Forest fires in the surroundings of Chernobyl: follow-up of potential radiological aspects

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Summary: Forest fires have been reported, since April 4, in the restricted and contaminated zone around Chernobyl. Since April 9, a new seat of the fire started in the red forest area close to the Chernobyl nuclear power plant, which was still currently visible on satellite imagery on 13/04 AM. Locally, increased dose rate levels have been measured, indicating that radioactive material, especially Cs-137, has been re-suspended by the forest fires. This radioactive material can be transported with the smoke plume over long distances. Atmospheric transport simulations have been executed to track the plume and calculate potential activity concentrations at ground level for large parts of the Northern hemisphere. The particulate stations of the International Monitoring System running in the context of the verification of the CTBT are followed to investigate potential detections and learn more about the released quantities of Cs-137 during the forest fires. Currently six detections in the IMS can be potentially linked with the fires. In addition, Cs-137 measurements in Ukraine have been reported through the "Ring of Five". Based on experience from historic fires in this area and experiments, the amount re-suspended during these forest fires can be locally a radiation protection issue and it is also possible that traces can be measured at larger distances by ultra-low detection techniques like IMS but don't pose any health risk in Western Europe due to the very low radioactivity level at such distances. Due to the expected low levels of radioactivity at large distances from the fires, the detection of radioactivity in Belgium by the online surveillance system (TELERAD) of FANC is unlikely. Nonetheless, the ultra-low detection set-up for air-concentrations Snow White at SCK CEN could still be able to detect the presence of very low levels of Cs-137 in the air in Belgium.

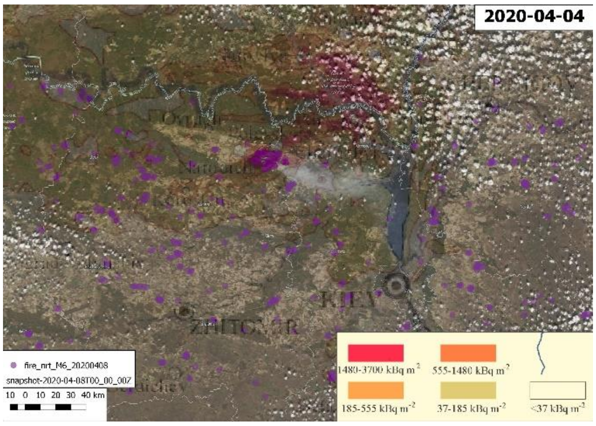
The Forest Fires

Forest fires have been reported, since April 4, in the restricted zone around Chernobyl. Such forest fires in the Cs-137 contaminated areas could release these historical contaminations to the atmosphere. Increased dose rate levels have been reported close to the forest fires. Dose rate levels, in the region around Chernobyl and other parts of Europe, have not been increased as can be learned from the EURDEP website.. However, Cs-137 detections in aerosol samples were reported in Ukraine at different locations (Ro5 information). These detections are discussed further in the following sections.

Satellite imagery, from MODIS Terra, shows clearly the forest fires around Chernobyl on 04/04 and on 13/04, as shown in Figure 1. As can be seen in the figure, the fires are still visible on the satellite image on 13/04 AM with a smoke plume close to the nuclear power plant in the highly contaminated areas. The forest fire close to the reactor, in the red forest, started to be visible on satellite imagery on the images from 09/04 AM. The region was covered by clouds on the satellite imagery on 14/04 (AM and PM) and 15/04 (AM), which covered any potential smoke plume. Different media have reported that the forest fires are now under control as rain has helped to extinguish part of the forest fires.

In the figure, the historical Cs-137 contamination reported in (UNSCEAR, 2000) is also shown and the corresponding legend is given in the figure. The purple dots are the fire and thermal anomalies reported by the Fire Information for Resource Management System on the relevant date.

2020-04-04 AM



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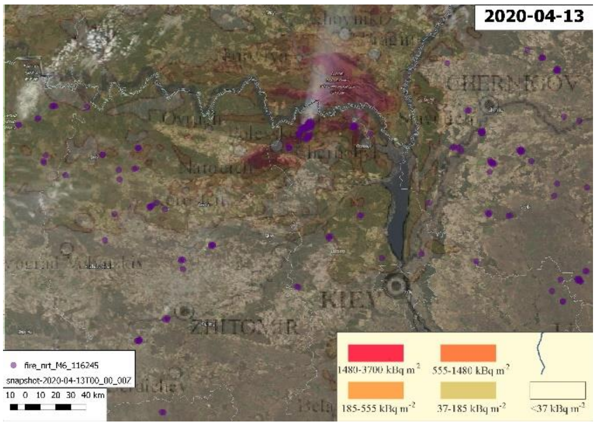


Figure 1 - Satellite image with the forest fires around Chernobyl.

