Identifying the possible source regions of elevated concentrations of Xenon-133 detected at the Takasaki Radionuclide Monitoring Station (JPX38) on 2 October 2017: Malaysian CTBT National Data Centre (MY-NDC) findings

F I A Rashid¹, a), M Z Zolkaffly¹, b)
¹MY-NDC, Planning and International Relations Division, Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia
afaisal_izwan@nuclearmalaysia.gov.my
bzulfakar@nuclearmalaysia.gov.my

Abstract. A couple of elevated concentrations of noble gas Xenon-133 were detected at the Takasaki Radionuclide Monitoring Station (JPX38) on 2 October 2017. Xenon-133 is among four relevant radioxenon isotopes that are used for monitoring and verification of nuclear explosions including Xenon-13, Xenon-133m and Xenon-131m. These radioxenon gases could be emitted either from nuclear explosion or civil nuclear facilities including medical isotopes production facilities, nuclear power reactors and nuclear research reactors. This paper presents the Malaysian CTBT National Data Centre (MY-NDC) findings in identifying the possible source regions for elevated concentrations of Xenon-133 detected at JPX38 on 2 October 2017. The findings will be useful in understanding the possible source of release for such Xenon-133 detection, whether coming from a late release of the 3 September 2017 North Korea nuclear test site or from civil nuclear facilities.

1. Introduction

The Comprehensive Nuclear-Test-Ban-Treaty (CTBT) is a multilateral treaty that banning all nuclear explosions – everywhere and by anyone. At the time of this study, the CTBT has not entered into force due to pending ratification from eight Annex 2 states of the CTBT namely, China, Egypt, India, Iran, Israel, North Korea, Pakistan, and United States [1]. A verification regime of the CTBT, which among others includes the International Monitoring System (IMS), was established to detect any nuclear explosion conducted on the planet. The IMS comprising a global network of 321 seismic, hydroacoustic, infrasound and radionuclide stations and 16 radionuclide laboratories is used to detect signals that could indicate a possible nuclear explosion [2].

Malaysia is one of the CTBT contracting states by signing it on 23 July 1998 and ratifying it on 17 January 2008 [3]. A Malaysian CTBT National Data Centre (MY-NDC) was established in December 2005 at the Malaysian Nuclear Agency (Nuklear Malaysia) and is tasked to provide technical information of CTBT related events to Nuklear Malaysia as the CTBT National Authority [4].
The IMS network of the CTBT inter-alia incorporates 40 noble gas monitoring stations that are capable to detect radioxenon gases in the atmosphere. In the case of underground nuclear explosion, noble gases like radioxenons are created in significant quantities and are the most likely radioactive signatures detected at IMS stations [5]. Due to their half-lives and fission yields, four radioxenon isotopes namely Xenon-135, Xenon-133, Xenon-133m and Xenon-131m are used for detecting nuclear explosion [6]. Table 1 shows the half-lives and the most intense γ-ray and X-ray of four radioxenon isotopes. These isotopes are artificial isotopes which are chemically inert, unaffected to deposition, and very difficult to contain, consequently they have increased probability to escape from a nuclear test site [7].

Table 1. Half-life and the most intense γ-ray and X-ray of four radioxenon isotopes.

| Radioxenon isotopes | Half-life  | Energy X-ray (keV) | Intensity (%) | Energy γ-ray (keV) | Intensity (%) |
|---------------------|------------|--------------------|---------------|--------------------|---------------|
| Xenon-135           | 9.14 hours | 30.80              | 2.1           | 249.77             | 90.0          |
| Xenon-133           | 5.243 days | 30.80              | 40.9          | 80.997             | 38.0          |
| Xenon-133m          | 2.19 days  | 29.62              | 46.1          | 233.22             | 8.2           |
| Xenon-131m          | 11.84 days | 29.62              | 44.4          | 163.93             | 1.91          |

Apart from nuclear explosion, these radioxenon isotopes can also be released from civil nuclear facilities, such as medical isotopes production facilities, nuclear power reactors and nuclear research reactors. However, the magnitude of release of radioxenons is different for each nuclear facilities and nuclear explosion. Within the region surrounding the North Korean nuclear test site, there are numbers of operational civil nuclear facilities situated in China, Japan, North Korea, South Korea and Taiwan as shown in Figure 1. It is also worth to note that after Fukushima nuclear accident in March 2011, most of the nuclear power plants in Japan were not operating during September until October 2017.

