STATUS OF THE UNITED STATES INTERNATIONAL MONITORING SYSTEM RADIONUCLIDE MONITORING STATIONS

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ABSTRACT

Veridian Systems Division (Veridian) is engaged in the development and upgrade of the 11 designated U.S. International Monitoring System (IMS) radionuclide monitoring stations. The U.S. IMS stations are planned to contain the Automated Radioxenon Sampler/Analyzer (ARSA) and the Radionuclide Aerosol Sampler/Analyzer (RASA). Initially prototyped by Pacific Northwest National Laboratory (PNNL) and for the past two years undergoing a field re-engineering and enhancement R&D program by Space Missile Defense Command (SMDC)/Veridian the ARSA system is designed to continuously sample the atmosphere and concentrate atmospheric xenon on cooled, activated charcoal traps. After collection the xenon sample is transferred to an electron-photon coincidence radiation detector for inspection and the data is transmitted to a data center. The RASA systems operate in a similar manner but collect aerosol samples on filter material for inspection with an HPGe radiation detector. Currently, these two pieces of equipment are at different levels of maturity: RASA systems are commercially available that meet IMS specifications, and those RASA systems already installed are in the process of being upgraded by Veridian. The manufacturing prototype ARSA system is currently being constructed and is scheduled for government review later in 2003. Several modifications were incorporated into the engineering prototype currently deployed in Guangzhou, China to improve its performance and reliability. This paper will focus on the current state of the ARSA and issues associated with the development of a first article, as well as progress to date for the ARSA in the International Noble Gas Experiment.

OBJECTIVE

The objective of the ARSA program is to support nuclear test-ban-treaty monitoring. The ARSA was designed as a continuous automated monitoring system for concentrating xenon gases and collecting the radiation spectrum for identification of four primary xenon nuclides (^{131m}Xe, ^{133m}Xe, ^{133}Xe, ^{135}Xe). The ARSA design is currently in a transitional phase between prototyping and low rate production. The data collected and lessons learned from operating the engineering prototype within the U.S. and its current location in Guangzhou, China are being utilized to implement design improvements to a manufacturing prototype currently in production. The following sections provide detail on the installation process, and performance of the ARSA with regards to the International Noble Gas Experiment and the current status of the manufacturing prototype.

Pre-Installation

The ARSA system was prepared for shipping on 20 August - 6 September 2002. The system was disassembled and the equipment, including spares, tools, and consumables, were inventoried and crated for shipment. Although the hardware was ready to be delivered to Guangzhou, the actual shipping was delayed while a request for a tariff free import was processed and the method of remotely communicating with the system was resolved. The tariff free import was resolved quickly but the method of remote communications took some time.

The Chinese requested that the system not transmit data anywhere but directly to the International Data Center (IDC) and that remote access be limited. To accomplish this Veridian proposed using a commercial data router at CN22 that could control the access to the machine by time, protocol, or IP address. A commercial router, the Cisco 806, was selected, procured, and would be hand carried to Guangzhou for the installation by Veridian. Once the communication issue was resolved the equipment was cleared for shipment to Guangzhou on 28 October 2002. The equipment arrived at the Canton airport in Guangzhou on 11 November 2002. Unfortunately, somewhere along the route the U.S. Department of Agriculture certification that the wood crating had been heat treated, as required by Chinese customs, had been misplaced, most likely while in transit through Hong Kong. This caused a concern and for the equipment to be released from customs it would have to be unpacked and the crates burned or an original certification of heat treatment would need to be provided. Veridian contacted the Department of Agriculture to obtain a duplicate certification and it was hand carried to China and delivered to the Chinese Customs on the day of arrival. Once Chinese customs received the certification, the equipment was released and delivered to the GERC on 18 November 2002.

On 19 November the Guangzhou Heavy Lifting Company was contracted to fabricate a lifting mechanism to hoist the equipment crates through the stairwell to the CN22 laboratory on the seventh floor of the building. The lifting mechanism was comprised of a truck mounted, gas powered, winch, with a cable running to a pulley in the stairwell at the ground floor. The cable was then routed up the stairwell to another pulley fastened to a beam system on the ninth floor. The cable was routed back down the stairwell and attached to the individual crates for hoisting. Figures 1 through 5 show the construction and operation of the hoisting mechanism.

