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Maximum reasonable radioxenon releases from medical isotope production facilities and their effect on monitoring nuclear explosions

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ABSTRACT

Fission gases such as ^{133}Xe are used extensively for monitoring the world for signs of nuclear testing in systems such as the International Monitoring System (IMS). These gases are also produced by nuclear reactors and by fission production of ^{99}Mo for medical use. Recently, medical isotope production facilities have been identified as the major contributor to the background of radioactive xenon isotopes (radioxenon) in the atmosphere (Stocki et al., 2005; Saey, 2009). These releases pose a potential future problem for monitoring nuclear explosions if not addressed. As a starting point, a maximum acceptable daily xenon emission rate was calculated, that is both scientifically defendable as not adversely affecting the IMS, but also consistent with what is possible to achieve in an operational environment. This study concludes that an emission of 5×10^9 Bq/day from a medical isotope production facility would be both an acceptable upper limit from the perspective of minimal impact to monitoring stations, but also appears to be an achievable limit for large isotope producers.

1. Introduction

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) bans explosions from any environment, including in the atmosphere, underwater, and underground. An international system was designed and is now under construction intended for the verification of the treaty. This International Monitoring System (IMS) is comprised of 321 stations (UNGA, 1996; Dahlman et al., 2009) at various locations across the globe. The data collected by this system of sensors is transmitted to an International Data Center, which analyzes the data every day. The IMS comprised of four types of technologies designed to detect nuclear explosions conducted in the various environs. For detection of underground nuclear explosions, seismic sensors are used to detect vibrations in the ground, hydrophones are used to detect water pressure pulses from underwater detonations, microphones are used to detect low frequency sounds from atmospheric detonations, and a number of radionuclide sensors are used to detect airborne nuclear debris that can be emitted from either atmospheric, underwater, or underground detonations.

The seismic, hydrophonic and acoustic sensors cannot discriminate nuclear explosions from phenomena such as the use of conventional explosives. Radionuclide sensors on the other hand, can identify nuclear explosions and discriminate between conventional explosions and actual nuclear explosions. The radionuclide technology of the International Monitoring System (IMS) consists of radionuclide particulate detectors (based on high resolution gamma spectrometry) and radioxenon detectors (based on high resolution gamma spectrometry or beta-gamma coincidence counting). The particulate systems are designed to identify debris from an atmospheric, shallow underground or shallow underwater nuclear explosion, whereas the radioxenon systems can also measure fission gases originating from deep underground or deep underwater explosions. Radioactive xenon has been used effectively for over a decade in the IMS, and various technologies and algorithms have been used to detect and discriminate faint radioxenon emissions from other anthropogenic sources such as reactor operations and medical isotope production (Kalinowski et al., 2010).

Each year millions of procedures utilizing medical isotopes are performed to address issues such as heart studies and other critical activities. Among the isotopes used for medical procedures, ^{99m}Tc, produced as decay product from ^{99}Mo, is by far the most prevalent (IAEA, 1989). There are two main production methods of ^{99}Mo; neutron capture on ^{98}Mo and through uranium fission. In the latter production route, the uranium targets are dissolved, followed by chemical separation to obtain a purified ^{99}Mo product (IAEA, 2004).

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However, the entire suite of fission products are also created during this process, including fission gases such as radioxenon.

Other sources such as nuclear reactor operations release radioxenon, though the emissions from fission-based medical isotope production are currently thought to be much higher (Saey, 2009). The non-proliferation monitoring community has had to develop a number of tools to discriminate radioxenon between civilian and explosion sources. One of the most powerful techniques is through the simultaneous measurement of multiple radioxenon isotopes ^{131m}Xe, ^{133}Xe, ^{133m}Xe and ^{135}Xe. In most cases, it is theoretically possible to determine the source of the radioxenon by forming ratios of the measured radioxenon airborne activity concentrations, which are in the order of mBq/m^3. Fig. 1 shows a schematic illustration of multiple isotopic radioxenon correlation (MIRC) plots that have been proposed to perform source determination using radioxenon isotopes (Kalinowski et al., 2010). It can be seen in this figure that the ratios originating from a nuclear power plant (NPP) have a distinct and different signature than those from an explosion or medical isotope production. In fact, these last two are very close to each other. A high environmental background of radioxenon will make it even more difficult to discriminate them.

Understanding the isotopic ratios so detection of radioxenons released as a by-product of fission-based medical isotope production can be accounted for is important; however, a better solution is likely to reduce emissions at the source. Even a perfect understanding of each source and measurement of all of the relevant radioxenons will potentially produce an unpredictable effect at large distances due to the potential mixing of multiple sources, uncertainties in atmospheric transport, and the statistical uncertainty in computed ratios when background levels are high. In effect, high levels of background from legitimate activities such as medical isotope production, even if the source is known, will adversely affect the ability to determine the addition of small signals coming from illicit activities such as nuclear explosions. The only solution to the problem is to reduce legitimate civilian effluents at the source.