On 3 September 2017, the North Korea conducted the sixth underground nuclear test which caused significant detectable earthquake in both North Korea and the neighboring countries [8]. The earthquake signal was picked up by over 100 IMS stations and the characterisation of the event was consistent with a man-made explosion [9]. From verification point of view, the explosion can only be classified as underground nuclear explosion only if the corresponding airborne radioactivity is detected, primarily in the form of noble gas radioxenon and radioargon [10].

Later, on 2 October 2017, two noble gas samples with elevated concentration of Xenon-133 were detected at one of the IMS radionuclide stations, namely the Takasaki Radionuclide Monitoring Station (JPX38), in Takasaki, Japan. JPX38 is equipped with automatic radioxenon collection and analysis system, known as the Swedish Unattended Noble Gas Analyzer (SAUNA) which employs scintillator beta-gamma coincidence detectors to detect airborne noble gas radioxenons [11]. Besides JPX38, there are other regional IMS radionuclide stations in the area surrounding the nuclear test site, namely CNX20 (Beijing, China), CNX22 (Guangzhou, China), RUX58 (Ussuriysk, Russia) and RUX60 (Petropavlovsk-Kamchatskiy, Russia) as shown in Figure 1.

Taking into account various possible sources of radioxenons, a robust analysis is critical to distinguish and identify the possible source of release of radioxenons detected at IMS stations. Hence, this paper aims at presenting MY-NDC findings in identifying the possible source regions of elevated concentrations of Xenon-133 detected at JPX38 on 2 October 2017. This study exhibits MY-NDC effort in understanding the possible source of release of such Xenon-133 detection at JPX38, whether they were coming from a late release of the 3 September 2017 North Korea nuclear test site or from operational civil nuclear facilities within the region.
2. Methods

The methodology that we used in this study is summarised in Figure 2. Firstly, we measured the radioxenon isotopes of Xenon-135, Xenon-133, Xenon-133m and Xenon-131m from two noble gas samples of JPX38 with collection stop on 2 October 2017 0650 UTC and 1850 UTC using beta-gamma coincidence technique. In this relation, we used Norfy review tool, a specialised noble gas analysis software developed by the Provisional Technical Secretariat (PTS) of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). As a result, we acquired the type of radioxenon isotopes present in the samples, along with its activity (in mBq) and concentration (in mBq/m³).

Next, we performed atmospheric transport modelling (ATM) in backward mode using the result from the preceding beta-gamma coincidence analysis. We use the Web Connected Graphics Engine (Web-Grape) software developed by the PTS of CTBTO for backward mode ATM. The backward mode ATM is operated with meteorological data from the United States National Centers for Environmental Prediction (NCEP). The backward mode ATM provides an insight on field of regard (FOR) which denotes the possible source region for radioxenons detected within one single sample. We also run possible source region (PSR) model to identify the most consistent point source location that would explain the detection scenario of radioxenons at JPX38.

Lastly, we run forward mode ATM to predict the potentially affected radionuclide monitoring stations. For this purpose, we used the Lagrangian Particle Dispersion Model HYSPLIT, developed by the National Oceanic and Atmospheric Administration – Air Resources Laboratory [12]. The meteorological data from the Global Forecast System (GFS) was used for this purpose. Several ATM forward mode simulations were generated with hypothetical releases at different release points, including from the nuclear test site and a few civil nuclear facilities. The result from the forward mode ATM has helped us to shortlist the PSR identified from backward mode ATM and predict the other potentially affected radionuclide monitoring stations.
3. Results and Discussion

3.1. Beta-gamma coincidence analysis
Both noble gas samples of JPX38 with collection stop on 2 October 2017 0650 UTC and 1850 UTC were analysed in this study using beta-gamma coincidence technique. Figure 3 illustrates beta-gamma coincidence histogram of both samples. We found that both samples detected Xenon-133. No traces of Xenon-135, Xenon-133m and Xenon-131m were detected from both samples. Table 2 shows the measurement category and activity concentration of Xenon-133 of both samples. Category C denotes anomalous Xenon detection at the station. We also acknowledged that no immediate releases of radioxenon gases were detected by the radionuclide monitoring stations within the region. This suggests that there are no direct pathways were created from the cavity to the surface to allow the propagation of particulates and noble gases during the test [13]. The absence of other radioxenon isotopes in the samples such as Xenon-131m has made the dating of nuclear fission not possible. If there are other radioxenon isotopes present in the samples, which in the correct isotropic ratio, it would have increased the evidence of a nuclear explosion source.

