Monitoring for Xenon Radionuclides and CTBT Verification

Byoung-Jik Kim*, Dong Myung Lee, Hong Mo Park, Kil Woo Lee and Hee Yeoul Choi
Korea Institute of Nuclear Safety, 34 Gwahak-ro, Yuseong-gu, Daejeon 305-338, Republic of KOREA
**Corresponding author: k712kbj@kins.re.kr*

1. Introduction

The Comprehensive Nuclear-Test-Ban-Treaty (CTBT), which was opened for signature in 1996, bans all nuclear explosions in all environments. Republic of Korea has been working to monitor compliance with CTBT by deterring and detecting any nuclear explosions conducted anywhere on Earth.

For the verification of CTBT, several techniques are implemented. Radionuclide monitoring is of particular importance since it is the only method which can provide absolute assurance that a nuclear detonation has occurred.

2. Radionuclide monitoring [1]

Initial tests of nuclear weapons were conducted in the atmosphere, and particulate fission product debris from such tests was readily observable over the entire hemisphere in which they were conducted. However, with the development and application of underground testing technologies, the release of particulate fission products could be largely or completely eliminated and only the nonreactive gaseous fission products which are produced directly in the detonation may be vented to the atmosphere. Therefore, the only opportunity to detect or confirm a suspect event may be through observation of the unique ratios of the radioxenon fission products.

2.1 Xenon radionuclides

Monitoring for xenon radionuclides which are produced in a nuclear detonation can provide a strong deterrent to the violation of a CTBT. There are 18 known radioactive xenon isotopes produced in nuclear fission with half-lives ranging from less than one second to 11.9 days. However, only four of these remain in significant amounts more than a day after a detonation. ^{135}Xe (9.10 hr), ^{133m}Xe (2.19 day), and ^{133}Xe (5.24 day) are the most abundant after a vent. The longer-lived radionuclide ^{131m}Xe (11.9 day) is also produced but its concentration is orders of magnitude lower than any of the others. However, ^{131m}Xe can enter the atmosphere from early reprocessing of nuclear fuels or from medical isotope production and usage. Therefore, its measurement is important in differentiating between a nuclear test and the other sources of radioxenon (i.e., reactor operations, fuel reprocessing, medical isotope production and usage). The nonreactive noble gas properties of the xenon radionuclids ensure that they will be the first and perhaps the only fission products released in a covert nuclear weapons test.

In order for radioxenon monitoring to be practical, it was necessary to develop an automated measurement system which could operate unattended for periods of months, measure the entire spectrum of radioxenons.

2.2 Xenon monitoring system for CTBT verification

For verification of a CTBT, an International Monitoring System (IMS) is proposed which may include a world-wide network of stations where airborne radionuclides, both particulates and radioxenon, are monitored continuously. To be practical, a radioxenon monitoring system must operate automatically, require only annual maintenance and consume only electric power, collect and measure the four radioxenons two or more times a day, differentiate between weapons test radioxenon and those from the previously mentioned sources and automatically transmit analytical data to the National Data Center (NDC) for relay to the Interanational Data Center (IDC). There is one system operated in Korea, which is same with the IMS but not included in the world-wide network.

High detection sensitivity requirements are necessary since venting from a nuclear detonation may only include a very small fraction of the total radioxenon produced. Subsequent atmospheric dispersion processes can result in major dilution before reaching a monitoring site. High sensitivity measurements of the four xenon radionuclides must be made in order to differentiate between atmospheric radioxenons from nuclear power reactor operations, nuclear fuel reprocessing, or medical isotope production and usage. Consecutive measurements two or more times each day are important radioxenon is the 9.1 hr ^{135}Xe which is more abundant than any of the other radioxenons during the first few days after a detonation, and its ambient background is negligible. However, its short half-life requires analysis soon after collection in order to minimize the loss of sample through decay.

2.3 The state of art [2, 3]

During the past years, research has been carried out to develop a radioxenon monitoring system which would meet the requirements. Such a system has been developed and demonstrated and once commercialized, may serve as a monitoring instrument for verification of a CTBT. The technology involves collection of the atmospheric xenon by passing filtered, dry, cold air through a large charcoal adsorption bed for a specified period of time, followed by xenon elution and readsorption on a smaller adsorption bed prior to its injection into a specialized gas cell scintillation counter where high sensitivity energy analysis and electron-photon coincidence counting of the four xenon radionuclides are performed.

Recently, a group of European researchers presented and discussed the activity concentration data from ambient radioxenon measurements in ground level air. The noble gas monitoring systems are designed to continuously measure low concentrations of the four radioxenon isotopes which are most relevant for detection of nuclear explosions. This European cluster is particularly interesting because it is highly influenced by a high density of nuclear power reactors and some radiopharmaceutical production facilities. The activity concentrations are studied to characterize the influence of civilian releases, to be able to distinguish them from possible nuclear explosions. It was found that the mean activity concentration of the most frequently detected isotope, ^{133}Xe, was 5-20 mBq/m^3 within Central Europe where most nuclear installations are situated, 1.4-2.4 mBq/m^3 just outside that region and 0.2 mBq/m^3 in the remote station. No seasonal trends could be observed from the data.

The xenon monitoring system in Korea detected the radioxenon isotopes ^{135}Xe, ^{133}Xe and possibly ^{133m}Xe, during the time period May 12-16, 2010. Calculations and observed activity concentrations suggest that the most likely explanation is radioxenon release in connection with target processing following neutron irradiation of for instance ^{235}U. Using atmospheric transport modeling, the source of release was estimated but other scenarios could not be ruled out. The nuclear explosion scenario is unlikely, since no seismic signal has been located to the area during the relevant time period.

3. Importance of monitoring for compliance [1]

The intent of a CTBT is to stop all nuclear explosions by all countries and thereby discourage weapons development. Support for a CTBT is dependent on countries being confident that a potential aggressor will not develop or test nuclear weapons. Treaty compliance is much more certain where reliable monitoring systems are in operation. A determined evader would seek to test in a manner which minimizes all observable indications of the test.

Essentially all of the evasion scenarios which conceivably reduce detectability by other monitoring methods (seismic, hydro-acoustic or infrasound) still have a substantial probability for, or in fact will result in venting of xenon noble gas radionuclides to the atmosphere. A worldwide monitoring system for continuous measurement of radioxenons should, therefore, provide a means for detection, and thus serve as a deterrent to conducting nuclear explosions.

REFERENCES

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