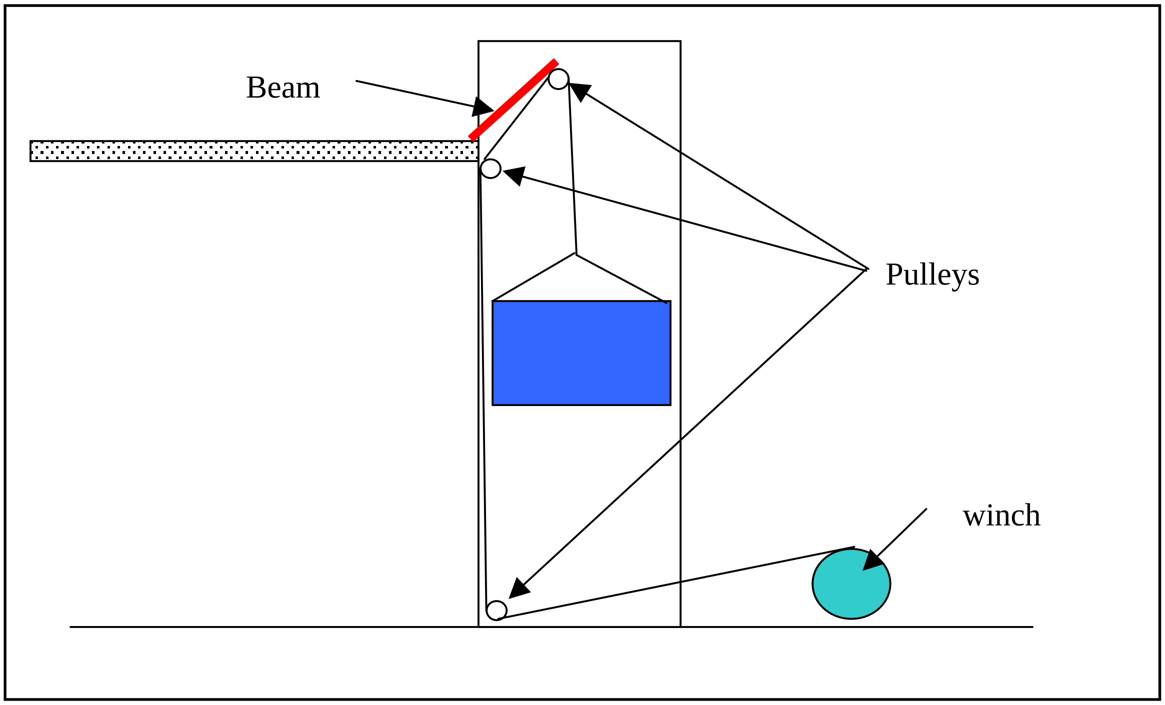

Figure 1. Hoisting mechanism design

Figure 2. Transferring the equipment from the delivery truck to the CN22 building

Figure 3. Truck mounted, gas powered winch and lifting cable

Figure 4. Beam assembly and upper cable pulleys

Figure 5. ARSA main crate arriving at the 8th floor

The crates were lifted to the seventh floor one by one starting with the lightest crate and going up in weight with each lift. Figure 5 shows the heaviest crate, approximately 900 kg containing the ARSA main assembly, arriving at the seventh floor. All of the crates except for the final crate were small enough to fit through the doorways and could be placed in the CN22 laboratory immediately. It was necessary to remove the main frame from the final crate and install a temporary wheel system allowing the ARSA to be transferred into the laboratory. Figure 6 shows the ARSA with the wheel assembly attached.

Figure 6. ARSA mainframe in CN22 laboratory with temporary wheels

<u>Installation</u>

Kickoff Meeting

The installation of the ARSA at CN22 began on 15 November 2002 with a kickoff meeting attended by representatives of Veridian, Gunagdong Environmental Radiation Research and Monitoring Center (GERC), PTS, Northwest Institute of Nuclear Technology (China), and the Chinese Ministry of Defense, see Figure 7.

Figure 7. Attendees at ARSA kickoff meeting

During the coordination meeting the state of the infrastructure and the list of action items from the coordination meeting, held in April 2002, were reviewed. It was found that all of the action items from the coordination meeting had been completed or an alternative solution was reached. It was also agreed that for remote access the data router would be configured to allow scheduled FTP and telnet sessions. The remote access would be controlled by programming the data router to open the specific ports assigned to FTP and telnet every Monday, Wednesday, and Friday from 12:30 to 13:00 UTC.

Establishment of Operation

The Establishment Of Operation (EOO) for CNX22 began on the 20 November 2002. There were five GERC technicians and engineers on hand during the installation period to help with the work. Each morning the install team and the representatives from the GERC would congregate to discuss the itinerary for the day as well as review the work that was done the prior day. At the conclusion of the daily review session at least one training session pertinent to the days work was conducted.

On the First day the ARSA system was positioned in place in the laboratory and set on vibration dampening pads to minimize dynamic coupling to the HPGe detector in the adjacent room, a manual particulate monitoring system. It was also necessary to position the ARSA with the lead shielding for the detector directly above a main support beam for the floor.

Individual ARSA system components were then installed including an air pump, cryogenic cooler, and electron-photon coincidence detector system, see Figure 8. The power was connected to the ARSA along with an individual ground cable to the ARSA framing.