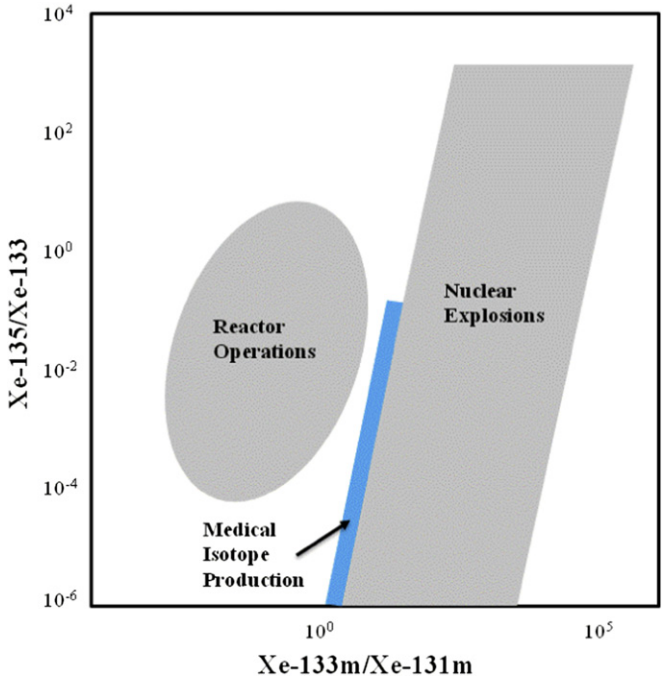

Fig. 1. Schematic illustration of the discrimination phase space of isotopic ratios of radioactive xenon isotopes originally proposed by Kalinowski et al.

Emissions reduction requires investment by the producers in most cases. Although essentially all production facilities are thought to have some emissions reduction technology, building or retrofitting current systems to meet some standard takes resources that might not exist especially if the driver for reducing emissions is not health and safety related. A relevant question is, therefore, what level of daily emission is acceptable so that the nuclear explosion monitoring mission is not greatly impacted, and is it possible to reduce emissions to that level in any conventional way? The following sections of this paper address that issue – the acceptable level of radioxenon that can be emitted from known, planned, or arbitrary location isotope production facilities will be calculated.

2. The International Monitoring System

The IMS currently has 40 radioxenon measurement stations planned for installation before entry-into-force (EIF) of the Treaty, and a plan for an additional 40 will be reviewed after EIF (Comprehensive Nuclear-Test-Ban Treaty, 1996). The locations of the radioxenon stations were set in the treaty before backgrounds were understood either in terms of magnitude or sources. The current requirement for minimum detection concentration (MDC) thresholds is 1 mBq/m^3 for ^{133}Xe, though most of the systems exceed (are better than) this requirement by a factor of nearly 10 ($\sim$0.1 mBq/m^3) (Ringbom et al., 2003).

The current IMS radioxenon network is very sensitive compared to other airborne radiation sensors, though as high a detection sensitivity as possible is needed for these systems. The benefit of using highly sensitive systems was seen following the Democratic People's Republic of Korea (DPRK) nuclear test of 2006, which was reported by a Swedish noble gas system using similar technology as that used in the IMS (Ringbom et al., 2009), as well as a system in Yellowknife, Canada (Saey et al., 2007). Conversely in 2009 during a second DPRK nuclear test, no xenon emissions whatsoever were reported following the DPRK announcement arguing that if radioxenon emissions occurred from that event, then lower detection thresholds may have been useful. Also, since the CTBT does not specify a lower threshold for nuclear tests, very small tests should be detectable and so more sensitive measurement capability is needed.

The need for additional sensitivity can be visualized from coverage maps of the IMS made by several groups. An example of one of these maps in shown in NAS (2012), which shows the percentage chance that a small nuclear explosion would be detected at one or more IMS station. These maps show two features relevant to this issue; first there are areas in which the global coverage could be better, which argues for more stations being necessary, and second, the assumed emission strength in this calculation is similar to that from medical isotope production facilities.

While the needs for improved monitoring are increasing, the needs for medical isotopes such as ^{99}Mo are also increasing. This means that the detection of xenon effluents from medical isotope production will be more common as more stations are commissioned, and as isotope production occurs at new locations. Indeed the IMS currently detects xenon isotopes at many stations, presumably originating from isotope production.

Under the rubric of cooperation under the CTBT, several individuals and groups have addressed the issue of isotope production and its influence on the global radioxenon background. The issue was highlighted at the 2011 CTBT International Science Symposium. Also, an annual Workshop on the Signatures of Industrial and Medical Isotope Production (WOSMIP) was first held in 2009 and is dedicated to the topic of understanding emissions from medical isotope production and their impact. As part of these discussions,