Impact of Chalk River shutdown on CTBTO North-American noble gas stations

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Context and scope of the project

Context

Radioxenon monitoring is a highly sensitive technique, but the identification of CTBT relevant events strongly depends on the local radioxenon background at the station. Detailed study of the IMS data has shown that the major contributors to detections at IMS stations are environmental releases from nuclear civil facilities. It is estimated that, all around the world, more than 500 nuclear facilities generate radioxenon which is released in the atmosphere during normal routine operations. The emissions from these numerous anthropogenic sources produce a significant background that may hide the radioxenon signals originating from nuclear explosions. Among all these facilities, medical isotopes production facilities have been identified as the most significant contributors.

Historically, the Chalk River Nuclear Labs, Canada, have supplied a large percentage of the world's demand in radiopharmaceuticals, the rest coming from facilities in Europe, Australia and South-Africa. In 2015, it was announced by the Canadian Government that Chalk River Nuclear Labs will cease production end of October 2016, with the option of resuming production on an emergency basis in the case of medical radioisotope shortages. It didn't happen. The reactor was definitely stopped at the end of March 2018.

Scope

The cessation of production activities at Chalk River provides a unique opportunity to assess how the noble gas stations of the CTBTO network and the RN products generated by the IDC are impacted by such facilities. To this end, different statistical parameters associated with the distributions of measured concentrations at four IMS stations are considered.

ATM was primarily used to determine whether the different meteorological conditions in the region could have impacted observations at the stations before and after shutdown.

Stations selection and time periods

Stations selection

Radioxenon isotopes can be observed at locations downwind from radioxenon emitting facilities. In the Northern hemisphere, the prevailing wind direction is from the west.

In order to demonstrate the impact of the Chalk River Nuclear Labs reactor shutdown on the noble gas background, the following four North-American noble gas stations were selected:

- CAX16 (SPALAX), Yellowknife, Canada;
- CAX17 (SPALAX), St-John, Canada;
- USX74 (SAUNA), Ashland, United States of America;
- USX75 (SAUNA), Charlottesville, United States of America.

In Fig. 1, the four stations considered in this study are located on a map of North America, together with the production site of Chalk River.

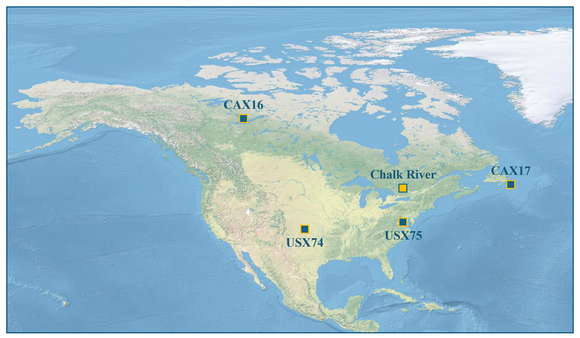

Fig. 1. Distribution of the four selected noble gas stations around the location of Chalk River Nuclear Labs on a map of North America.

Time periods under investigation

In order to assess the impact of the facility shut down with a sufficient statistics and to smooth the influence of the seasonal meteorological patterns, two 12-months periods were selected before and after the shutdown, i.e.:

- from 01/11/2014 to 31/10/2015, and 01/11/2015 to 31/10/2016 (i.e. 2 years before shutdown);
- from 01/11/2016 to 31/10/2017, and 01/11/2017 to 31/10/2018 (i.e. 2 years after shutdown).

Radioxenon observations at North American noble gas stations

CAX16

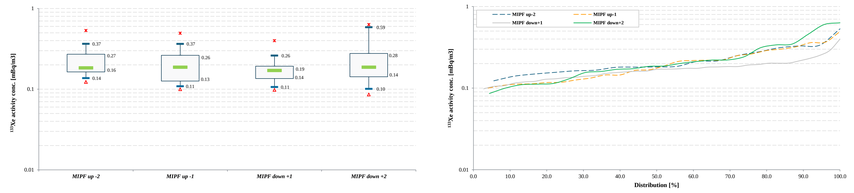

Fig. 2. Box-and-Whisker plot (left) and data fraction (right) of ^{133}Xe detections at CAX16.

From Fig. 2, it is clear that CAX16 was not impacted by the emissions from Chalk River. Over the whole period under investigation, the radioxenon background constantly remained at a low level. The variations observed in the two figures are related to the poor statistics of detections at the station (between 6.2% and 10.2% of measurement above Lc per year). CAX16 can be considered as a low radioxenon background station, with no peak detection. Only unusual wind configurations will transport emissions from Chalk River to CAX16 (cf. Fig. 6). The cessation of activities at Chalk River had little impact on the station detection profile.

