Radionuclide analysis of the National Data Centre preparedness exercise 2019 (NPE2019): Malaysian National Data Centre (MY-NDC) findings

F I A Rashid\textsuperscript{1, a}) and M Z Zolkaffly\textsuperscript{1, b)}

\textsuperscript{1}Planning and International Relations Division, Malaysian Nuclear Agency, 43000 Kajang, Selangor, Malaysia.

\textsuperscript{a}faisal_izwan@nuclearmalaysia.gov.my
\textsuperscript{b}zulfakar@nuclearmalaysia.gov.my

Abstract. The National Data Centre preparedness exercise (NPE) simulates fictitious violation of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) and is regularly conducted by the National Data Centres (NDCs) for NDCs. The purpose of the exercise is to increase the NDCs' preparedness and capabilities to perform objective analysis of possible treaty violation events. In November 2019, the NPE2019 has officially launched as a combined radionuclide and waveform scenario. The scenario started as a fictitious state named RAETIA announced a reactor incident with a release of unspecified radionuclides into the atmosphere. The simulated concentration of particulate and noble gas isotopes at several radionuclide stations had been provided as a case study. Hence, the NDCs are tasked to check the consistency with the announcements as well as to identify potential source region of such release. This paper aims at presenting MY-NDC's radionuclide analysis findings of NPE2019. The analysis involved among others, multiple nuclide isotopic analysis, and atmospheric transport modelling (ATM). Consequently, the analysis had enabled MY-NDC to identify the potential source region of the radionuclide release as well as to discriminate the source of such release, whether coming from civil nuclear facilities or nuclear tests.

1. Introduction
The Comprehensive Nuclear-Test-Ban Treaty (CTBT) is a multilateral treaty that bans nuclear explosion anywhere on Earth whether for military or peaceful purposes. Malaysia is one of the contracting states to the treaty through its signature and ratification on 23 July 1998 and 17 January 2008, respectively [1]. Under the CTBT, a Malaysian CTBT National Data Centre (MY-NDC) has been established in December 2005 which provides technical information of CTBT related events to the Malaysian Nuclear Agency (Nuclear Malaysia) as the CTBT National Authority [2].

The National Data Centre Preparedness Exercise (NPE) is an exercise that simulates a fictitious violation of the CTBT. It aims to measure the readiness of the National Data Centres (NDCs) to fulfill their duties concerning the CTBT verification [3]. In the exercise, the NDCs are tasked to clarify the nature of the fictitious event based on independent technical judgment, whether the treaty incompliance has been triggered.

The NPE2019 had officially started on 22 November 2019. In the NPE2019, a hypothetical scenario describes that a TRIGA reactor accident had taken place on 30 July 2019 in a fictitious location of Pavia,
Raetia (45.18° N, 9.16° E) as shown in Figure 1 (a). Subsequently, the state of Raetia had announced a small release of radioactive isotopes to the environment but claimed the release was below the hazardous limit for human health. Upon the announcement, the neighboring state named Eastria (in real-world, Eastria is located in the territory of Austria with particulate and noble gas IMS station coded VIP00 and VIX00, respectively) has provided its national radionuclide measurements to the International Data Centre and requests IDC’s assistance to identify potential sources. For the purpose of this exercise, the radionuclide measurements were also made available to the NDCs. The measurements consist of synthetic particulate and noble gas (radioxenon) data measured at selected International Monitoring System (IMS) radionuclide stations as shown in Figure 1(b). The particulate data consists of activity concentrations of Cs-134, Cs-137, Ba-140, La-140, and I-131 whilst the noble gas data comprising activity concentrations of Xe-131m, Xe-133m, Xe-133, and Xe-135. The chronology of particulate and noble gas detections after the Pavia’ reactor accident is illustrated in Table 1. Hence, using the provided data, the NDCs are tasked to perform independent analysis in order to check the consistency with the announcements from the state of Raetia as well as to identify potential source regions of such release. Thus, this paper aims at presenting MY-NDC’s radionuclide analysis findings of NPE2019.