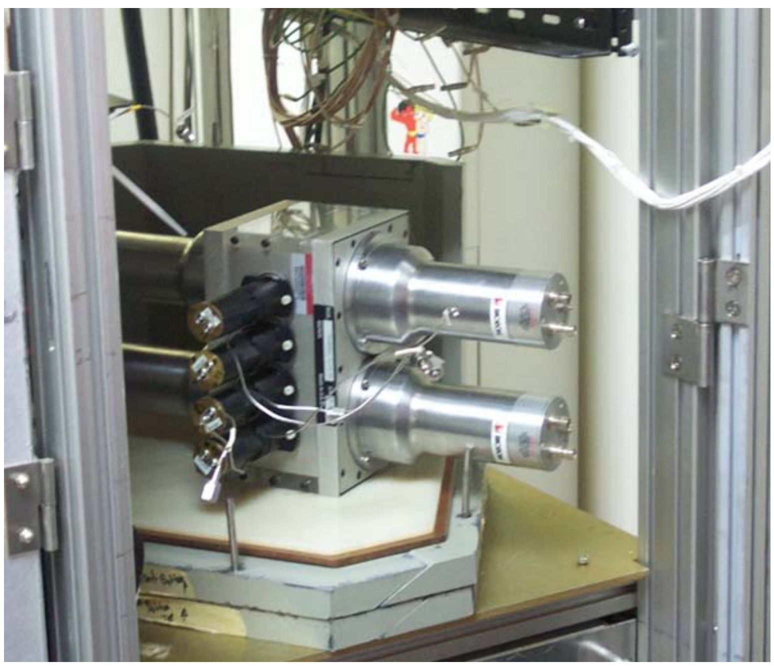

Figure 8. Installing the electron-photon coincidence detector

On the second day of the EOO the remainder of the mechanical hardware was installed on the system. The software on the station computer was installed, a GUI to control the system and view the instrumentation outputs in real time as well as a detector data viewer and a viewer for looking at the instrumentation history or State-of-Health (SOH). The system was then temporarily connected to the communications interface (ADSL modem).

Power was applied to the system but on initial startup a misconnected temperature sensor (on the cryogenic cooler motor) caused the system to shutdown after approximately five minutes. Because of the misconnection it appeared that the cooler compressor temperature was beyond the preset safety limit and the system shut down automatically. Once the misconnection was corrected the system was restarted and ran over-night in bypass mode where the process flow is diverted away from the gas processing section but does generate SOH data from all sensors and allows the operator to manually control the system.

On the third day of the EOO the system was leak tested, Veridian trained the local operators on how to leak test the system and oversaw the local operators as they performed the actual tests, see figure 10. Also on the third day, the nitrogen carrier gas was connected to the system, see figure 11 and a few sample spectra were collected to be sure the detector was functioning.

Figure 9. Leak testing the ARSA gas process deck

Figure 10. Nitrogen carrier gas supply

Over the weekend the system had stopped running, apparently after a power outage and it was found to have stopped even though the power was on at the station. The fault was traced to the main power wiring where a commercial connector had failed. The failed connector was removed and the replaced, see figure 12, with twisted pairs and commercial wire nuts and the system was restarted.

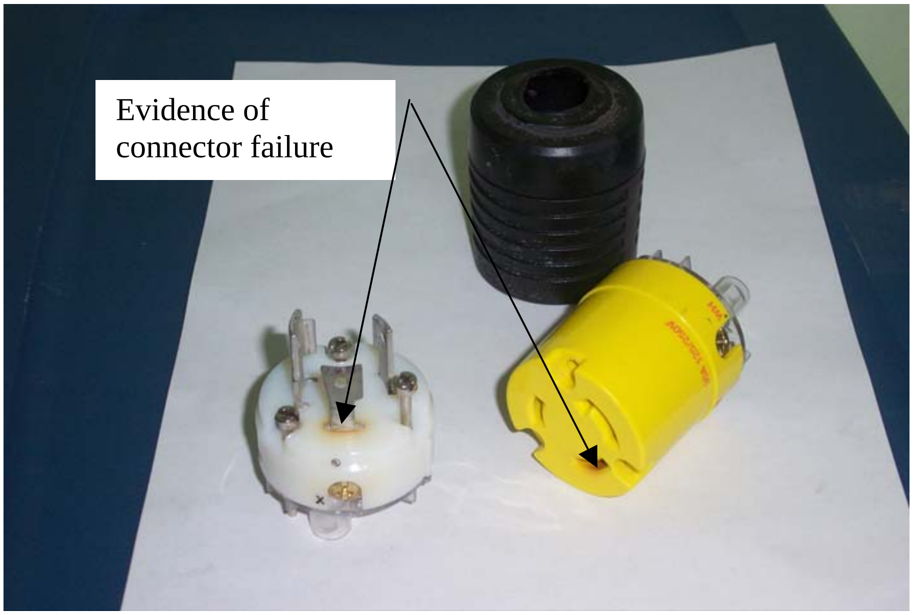

Figure 11. Failed main power connector

<u>Communications</u>

During the second week of the installation the software and communications were configured and the system operation was monitored closely. The ARSA was configured to communicate over the internet through a Linksys broadband router and ADSL modem. Because of the inconvenience of remote access, the ARSA SOH messages were modified, as requested by the PTS, to include approximately 140 process sensors in the SOH message process sensor block. CNX22 was also configured to transmit data to the IDC only. Since the installation, the SOH message size has been reduced per the request of the PTS, to 40 sensors, to reduce the amount of data delivered.