Atmospheric Transport Modelling and potential impact on Belgium

In order to verify the trajectory of potential releases of the historical Cs-137 contamination in these forests due to the fire, the trajectory has been followed-up through Atmospheric Transport Modelling.

The spread of radionuclides through the atmosphere can be predicted using atmospheric transport and dispersion models. These models make use of numerical weather data (such as wind speed and wind direction) and release information to calculate radionuclide concentrations at any location and time. The release information, more specifically the location and time of the release, the amount of mass released and feedback on the height of the plume were taken from the Global Fire Assimilation System (CAMS – GFAS[1,2]). GFAS combines fire radiative power observations from satellite-based sensors, fire observations and meteorological information from the ECMWF to produce daily estimates of biomass burning emissions as well as information on the plume. Numerical weather prediction data was taken from the European Center for Medium-Range Weather Forecasts (ECMWF). The resulting atmospheric transport and dispersion calculations provide insight in how the fire plume containing Cs-137 moves through the atmosphere, as shown in Figure 2. The levels of Cs-137 released to the atmosphere are difficult to assess. For this reason the calculation is done for a unit release of 1 TBq Cs-137. Air concentrations shown have consequently to be scaled by the currently unknown real release quantity. The source term will be refined in the following days with the use of the observations in the IMS network or communicated by national institutes via the Ro5.