CAX17

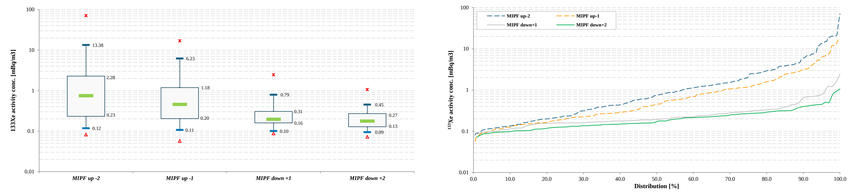

Fig. 3. Box-and-Whisker plot (left) and data fraction (right) of ^{133}Xe detections at CAX17.

CAX17 was significantly impacted by the emissions from Chalk River. Prior to shutdown, very high concentrations were frequently measured, the median background and the dispersion were high, indicating a strong regional source. This can be explained by (1) the relative proximity of the measurement site with the emitting facility and (2) the fact that the station is very sensitive to the facility location (cf. Fig. 6). Since the shutdown of Chalk River, CAX17 can be considered as a low radioxenon background station. Some peak detections up to 1 mBq/m^3 can still be observed, possibly originating from weak regional nuclear civil facilities.

USX74

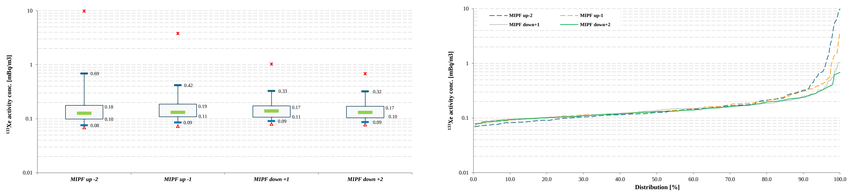

Fig. 4. Box-and-Whisker plot (left) and data fraction of ^{133}Xe detections at USX74.

USX74 was not strongly impacted by the releases from Chalk River. It cannot be excluded that elevated peaked emissions at the facility were detected from time to time by the system, as high concentrations were sometimes measured. This is supported by the significant decrease of maximum detections in Fig. 4, while the IQRs remained similar over years. Over the whole period under investigation, USX74 can be considered as a low radioxenon background station. The range of activity concentrations was significantly reduced after shutdown. It is then reasonable to assume that the station was sporadically affected by the emissions from Chalk River under relatively specific meteorological configurations (cf. Fig. 6).

USX75

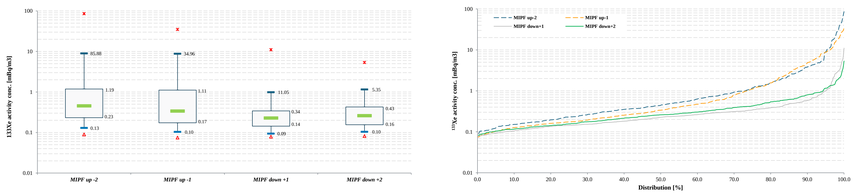

Fig. 5. Box-and-Whisker plot (left) and data fraction of ^{133}Xe detections at USX75.

USX75 was significantly influenced by the emissions from Chalk River. Very high concentrations were measured and the large dispersion of the detections was indicative of a strong regional source. Again, this can be explained by (1) the relative proximity of the measurement site with the Chalk River facility and (2) the fact that the station is under the influence of the facility (cf. Fig. 6). Significant background decrease was observed after shutdown and USX75 can now be considered as an average radioxenon background station, with elevated dispersion of the detections. Some peak detections up to several mBq/m^3 can still be observed, suggesting the influence of regional nuclear civil facilities.

Atmospheric Transport Modelling (ATM) considerations

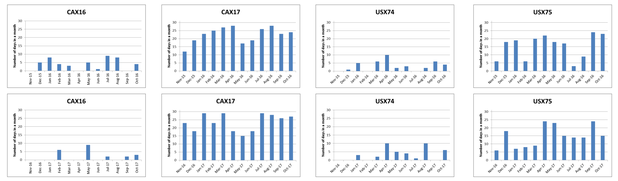

Fig. 6. Number of days per month for which an hypothetical release from Chalk River would be detected at the stations. Periods: Nov. 2015 – Oct. 2016 (up), Nov. 2016 – Oct. 2017 (down).