<u>Tuning</u>

During 10 March 2003 through 14 March 2003 a second trip to Guangzhou was made to complete the tuning of the system. It was decided to wait several weeks before performing the tuning to operate the system for some time at a specific location and allow it to stabilize and see if any optimizations are required. For instance, in Guangzhou, the radon levels appear to be much higher than what was seen during operation in Charlottesville, Virginia. This resulted in an elevated radon level in the spectra and an increased MDC. To compensate for the increased radon levels the gas processing parameters needed to be adjusted, i.e. adjusting some of the processing temperatures and flow rates. All of the gas processing parameters were adjusted remotely and took approximately one month to optimize the settings. Once the system was optimized remotely we went to the site for further optimization, mainly increasing insulation on the gas processing lines. All of these actions contributed to a reduced radon level, Figure 13 shows the improvement in radon rejection in the spectra for cell 3.

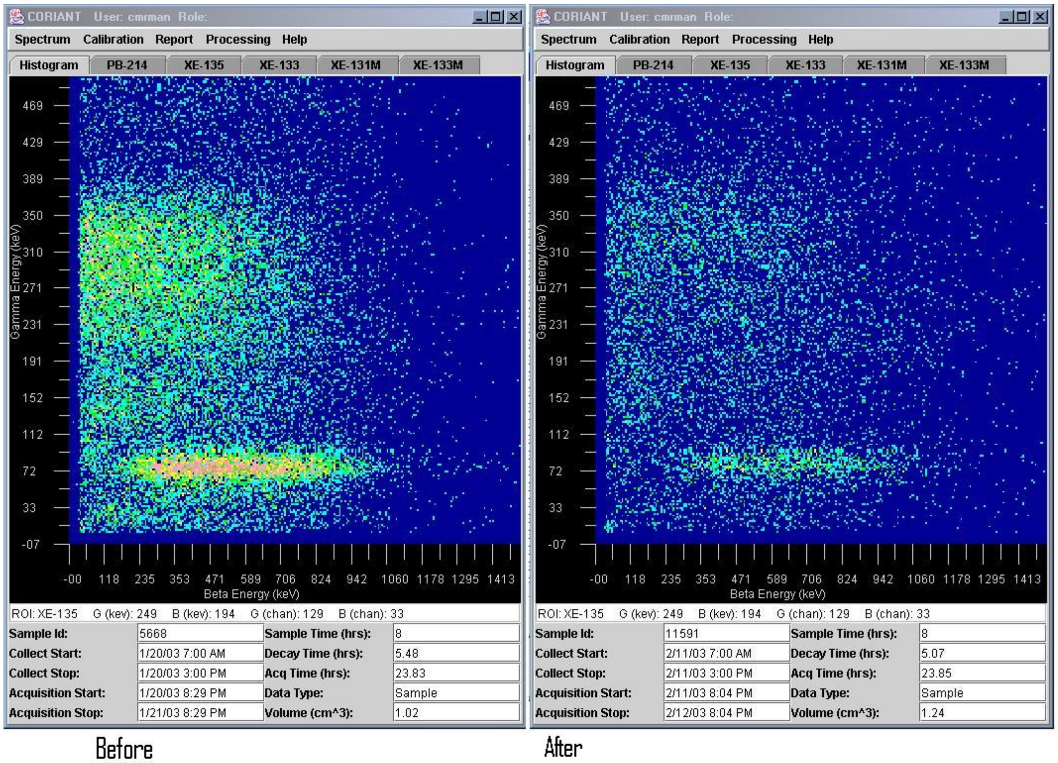

Figure 12. Radon improvement in cell 3 after optimization

All of the ARSA instrumentation was calibrated during the tuning trip including the gas quantification system which is composed of two instruments. The first instrument, a pressure sensor for measuring the sample absolute pressure, was calibrated with a mechanical, class 4A, pressure gauge. The second instrument, a Thermal Conductivity Detector (TCD) that determines the amount of xenon in the collected sample, was calibrated by passing known mixtures of nitrogen and carbon dioxide gas through the detector. The carbon dioxide gas interferes with the xenon measurement; therefore known levels of CO2 will appear as a proportional value of xenon. The instrument's zero reference point for both xenon and CO2 is calibrated by backfilling the instrument with 100% dry nitrogen. The span value for xenon is calibrated by backfilling with 100% CO2, this represents a xenon concentration of 28%. The CO2 span value was calibrated by backfilling the detector with a mixture of 30% CO2 and 70% dry nitrogen. Table 1 shows the results of the gas quantification procedure.