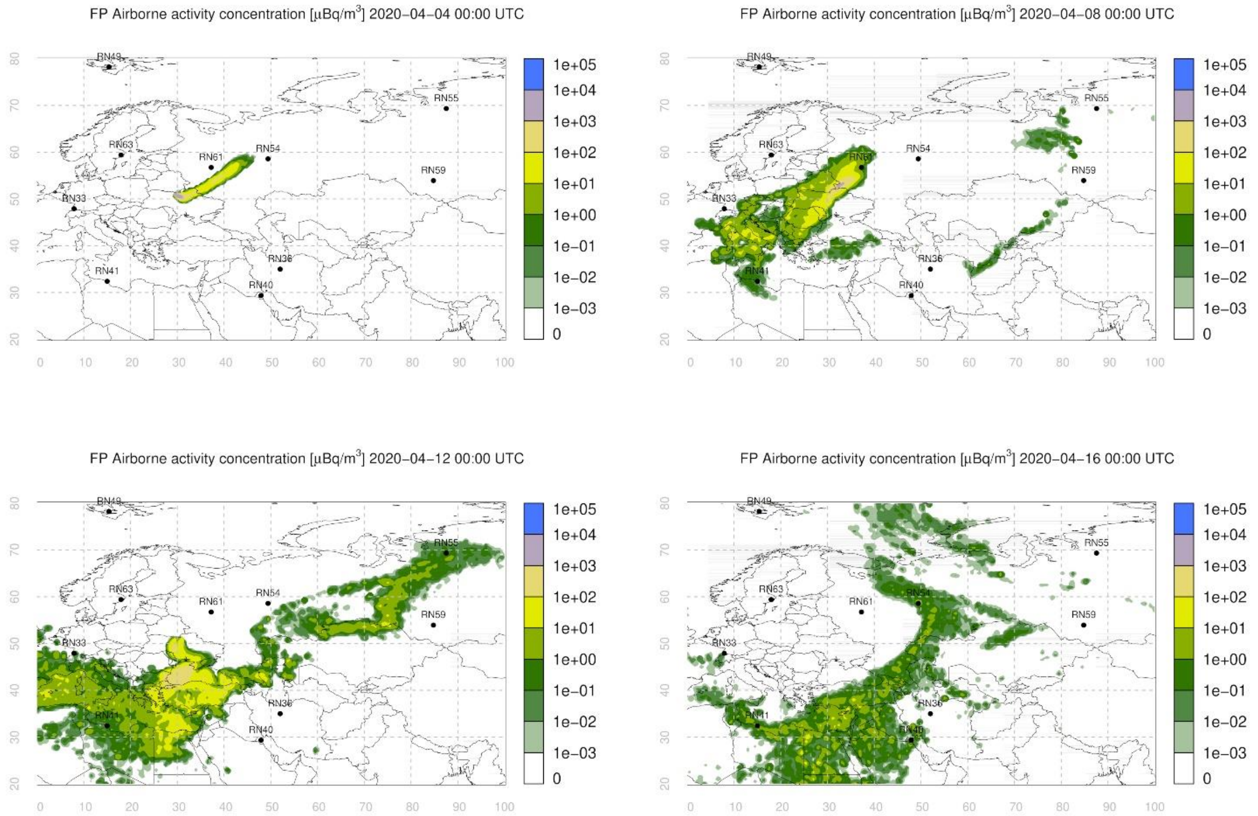


Figure 2 - The plume of radionuclides at different times as simulated by the atmospheric transport and dispersion model. The calculation is done for a unit release of 1 TBq Cs-137.

The atmospheric transport simulations allow to construct simulated activity concentrations at any location. This helps to select which stations are most likely to detect radionuclides in the coming days. In Figure 3, an example is shown for IMS stations potentially affected by radionuclides released from the forest fires. Note that the concentrations in Figure 2 and Figure 3 should be interpreted with care: they provide an estimate assuming a release of 1 TBq, which is likely an overestimation. If detections are reported, the simulations can be rescaled to match the detections. That way, the source term is rescaled and the simulations refined. If no detections are made, the station detection threshold can still help to define an upper bound of the release.