![Figure 1](image1.png)

**Figure 1.** (a) Location of the reactor accident in Pavia, Raetia and, (b) location of IMS stations.

| IMS Station | 30-Jul | 31-Jul | 1-Aug | 2-Aug | 3-Aug | 4-Aug | 5-Aug | 6-Aug | 7-Aug | 8-Aug | 9-Aug | 10-Aug | 11-Aug |
|-------------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|
| Particulate Detection | | | | | | | | | | | | | |
| CNP21 | | | | | | | | | | | | | |
| KWP40 | | | | | | | | | | | | | |
| LYP41 | | | | | | | | | | | | | |
| NEP48 | | | | | | | | | | | | | |
| IRP36 | | | | | | | | | | | | | |
| RUP55 | | | | | | | | | | | | | |
| VIP00 | | | | | | | | | | | | | |
| Noble Gas (Radioxenon) Detection | | | | | | | | | | | | | |
| DEX33 | | | | | | | | | | | | | |
| VTX00 | | | | | | | | | | | | | |

**Table 1.** Chronology of detections.
2. Methods

2.1. Particulate data analysis
The particulate data is analysed to identify nuclide ratios from relevant radionuclides. The ratios are important due to their usability to characterise the source in order to discriminate a civil reactor release or nuclear explosion. Moreover, the nuclide ratios are commonly used to acquire timing information by comparison with scenarios calculated from nuclear data [4]. In NPE2019, the provided measurements were in the form of nuclide activity concentrations. Thus, these measurements were converted into nuclide ratios using the following conversion equations proposed by Axelsson et al. [5]. Equation (1) and (2) were used to convert activity concentrations into nuclide ratios for independent decay nuclides and parent-daughter decay nuclides, respectively.

\[ R = \frac{c_2\lambda_1}{c_1\lambda_2}e^{\xi_c} - \eta_A \]

where C is nuclide activity concentration, \( \lambda \) is the nuclide decay constant \([s^{-1}]\), \( \xi \) is decay correction and \( \eta \) is correction term. The decay correction \( (\xi) \) is further divided into 3 types, namely \( \xi_c \) is decay correction during collection, \( \xi_p \) is decay correction during processing and \( \xi_A \) is decay correction during acquisition. The respective decay corrections and correction terms were calculated using the following equations.

\[ \xi_c = \frac{1-e^{-\lambda_1 t_c}}{1-e^{-\lambda_2 t_c}} \]

\[ \xi_p = e^{-(\lambda_1 - \lambda_2) t_p} \xi_c \]

\[ \eta_A = \frac{\lambda_2}{\lambda_2 - \lambda_1} (\xi_A - 1) \]

where \( t_c \), \( t_p \) and \( t_A \) is collection time, processing time, and acquisition time, respectively. Using these equations, the nuclide ratios of Cs-134/Cs-137 (independent decay nuclides) and La-140/Ba-140 (parent-daughter decay nuclide) were obtained. These ratios were then used to characterise the source as well as for the dating of a nuclear event.

2.2. Noble gas data analysis
By using the same conversion equations for particulate data analysis, the activity concentrations of radioxenon isotopes were converted into 2 main nuclide ratios, namely Xe-135/Xe-133 and Xe-133m/Xe-131m. These xenon nuclide ratios were then examined to distinguish nuclear explosion sources from civilian releases using multiple atmospheric xenon isotopic activity ratios as suggested by M B Kalinowski et al. [6].

2.3. Atmospheric Transport Modelling (ATM)
The ATM is used to assess the consistency between measurements and potential source locations. In the context of NPE2019, the ATM was simulated in two modes – backward and forward. For backward mode, the Linux-based software developed by the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO) called the Webconnected Graphics Engine (WEB-GRAPE) was utilised for the visualization of atmospheric transport models and identification of possible source regions of radionuclides detected by IMS stations [7]. The software computes trajectories of particles to determine the transport and dispersion of particles in the atmosphere, thus leading to the determination of possible source regions[8]. Meanwhile, for the forward mode ATM, the Lagrangian Particle Dispersion Model HYSPLIT invented by the National Oceanic and Atmospheric Administration – Air Resources Laboratory was used. The software was utilised for predicting the potentially affected IMS radionuclide stations by simulating hypothetical release from possible source regions identified from backward mode ATM [9]. Table 2 lists the key parameters and data used to simulate both ATM modes.
Table 2. Key parameters and data used for simulating backward and forward mode ATM

| Parameters                  | Backward ATM                                      | Forward ATM                                      |
|-----------------------------|---------------------------------------------------|--------------------------------------------------|
| Meteorological data         | European Centre for Medium-Range Weather Forecasts (ECMWF) | Global Data Assimilation System (GDAS), 10 degree |
| Total run time              | 14 days in reverse time                           | 14 days in forward time                          |
| Number of particles release | Not applicable                                    | 200,000                                          |
| Release time                | Not applicable                                    | 30 July 2019, 0600 UTC                           |
| Duration of release         | Not applicable                                    | 24 hours of continuous release                    |
| Rate of hypothetical release| Not applicable                                    | 1.04 E+8 Bq/hr                                   |
| The initial point of projection | IMS radionuclide stations                      | Pavia’s reactor site and selected radioisotope production facilities |