Table 1. Gas quantification calibration

Gas mixture	Xe reading	CO2 reading
100% nitrogen	-0.4%	-2.5%
100% CO2	27.2%	
30% CO2 + 70% nitrogen		31.3%

The radiation detector was calibrated using a combination of Eu-152 and Cs-137 sources placed directly on top of the beta cells and inside the gamma detector. The Eu-152 source provides multiple lines for checking the gamma energy calibration. The beta cell energy calibration was checked using the Cs-137 source. The 662 keV gamma ray from Cs-137 will create coincident events in the detector assembly through Compton scattering in the sodium iodide and Compton electrons produced in one of the plastic scintillators.

A particular item of interest in the Cs-137 coincidence spectrum is a line that can be seen where the sum of the photon and electron energy is 662 keV, equal to the original photon energy. If this line is extended to intersect both axes it will cross at the 662 keV point, indicating that the full energy of the photon would have been deposited in a single detector volume. Another area of interest in the spectrum is at the photon energy 184 keV. This energy represents the photon backscatter detected in the sodium iodide block. Also there is a concentration of events with an electron energy at approximately 480 keV that corresponds to the Compton edge in the plastic scintillator spectra. See figure 14 for a spectrum taken from cell 1.

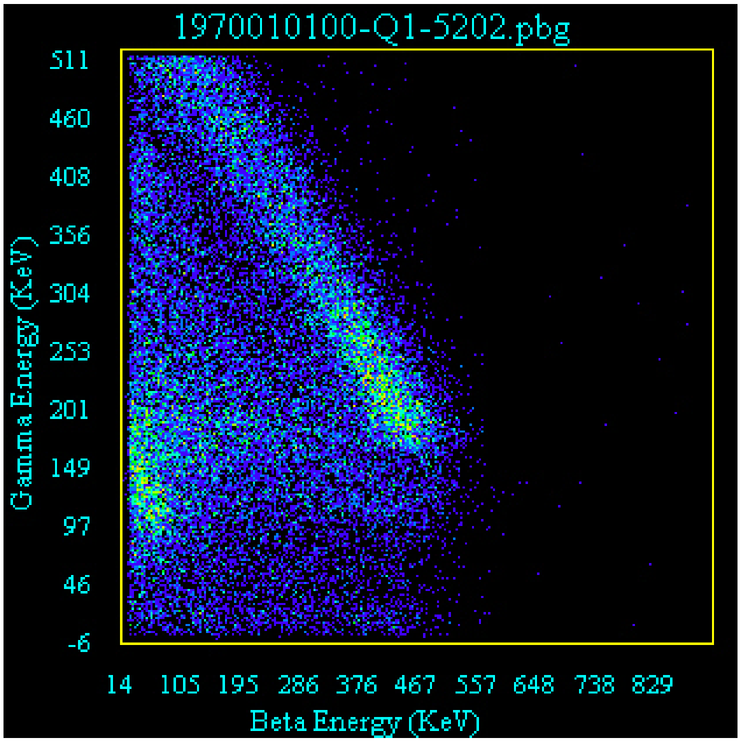

Figure 13. Typical calibration spectrum from cell 1

<u>On-Site Training</u>

The CN22 local operators were trained through hands-on interaction with the ARSA as well as several formal presentations throughout the establishment of operation and tuning phases of the installation. The local operators received training on the topics in Table 2.

Table 2. CN22 operator training topics

Topic	Method
ARSA Introduction	Presentation
ARSA Process Flow	Presentation
ARSA Control Software	Presentation
ARSA Safety Features	Presentation
ARSA Scheduled Maintenance	Presentation
ARSA QNX Operating System	Presentation
ARSA Normal Operational Parameters	Presentation
IDC Radionuclide Data Products	Presentation
Radionuclide Review	Presentation
Xe Processing	Presentation
System Leak Testing	Hands - on
Replacing Consumables	Hands – on
IDS operation	Hands – on
TCD Calibration	Hands – on
Control and Sensor Hardware	Hands – on
System Configuration Files	Hands – on
PHD, SOH, and Alert Message Format	Hands – on

Figure 15. Hands – on training of operators for replacing air pump consumables

<u>Performance Testing</u>

The goal of the performance testing period was to show that the ARSA system is functioning in a similar manner as when it was installed in Charlottesville. In general, the ARSA installed at CNX22 had been operating reliably since November 2002 with the exception of four issues that have affected the system.

1. The system shutdown automatically at the end of December due to faulty read of one of the temperature sensors. The system was restarted without problem
2. The TCD wiring harness became disconnected resulting in an elemental xenon volume of zero being reported. The connector was secured with no real affect on system operation.
3. During March the system shut down automatically due to a reported temperature for the main air pump. The resistance thermal device (RTD) used to monitor the pump motor temperature became loose. The local operators repaired the connector and the system was restarted.
4. During April the system shut down due to an excessive temperature being reported on the final charcoal trap. The fault was intermittent and took some time to repair. In the end it was found that the system had a faulty thermocouple where the electrical insulation was damaged causing erroneous readings.