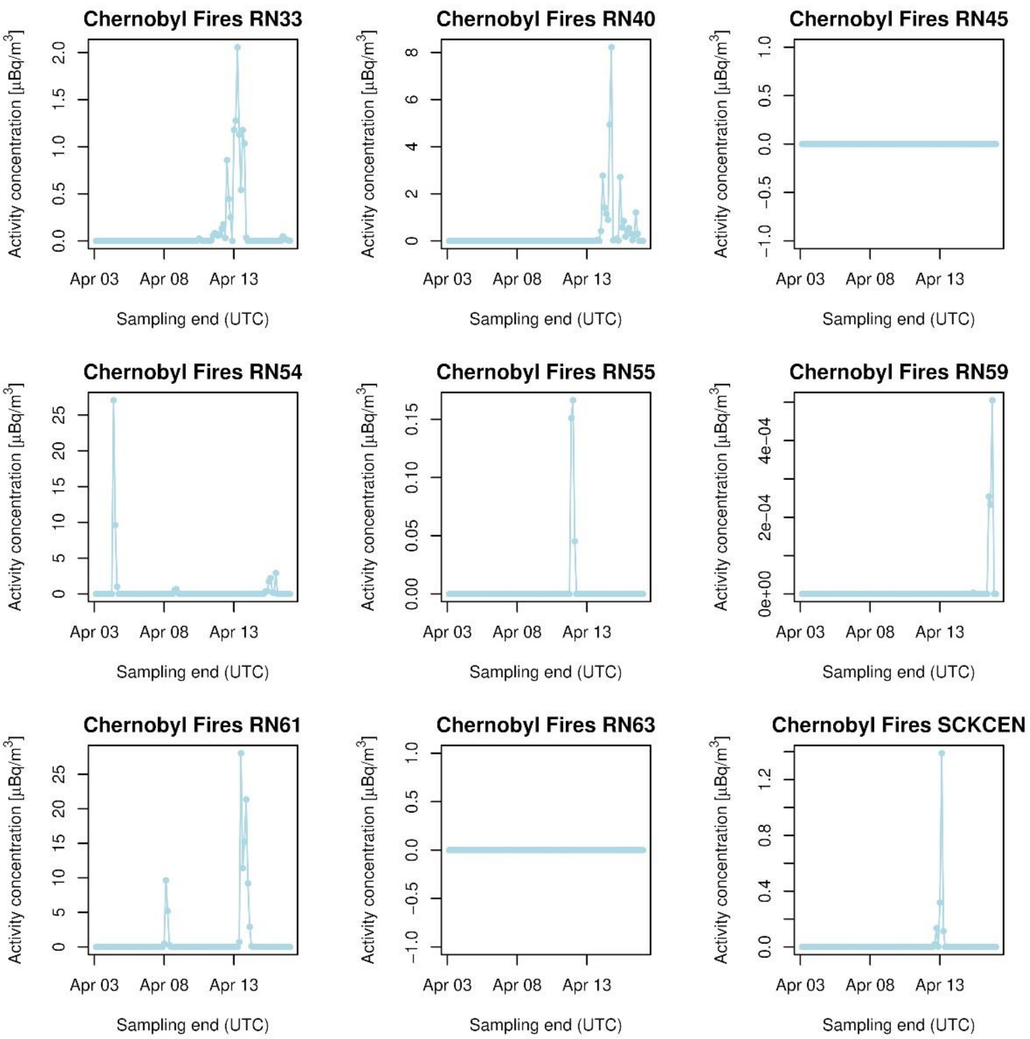


Figure 3 – Atmospheric transport modelling of the Cs-137 activity concentration at relevant IMS stations and at the Snow White system at SCK CEN.

The potential radioactive contamination of the plume is expected to be too low to be measured in Belgium by the online surveillance system (TELERAD) of FANC and will thus not represent a safety concern in Belgium. As will be discussed in the following section, the Snow White air sampling system at SCK CEN could potentially measure such very low levels of radioactivity. As shown in Figure 3, the expected activity concentration at the Snow White location would be around 0.035 µBq/m^3 for a weekly sample with the assumption that the released amount is 1 TBq.

Potential Radioactivity Detection in Belgium (Snow White at SCK CEN)

The SCK CEN operates an ultra-sensitive system for the detection of ultra-low levels of radioactivity in the air. The system is sampling air for a week, followed by a few days of decay to decrease the contribution of the natural radioactivity in the sample, which allows to enhance the detection capability for artificial radionuclides. Finally, the sample is measured for at least one day but this period can also be extended depending on the detection level to be reached. This means that there is a delay of at least a few days between the end of the sampling and the results of the measurement. For the moment, the relevant sample has not yet been measured as it is currently in the decaying period. It is important to note here that the purpose of this system is not for emergency planning (where fast results are needed) in Belgium, for which the FANC operates the TELERAD network, but rather to monitor the air for ultra-low detections of artificial radionuclides which do not pose any health concern but still needs to be characterized to understand events that release small amounts of radioactivity in Belgium or larger amounts outside Belgium (where the atmospheric transport will dilute the amounts that can be measured in Belgium).

Potential Radioactivity Detections outside Belgium (IMS, Ro5)

The radionuclide monitoring stations of the International Monitoring System (IMS) for the verification of the Comprehensive nuclear-Test-Ban Treaty (CTBT) are closely followed-up for potential Cs-137 detections. The stations have a very low detection limit and collect samples of air over 24 hours. 4 IMS stations are relatively close to Chernobyl: RUP61 (Dubna, Russia), RUP54 (Kirov, Russia), DEP33 (Freiburg, Germany) and SEP63 (Stockholm, Sweden). The location of these stations are shown in Figure 4. In addition, at larger distances the following stations are also closely followed-up: KWP40 (Kuwait City, Kuwait), RUP59 (Zalesovo, Russia), RUP56 (Peleduy, Russia) and MNP45 (Ulaanbaatar, Mongolia).

