beta-Gamma Coincidence) and Quantification

The Xenon International nuclear detection system is a set of four beta-gamma coincidence detectors that each consist of a plastic scintillator (BC404) beta cell housed inside of a NaI(Tl) well-detector. The plastic scintillator is a sealed gas volume that xenon gas is delivered to and held for the 12 hour count. This configuration allows for beta particles to be detected by the plastic scintillator while the gamma rays pass through the plastic and are detected by the NaI(Tl) detector. The counts are recorded, but only those events that measured a coincidence between the beta and gamma detectors are analyzed, which eliminates a significant amount of background counts (approximately a factor of 100 reductions in the background). Each detector counts a gas background for nearly 11 hours prior to a 12 hour sample count.

After the sample has finished counting and the count data is recorded, the system quantifies the stable xenon volume by measuring the composition of the gas counted in the detector. The quantification is performed via a binary gas analysis using an absolute pressure gauge and a relative gas composition pressure gauge. By knowing the pressure, volume, and xenon gas composition to high precision, the stable xenon gas volume is capable of being measured to a relative uncertainty of 2.7%.

1.10 Archive

The Xenon International system will have 16 archive bottles for archiving measured samples. The archive bottles can be sent to an IMS laboratory or to a laboratory of choice for validation of the system detection measurement. The archive bottles will cycle through every 4 days (6 hour samples, 4 samples per day). If a sample is not selected for reanalysis the Xenon International system will evacuate the old sample and thus reuse the bottles for the next four days.

1.11 Data

The Xenon International system automatically generates several different data types including the status of health data, log data, and IMS 2.0 data files. The IMS 2.0 formatted data files contains the spectral data for all four radioxenon isotopes including sample files, gas background files and detector background files. The sample files are sent every two hours as *SAMPLEPHD preliminary files* and at the end of the 12 hour count as *SAMPLEPHD full* files. All data is saved on the system and is accessible for retrieval or analysis on the system.

1.12 Data Analysis

Radioxenon activity concentrations are automatically calculated on the Xenon International system, and can be calculated on the system from *sample files*, *gas background files* and *detector background files* that are saved on the system. The activity concentration can also be calculated at the data center from data files sent from the Xenon International system.

1.13 Connectivity

The Xenon International system connects directly to the internet for full access to all system functions from a remote location in addition to the ability to locally access to the system. The Xenon International system is GCI compatible. All system functions including the status of health viewing, data analysis, detector settings are available to the user.

2.0 Further Information

Additional high level and detailed descriptions of the Xenon International system are available from the following information sources:

https://tbe.com/energy/xenon-international

System Design Description for Xenon International Laboratory Prototype (PNNL-26220) (Jan 2017)

Xenon International Field Manual (Dec 2017)

Pacific Northwest
NATIONAL LABORATORY

www.pnnl.gov

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

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