Other than during the times above the system had operated well and commensurate with it's performance before being shipped to CN22. Data from CNX22 is given below from the period of 29 March 2003 to 11 April 2003 and is compared to test data while in Charlottesville and provided in the pre-shipment test report. Table 3 lists the performance requirements for IMS radioxenon sampling systems.

Table 3. IMS requirements for radioxenon sampling systems

Requirement	Characteristics	Minimum requirements
1	Air flow	0.4 m^3 h^{-1}
2	Total volume of sample	10 m^3
3	Collection time	≤ 24 h
4	Measurement time	≤ 24 h
5	Time before reporting	≤ 48 h
6	Reporting frequency	Daily
7	Isotopes measured	^{131m}Xe, ^{133m}Xe, ^{133}Xe, ^{135}Xe
8	Measurement mode	Beta-gamma coincidence or high resolution gamma spectroscopy
9	Minimum detectable concentration	1 mBq m^{-3} for ^{133}Xe

1. The total airflow produced by the system during the pre-shipment testing period and performance test can be seen in figure 16. The mean values are 5.94 and 7.24 m^3 h^{-1} for the pre-shipment and performance test periods respectively.

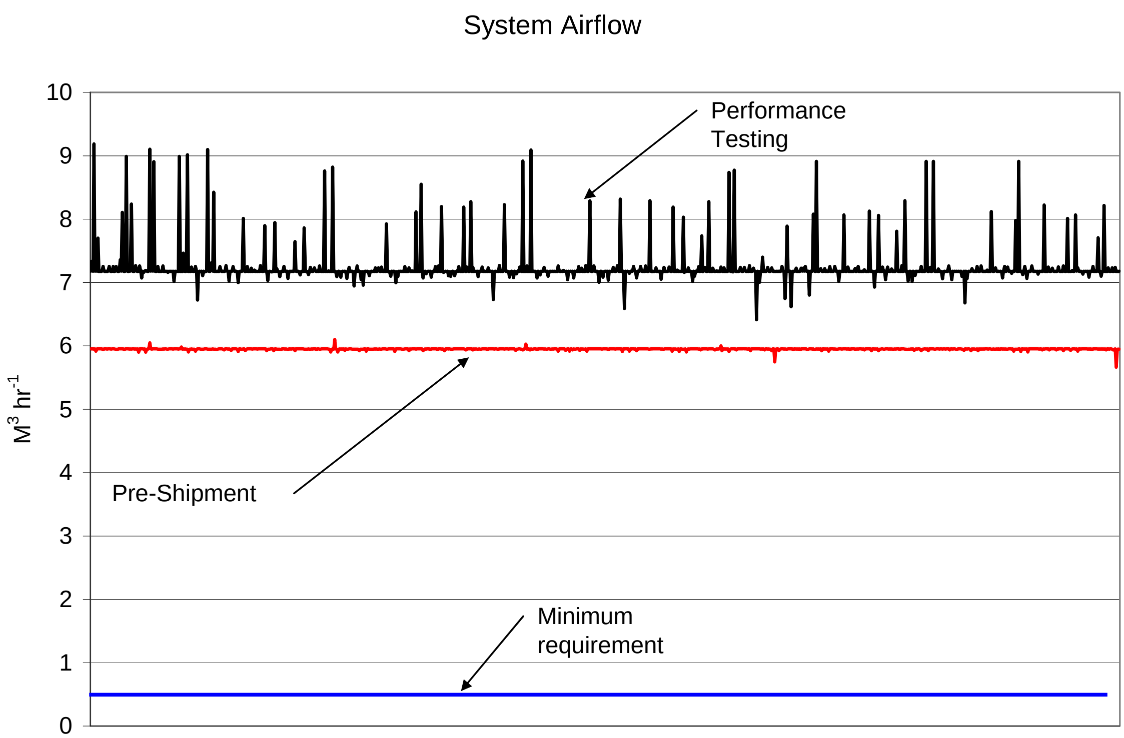

Figure 16. Total airflow through system during pre-shipment testing

2. The total volume of each sample during the pre-shipment and performance testing periods are shown in Figure 17. The mean values are 17.11 and 16.47 m^3 for the pre-shipment and performance tests respectively.