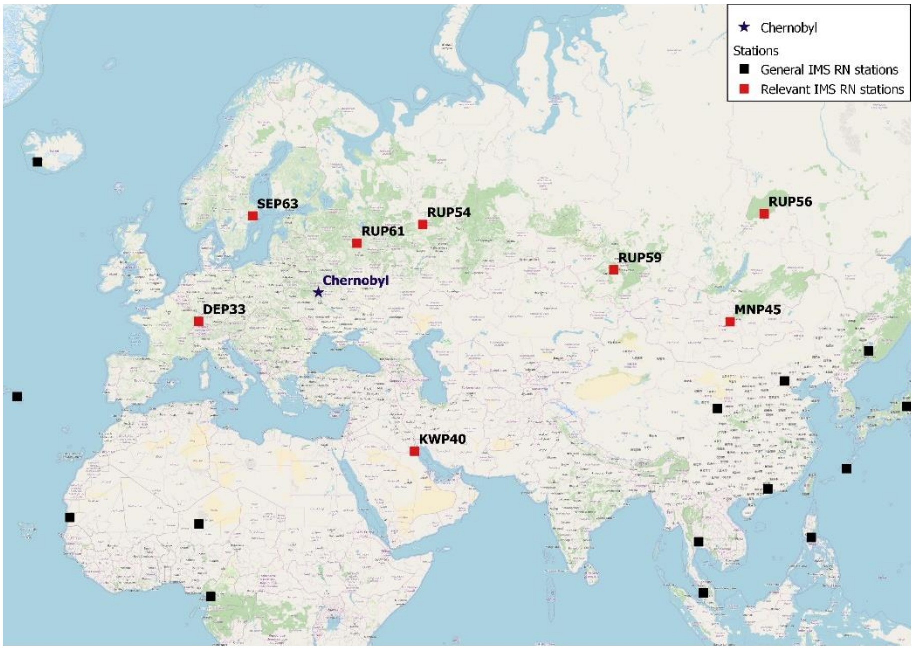


Figure 4 - Location of the IMS radionuclide stations (squares) in the surroundings of Chernobyl. The IMS RN stations that are currently followed-up are indicated by the red squares.

The spectra of the samples from 03/04 to 13/04 (last samples available) at DEP33, KWP40, RUP54, RUP59, RUP61, RUP56, MNP45 and SEP63 were reviewed. Nine relevant Cs-137 detections were observed in this period and at these stations as shown in Table 1. It should be noted that only four detection (at RUP54 on 05/04, MNP45 on 13/04 and KWP40 on 09 and 10/04) were above the Minimum Detectable Concentration (MDC), all the others were below and have thus a higher probability of being false positives.

Table 1 - Relevant Cs-137 detections in the region during the period from 03 to 13 April.

Station	Collection stop	Cs-137 [$\mu Bq/m^3$]	Unc. [%]	MDC [$\mu Bq/m^3$]	Chernobyl possible source (based on SRS – CTBTO)
RUP54	04-04-2020 04:46	1.01	32.04	1.58	Yes
RUP54	05-04-2020 05:16	3.89	8.64	1.27	Yes
RUP54	11-04-2020 05:18	0.89	29.88	1.27	Yes
RUP61	08-04-2020 07:15	1.98	23.32	2.24	Yes
RUP61	09-04-2020 07:31	1.71	26.90	2.27	Yes
KWP40	08-04-2020 06:51	3.49	23.71	4.00	No
KWP40	09-04-2020 06:51	5.25	16.68	4.12	No
KWP40	10-04-2020 06:51	5.40	15.00	3.73	No
MNP45	13-04-2020 03:24	19.1	6.29	4.53	Yes

To estimate the possible origin of the detections in the IMS, the CTBTO provides Source-Receptor Sensitivity (SRS) fields for each sample. The SRS fields are the results of the inverse modelling of the atmospheric transport, *i.e.* starting from the detection at an IMS station and tracking back in time the atmospheric transport, and provides what can be seen as a dilution factor between the location of the detection and each grid cell of the calculation domain. This means that the higher the SRS value, the lower the source term needs to be to explain the observed detection. In this manner, locations with a high SRS value are more likely (as the likelihood of low releases are higher than the likelihood of high releases).

Based on the Source-Receptor Sensitivity (SRS) fields provided by the CTBTO for each sample, the detections at KWP40 cannot originate from the Chernobyl region as the possible source region is staying over the Middle East, Northeast Africa and North Africa from 03 April onwards. The SRS fields for the six other samples are showing that the Chernobyl region could be a possible source for the Cs-137 detection. The SRS fields for each sample at relevant timings are shown in Figure 5. Based on the SRS fields; the Cs-137 detection at KWP40 will thus not be analyzed further.