Perform beta-gamma coincidence analysis for two JPX38 noble gas samples (collection stop 2 October 2017 0650 UTC and 1850 UTC)

**Expected Result:**
Type of radioxenons present in the samples, its activity and concentration

Perform backward ATM using results from beta gamma analysis

**Expected Result:**
List of PSR

Perform forward ATM from the list of possible source regions identified from backward ATM to predict the potentially affected radionuclide monitoring stations

**Expected Result:**
Shortlisted list of PSR and identify other

Figure 3. Beta-gamma coincidence histogram of (a) Sample 1 and (b) Sample 2.
Table 2. Measurement category and activity concentration of Xenon-133 for both samples.

| Sample | Station | Collection Stop       | Category | Concentration (mBq/m³) |
|--------|---------|-----------------------|----------|------------------------|
| 1      | JPX38   | 2 Oct 2017, 0650 UTC  | C        | 0.71 0.0619            |
| 2      | JPX38   | 2 Oct 2017, 1850 UTC  | C        | 0.95 0.06631           |

We also plotted activity concentration of Xenon-133 detected from both samples with historical detection of Xenon-133 at JPX38 from 1 January 2016 until 31 December 2017 as shown in Figure 4. We found that similar Xenon-133 activity concentration have been detected at JPX38 within that period. Within that period, most of Xenon-133 concentrations detected at JPX38 were between 0.1 to 0.4 mBq/m³. Thus, in this case, concentration of Xenon-133 of sample 1 and 2 were far above the usual range and considered as significant. This argument is further justified based on the assignment of category C as anomalous Xenon detection to both samples.

Figure 4. Historical detection of Xenon-133 at JPX38 from 1 January 2016 – 31 December 2017.

3.2. Backward mode ATM

We run backward mode ATM to identify the possible source regions for Xenon-133 detected at JPX38. Figure 5 shows the result of backward mode ATM from JPX38, starting from the initial detection of Xenon-133 on 2 October 2017 and backtracking until 26 September 2017. The simulations showed at early stage, the Xenon-133 plume circulated in the middle of Japan and later on moving towards nuclear test site in North Korea. At longer backward transport time, the plume started to spread out and cover the territory of China and Russia. The relatively high values of PSR were recorded for nuclear test site in North Korea which indicates the nuclear test site as a likely source for the Xenon-133 detections at JPX38. Based on the backward mode ATM performed in the context of this study, we also found that most of the regional nuclear reactors could be ruled out as PSR. Nevertheless, other regional source cannot be completely excluded.
3.3. Forward mode ATM

The forward mode ATM was performed for PSRs, previously identified from backward mode ATM. Figure 6 shows the dispersion of Xenon-133 plume over seven days, assuming 24 hour hypothetical release on 28 September 2017 from nuclear test site, using 0.5 degree GFS meteorological data and 200,000 particle released.

The forward mode ATM assuming release on 28 September 2017 shows the prevailing wind directions to the north east. The forward simulations also indicated that RUX58 station would have detected the Xenon-133 plume as well. Our further investigation revealed RUX58 detected several peaks of Xenon-133 as well as Xenon-131m and Xenon-135 during October 2017. Despite RUX58 detected such peaks, the station was a non-certified IMS station. Hence, calibration parameters of this non-certified noble gas system might be an issue. Further, RUX58 also was not in operation for quite a long time and just went back online in between, at the days indicated by the forward simulations. Consequently, special precaution must be made as Xenon-131m signal was on the edge of detection limit. From forward simulation, a late release from nuclear test site remains one of the PSR. Nevertheless, magnitude and phase of detections predicted from the forward simulation did not match with the actual detections at JPX38 as shown in Figure 7. Based on the forward simulation, we were also of the view that other regional source might also be associated with the Xenon-133 detection at JPX38.

We also noted that most of nuclear power plants in Japan were not in operation and therefore can be excluded as possible source of release of radioxenons.
**Figure 6.** Forward mode ATM from nuclear test site.

**Figure 7.** Magnitude and phase of detections predicted from the forward simulation with different release time assumptions.
4. Conclusion
Results from beta gamma coincidence analysis confirmed significant activity concentrations of Xenon-133 in both samples at JPX38 on 2 October 2018. No other radioxenon isotopes were detected from both samples. Backward ATM simulations suggest the nuclear test site as possible source location with high correlation PSR factor. However, other regional sources could not be completely ruled out as possible source location. Forward ATM simulation shows strong correlation with nuclear test site as well as others regional civil sources. In conclusion, we found that the results were not conclusive with regard to a possible association to the explosion on 3 September at the nuclear test site. Other regional civil sources could also explain such detection at JPX38.

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