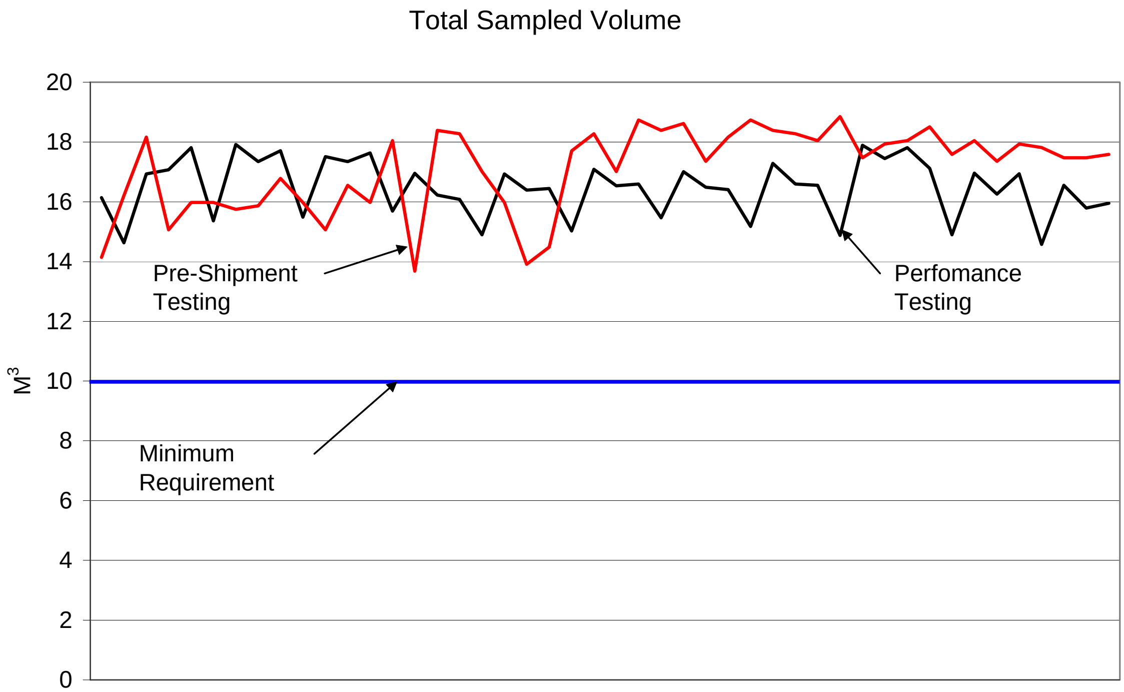

Figure 17. Total air volume sampled

3. The collection time for each sample for both the pre-shipment and performance test periods is eight hours plus or minus ten minutes. The collection time was determined by calculating the amount of time the process flow control valve was open for each collection side.

4. The mean measurement time for the gas samples during the pre-shipment and performance tests is 24.00 hours with a standard deviation of 0.01 hours. The mean measurement time for the gas background measurements is 7.36 hours with a standard deviation of 0.01 hours.

5. The time before reporting data was examined by comparing the dates a sample acquisition stopped and the date the data was transmitted. In all cases the dates were the same indicating no more than 24 hours passed before the data was reported.

6. During the testing periods the gas sample data was consistently reported three times per day.

7. Figure 18 displays the spectra measured for a sample collected on the 10th of April. The data is visualized using the software package Coriant. The outlined boxes are indicative of the regions of interest for the four isotopes of interest (^{131m}Xe, ^{133m}Xe, ^{133}Xe, ^{135}Xe). The abscissa and ordinate represent the beta and gamma measurement energy range which provides evidence of the measurement mode, beta-gamma coincidence. Note that this sample appears to have a small amount of ^{131m}Xe in the spectrum.