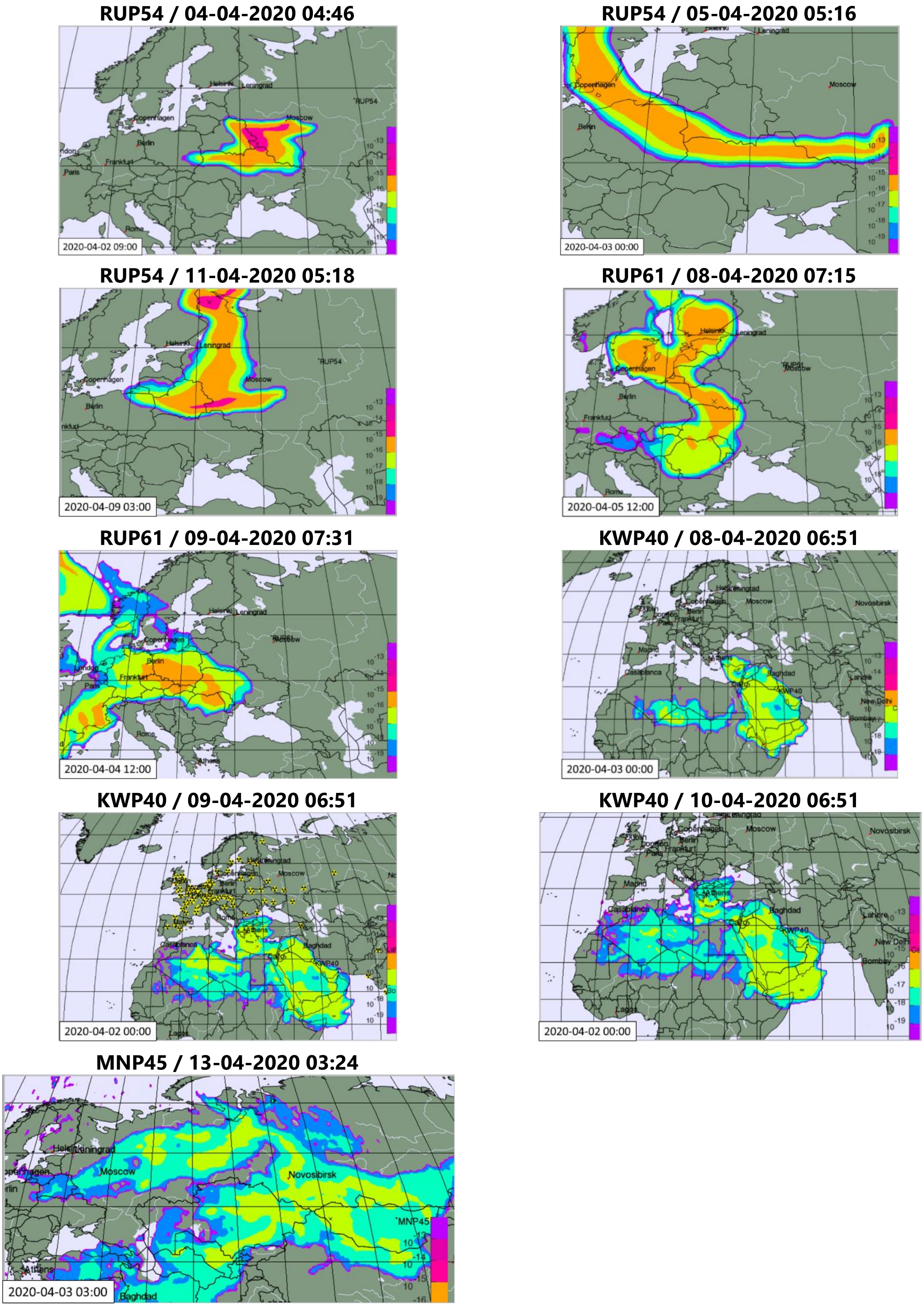


Figure 5 – SRS fields for the relevant Cs-137 detection in the IMS over the period from 03/04 to 13/04.

Cs-137 detections are quite often seen at RUP54 and RUP61. This is highlighted by the yearly detection rate of Cs-137, as shown in Table 2, since 2013. The detection rate of Cs-137 at MNP45 is much lower for the period from 2013 to 2017 included as shown in the Table 2. However since 2018, the detection rate has increased significantly at this station and Cs-137 is thus regularly observed in recent years. This seems to suggest that a new background source of Cs-137 is since then contributing to the Cs-137 background at this station.

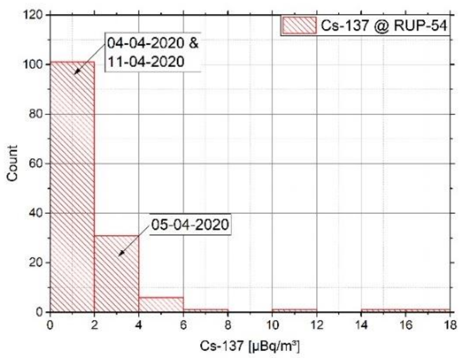
The yearly detection rate is the amount of samples where the CTBTO flagged the presence of Cs-137 on the amount of samples taken by the station over the corresponding year. These regular Cs-137 detections are part of the radiation background from the normal operation of civilian nuclear facilities. One should remember here that these monitoring systems are ultra-sensitive and can detect very small amounts of radioactivity in the air.