3. Results and Discussion

3.1. Particulate data analysis

Figure 2 (a) and (b) depict the nuclide ratios of Cs-134/Cs-137 and La-140/Ba-140 from CNP21, KWP40 and LYP41. As can be seen clearly from the figures, the Cs-134/Cs-137 and La-140/Ba-140 ratios from the three IMS radionuclide stations were within 3.94 to 3.97 and 0.42 to 0.44, respectively. Since the variation of the ratios is very low, they can be considered constant over time. The smooth and constant Cs-134/Cs-137 ratio indicates that radioactive material was predominantly released from the same type of source material. Moreover, the ratio of Cs-134/Cs-137 above 0.01 signified that the source was highly probable from a source other than the nuclear explosion [10].

![Figure 2](image-url)
3.2. Noble gas data analysis
Table 3 lists the nuclide ratios of Xe-135/Xe-133 and Xe-133m/Xe-131m measured at DEX33 and VIX00. These ratios were further examined using multiple atmospheric xenon isotopic activity ratios as illustrated in Figure 3. From Figure 3, it is evidently shown that radioxenon nuclide ratios measured at DEX33 for sample collection date of 2 August 2017 and VIX00 for sample collection date of 2, 3 and 7 August 2019 fall within the civil region. Consequently, it can be concluded that the xenon isotopes detected at these radionuclide stations were not a result of a nuclear test, but most likely from civilian applications that may include PAVIA’s reactor, commercial nuclear power plants, and possibly medical radioisotope production facility.

Table 3. Xe-135/Xe-133 and Xe-133m/Xe-131m ratios at DEX33 and VIX00.

| IMS  | Collection date | Xe-135/Xe-133 | 133m/Xe-131m |
|------|----------------|---------------|--------------|
| DEX33 | 2-Aug-19       | 0.026         | 1.04         |
| DEX33 | 3-Aug-19       | 0.01          | -            |
| DEX33 | 4-Aug-19       | -             | -            |
| DEX33 | 5-Aug-19       | -             | -            |
| DEX33 | 6-Aug-19       | -             | -            |
| DEX33 | 9-Aug-19       | -             | -            |
| VIX00 | 2-Aug-19       | 0.026         | 1.59         |
| VIX00 | 3-Aug-19       | 0.005         | 4.5          |
| VIX00 | 4-Aug-19       | -             | -            |
| VIX00 | 5-Aug-19       | -             | -            |
| VIX00 | 6-Aug-19       | -             | -            |
| VIX00 | 7-Aug-19       | 0.001         | 1.07         |
| VIX00 | 8-Aug-19       | -             | -            |

Figure 3. Multiple atmospheric xenon isotopic activity ratios for DEX33 and VIP00 samples
3.3. Backward and forward mode ATM
The backward mode ATM was simulated from the earliest sample collection date at the respective radionuclide station until the date of PAVIA’s reactor accident in the morning of 30 July 2019. The results of backward mode ATM from CNP21, KWP40, LYP41, IRP36, RUP55, VIP/X00, and DEP/X33 are shown in Figure 4. ATM simulation could not be performed for NEP48 due to unavailable SRS data. The plume is colour-coded according to its threshold sensitivity (m$^3$) which varies from $10^{-19}$ (low sensitivity) to $10^{-13}$ (high sensitivity). Moreover, it should be noted from the Figure that the region surrounding Raetia and Eastria has several operating nuclear power plants as well as 2 isotope production facilities (IPF), namely TYCO and IRE. Upon observation, the results concluded that the possible source regions for nuclides detected at all stations except DEP/X33 include PAVIA’s reactor, nuclear power plants as well as TYCO and IRE. Interestingly, the backward ATM showed that DEP/X33 station will not be affected by the release from Pavia’s reactor accident.

Figure 4. Results of backward mode ATM.
The forward mode ATM was performed for 3 distinct locations, which are Pavia’s reactor site, TYCO, and IRE as illustrated in Figure 5 (upper left), Figure 5 (upper right), and Figure 5 (bottom left), respectively. In Figure 5 (upper left), the modeling showed that any release from Pavia’s reactor on 30 July 2019 will affect all IMS radionuclide stations in the vicinity except DEP/X33. This finding concurred very well with the result from a backward mode ATM. Therefore, it can be concluded that the source of nuclides detected at DEP/X33 was originated from sources other than Pavia’s reactor. Based on Figure 5 (upper right), the forward ATM demonstrated that any release from TYCO IPF on 30 July 2019 0600UTC will be measured at all IMS radionuclide stations excluding RUP55 and CNP21. Thus, the source of nuclides measured at RUP55 and CNP21 is most likely from sources other than TYCO IPF. Meanwhile, the release from IRE IPF on the same release data as TYCO IPF will result in detection at all IMS radionuclide stations as displayed in Figure 5 (bottom left). The results of these 3 release scenarios are summarised in Table 4.