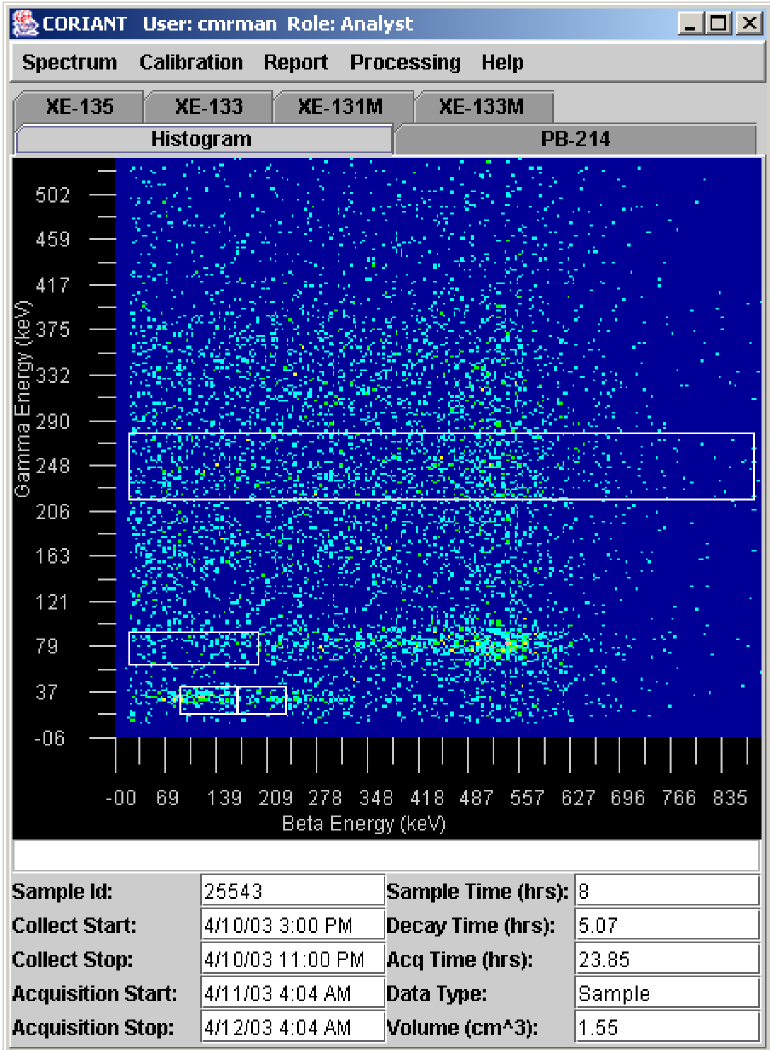

Figure 18. Sample beta-gamma coincidence data

8. The minimum detectable concentration for the testing periods was consistently below the 1 mBq m^{-3} limit for ^{133}Xe. The mean values for each of the sample cells are reported in table 4.

Table 4. Mean ^{133}Xe MDC (mBq m^{-3})

Detector Cell	*Pre-shipment MDC*	*Performance Testing MDC*
1	0.60	0.63
2	0.43	0.40
3	0.56	0.51
4	0.52	0.47

Post Initial Testing

Since completing the initial testing period, early April 2003, the ARSA has experienced two failures that have accumulated a significant amount of downtime. The first failure, due to a thermocouple grounding out intermittently and picking up stray current caused a temperature safety switch to trigger an automatic shutdown of the system. Unfortunately this failure was not a hard fault and at times the system would run for weeks without the fault occurring, other times it would run for hours. The fault initially appeared near the end of April and was not diagnosed for certain until the beginning of July.

The second failure occurred between April and July where a valve failed in the gas processing section of the system. The failure was not immediately evident to the operators and the data quality was severely affected for approximately one week. Typically when a valve fails on the system the flow rate or pressure will be adversely affected that initiates an automatic shutdown. In this case the system ran for several days before the problem was noticed. The valve failure affected the gas processing in the system which caused an exceptionally high level of radon to be in the spectra. The system was diagnosed by examining the SOH data and performing diagnostic procedures remotely. Once the problem was identified the local operators were able to replace the failed valve.

During July 2003 representatives from Veridian traveled to Guangzhou to replace the failed thermocouples and perform any required maintenance on the system. Since the system had seen two failures that created a significant amount of downtime, Veridian found it necessary to perform an inspection of the system. At the time of writing this paper the maintenance visit is scheduled but has not been performed. The system should be repaired within a couple weeks and ready to begin the International Noble Gas Experiment Phase IIIB. During Phase IIIB the system performance and reliability will be scrutinized and compared to the three other systems in the experiment, the French SPALAX, Swedish Sauna, and the Russian ARIX.

First Article, Manufacturing Prototype

In July 2002, Veridian performed a commercial review for possible manufacturing partners for the ARSA system. During this review 17 vendors were contacted of which 4 were requested to submit proposals. The companies were reviewed based on cost, past performance, relevant work within and outside of atmospheric sampling and radiation measurements, as well as manufacturing and management capacity. The AMETEK Corporation, (formerly ORTEC) in Oak Ridge, TN was selected to build the ARSA systems. Currently AMETEK is in the process of building the manufacturing prototype with the guidance of Veridian. Lessons learned during the operation of the ARSA in Virginia and China have been integrated into the baseline package. The first article is scheduled for delivery to the IMS station RN75 in Charlottesville, Virginia in November 2004. Once installed the system will be subjected to a requirements Validation test to be performed by representatives from Sandia National Laboratories. The requirements for the first article are drafted but have not been finalized and are currently being reviewed by U.S. and International experts. Once the first article is found to be acceptable and meet all requirements agreed upon the system drawings and documentation will be updated and the system will be ready to begin low rate production. The development of the ARSA is being managed through a Technical Program Plan that has been developed based on the SMDC version of the DOD 5000 acquisition model.

CONCLUSIONS AND RECOMMENDATIONS

The Automated Radioxenon Sampler Analyzer has been installed in Guangzhou, China since November 2002. The system ran reliably for approximately 6 months before suffering from an intermittent problem related to a failing thermocouple. The only other hard fault seen with the system was a failed valve in the gas processing section. After the system was initially installed it was allowed to run for over a month to determine how the local environment would affect performance. It was found that the radon levels in Guangzhou were significantly greater than in Charlottesville, Virginia, where the system was initially tested. The gas processing portion was optimized remotely by adjusting the timing and temperatures and the radon level was reduced significantly. After remote optimizations were performed a team traveled to Guangzhou to perform on-site tuning activities. Once the tuning was completed the system performance met or exceeded the performance level set in Charlottesville. A short while after the tuning trip was completed the system has not operated reliably due to an intermittent failure and a hard failure. The system is scheduled for repair in late July 2003. Once the system has shown that it is running well and reliably it will enter into the International Noble Gas Experiment Phase IIIB. The experiment will compare the performance of the four systems participating to determine applicability to the International Monitoring System network.