Fig. 6 gives the number of days per month for which an hypothetical release from Chalk River would be detected at CAX16, CAX17, USX74 and USX74 for the year before (up) and after (down) shutdown. For the four stations, the sensitivity to Chalk River appears to be globally similar before and after shutdown. We can conclude that the changes in radioxenon detections before and after the shutdown are not associated with a significant change in meteorological conditions.

It could however be noted that the sensitivity is somewhat lower for CAX16 during Nov. 2016 to Oct. 2017 period. This figure also clearly demonstrates that CAX17 and USX75 are regularly under the influence of air originating from Chalk River, while this is much less common for USX74 and especially for CAX16.

Implications for nuclear explosion monitoring

For the noble gas technology, a categorization scheme based on 3-level activity concentrations has been implemented as screening method. Spectra are reported as Level A (no radioxenon detected in the spectrum), Level B (radioxenon detected within the typical range of the station) and Level C (anomalous radioxenon detection). Anomalous radioxenon detections (Level C) trigger particular interest from States Signatories. The discrimination Level B vs. Level C is based on an abnormal concentration threshold, T_{Abn}. This discrimination parameter is dynamically determined based on up to 365 days radioxenon measurements at the station using the formula

$$T_{Abn} = \text{median} + 3\,(Q_3\text{-}Q_1)$$ where Q_1 and Q_3 are the values of the 1st and the 3rd quartiles of the data set, respectively.

As T_{Abn} is based on the station history, the cessation of radiopharmaceutical production at Chalk River affords a special opportunity to assess the delayed impact of the shutdown on the categorization of the IDC RN products. Fig. 7 shows how T_{Abn} developed over time at the different stations from Nov. 2014, i.e. two years prior to shutdown, to October 2018, i.e. two years after shutdown.

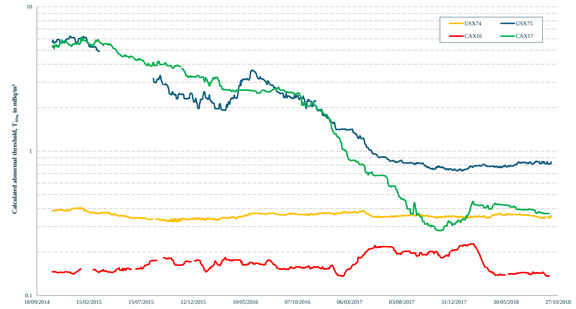

Fig. 7. Time series of T_{Abn} from Nov. 2014 to Oct. 2018 for the four CTBTO stations.

As expected from previous observations, T_{Abn} stayed rather constant over time at CAX16 ($\overline{T}_{Abn}$ = 0.08 mBq/m^3) and USX74 ($\overline{T}_{Abn}$ = 0.37 mBq/m^3) while it decreased by 7 at USX75 and by 14 at CAX17. Today, T_{Abn} looks stabilized at the four stations.

The categorization process was similarly affected by the shutdown of Chalk River. Practically, a detection of 1 mBq/m^3 of ^{133}Xe at USX75 or CAX17 would have been categorized as a Level B before shutdown in 2014. The same event would be categorized as a Level C today, after shutdown.

During the period 21 – 25 Oct. 2006, a small concentration of about 0.70 mBq/m^3 of ^{133}Xe was detected at CAX16. This detection was identified as a release from the 2006 DPRK nuclear test. Assuming that a nuclear test explosion of a similar yield is performed today within the same conditions (i.e. release of similar strength, similar dispersion pattern), that event would have possibly triggered a Level C at CAX17. Air masses transport parameters should be calculated to confirm that hypothesis. In that situation however, it would have been easier for States Signatories to interpret the detection at CAX16 and take following actions based on more solid information.

Preliminary conclusions

Radioxenon concentrations at stations with high sensitivity to emissions from Chalk River (CAX17, USX75) significantly decreased after cessation of production activities. ATM calculations confirm that the overall exposure of the stations did not differ significantly over years, indicating that the changes in detections history can be attributed to the facility shutdown. USX74 was less affected by air masses from the Chalk River area. The median value at the station only slightly decreased after shutdown, but there was a clear reduction in both extreme detections and dispersion. Finally, CAX16 was very rarely affected by air masses from the Chalk River area and therefore no change in the statistical parameters was observed. The facility shutdown impacted the categorization of IDC RN products provided to States Signatories. With the current radioxenon background configuration at CAX17 and USX74, detections will be categorized as Level C at much lower concentrations.