Moreover, Figure 5 (bottom right) shows the comparison between measured and simulated concentrations of Xe-133 at VIP/X00. It can be seen that the pattern of detection is identical despite varying concentrations. This evidence shows the source of nuclides measured at VIP/X00 is most likely coming from Pavia’s reactor site. Since the simulation presented in this paper is simplified modelling, thus, the varying concentrations between actual and simulated measurements are well expected. Moreover, the variation is also due to the fact that the air concentration results are very sensitive to the meteorology and processes that might affect the wet and dry scavenging, which were not taken into consideration in the simulation [11].

![Figure 5](image-url)

**Figure 5.** Forward ATM from Pavia’s reactor site (top left), TYCO IPF (top right), IRE IPF (bottom left) and measured versus simulated concentrations of Xe-133 at VIP/X00 for hypothetical release from Pavia’s reactor site on 30 July 2019, 0600UTC (bottom right).
Table 4. Summary results of the forward ATM from 3 different sources of release.

| Source of release | Affected IMS Stations | Non-Affected IMS Stations |
|-------------------|-----------------------|---------------------------|
| Pavia’s reactor   | CNP21, KWP40, LYP41, IRP36, RUP55, NEP48, and VIP/X00 | DEP/X33 |
| TYCO IPF          | KWP40, LYP41, IRP36, NEP48, VIP/X00, DEP/X33 | CNP21 and RUP55 |
| IRE IPF           | CNP21, KWP40, LYP41, IRP36, RUP55, NEP48, VIP/X00, and DEP/X33 |

Despite these IMS radionuclide stations detected the particulate and radioxenon isotopes, it is important to highlight that some of these stations were non-certified IMS stations. The non-certified stations were VIP/X00, RUP55, IRP36, and LYP41. Thus, the only certified stations in NPE2019 were CNP21, KWP40, NEP48, and DEP/X33. Hence, the calibration parameters of the non-certified IMS radionuclide stations might be an issue.

The NPE2019 scenario is rather complex due to a challenging environment surrounding the area of the case study. In reality, Pavia’s reactor accident is co-located in a region with a dense population of nuclear power plants as well as two global medical isotope production facilities, namely IRE and TYCO. In normal operation, such civil facilities emit related particulates and radioxenon gases into the atmosphere, limited to the release threshold as stipulated by their respective national regulations. As reported by A Pascal et al, the average release of radioxenon gases from IRE IPF and TYCO IPF is $2.7 \times 10^{12}$ Bq/day and $2 \times 10^9$ Bq/day, respectively [12]. Additionally, the same literature also reported that the continuous and pulsed releases from civil nuclear power plants are in the range of $1.3 \times 10^{12}$ Bq/year. Figure 6 shows the dispersion of radioxenon gases from the operation of medical radioisotope facilities and nuclear power plants around the globe [13]. The emission of radioxenon gases from these facilities could have a major effect, in terms of radioxenon measurements at the IMS radionuclide stations.

Figure 6. Dispersion of radioxenon gases from the operation of medical radioisotope facilities and nuclear power plants.
4. Conclusion

The radionuclide analysis for NPE2019 was classified into 3 types, namely particulate data analysis, noble gas data analysis, and ATM. The results from particulate data analysis confirmed that the source was predominantly released from the same type of source material and highly probable from a source other than a nuclear explosion, based on the ratio of Cs-134/Cs-137. On the other hand, the noble gas data analysis showed that using multiple atmospheric xenon isotopic activity ratios, the source of xenon isotopes detected at DEX33 and VIX00 were not a result of a nuclear test, but most likely from civil applications that may include PAVIA’s reactor, commercial nuclear power plants, and medical isotope production facility. The results from backward mode ATM revealed that the possible source regions for nuclides detected at all radionuclide stations except DEP/X33 include PAVIA’s reactor, nuclear power plants as well as TYCO and IRE. Moreover, the forward mode ATM concluded that any release from Pavia’s reactor will affect the measurements at all radionuclide stations except DEP/X33. Taking all these scenarios into account, it can be concluded that the abnormal measurements of nuclide at DEP/X33 station were unlikely from Pavia’s reactor. The particulates and radioxenon detected at VIP/X00 were most likely from Pavia’s reactor site. Meanwhile, detection at other stations could also be originated from Pavia’s reactor site. However, owing to the complex environment in the region, the nuclide emissions from IRE IPF, TYCO IPF, and civil nuclear power plants could not be totally ruled out as a possible source.

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