Table 2 - Detection rate of Cs-137 at RUP54 and RUP61 since 2013. The detection rate is based on the number of flagged detections by the CTBTO during each time period.

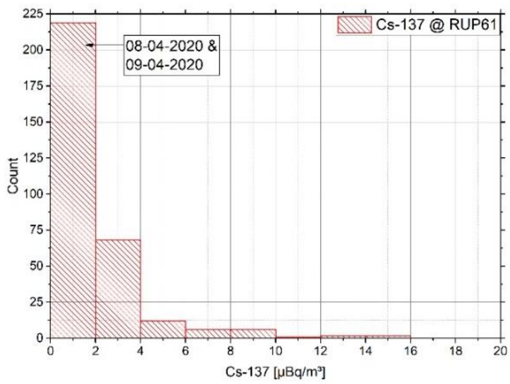
	Detection Rate Cs-137 [%]		
Year	RUP54	RUP61	MNP45
2013	5.0%	17.7%	0.0%
2014	5.8%	14.5%	0.3%
2015	6.6%	13.3%	1.4%
2016	3.8%	6.9%	0.6%
2017	7.8%	6.5%	3.0%
2018	10.7%	13.5%	10.0%
2019	8.9%	22.8%	9.7%

In addition to the detection rate, the distribution in Cs-137 activity concentration since 2013 was investigated at each station. The distribution plot is shown in Figure 6, where the specific Cs-137 detections observed at RUP54, RUP61 and MNP45 in the period from 03 to 13/04 are also shown. The detections at RUP54 and RUP61 are thus clearly within the normal Cs-137 background observations in the history of the stations. However, the Cs-137 detection at MNP45 on 13/04 is clearly on the higher end of the historically observed Cs-137 activity concentrations.

RUP54



RUP61



MNP45

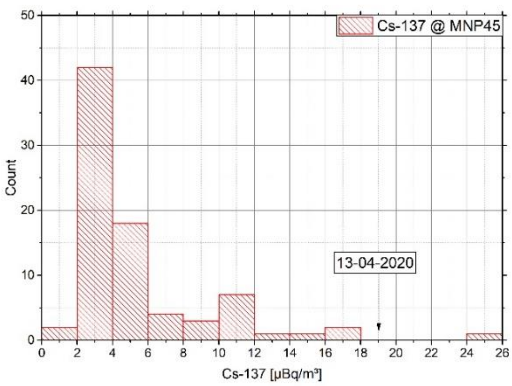


Figure 6 – Distribution of the Cs-137 activity concentration at RUP54 [top left], RUP61 [top right] and MNP45 [bottom left] since 2013. The relevant Cs-137 detections in the period from 03 to 12/04 are highlighted in the distribution plot.

The IMS radionuclide network will continuously be followed-up in the coming days to check if any other Cs-137 detection is seen in the network and further investigation of the Cs-137 detections at RUP54, RUP61 and MNP45 will be performed. Even though the detections at RUP54 and RUP61 are within the Cs-137 background, the timing of some of these detections are clearly in agreement with the expectations from the atmospheric transport modelling and could thus originate from the forest fires around Chernobyl. The timing of the detection at MNP45 is not in agreement with the latest atmospheric transport modelling results, as no detection at all would be expected at MNP45.

It has to be noted that the samples in the IMS are collected over 24 hours, followed by a 24-hour decay period to decrease the short-lived isotopes from the background and then again followed by a 24-hour acquisition of the spectrum. This means that there is at least a 48h delay between the end of the collection and the reporting of the spectrum.

Via the Ro5 (Ring of 5 network: an informal network of institutes in Europe performing measurements of ultra-low levels of radioactivity in the environment), we were informed about Cs-137 air-concentration measurements in Ukraine. Measurement results are reported at 5 locations (the results for some stations are provided up until 13/04/2020). These locations are shown in Figure 7. At 4 locations, Cs-137 has been observed (not at ZNPP) with the highest values measured in Kiev on 10 and 11/04/2020 reaching levels of 700 $\mu Bq/m^3$. If we assume that this maximum value of 700 $\mu Bq/m^3$ will stay in Kiev for 7 days (1 week), people will have inhaled (inhalation rate 1 m^3/h) around 0.12 Bq. This has to be compared with 8000 Bq of natural radioactivity present in the body at any moment.

The Ukrainian colleagues provided also an assessment of the potential source term released. They obtained an estimated daily release of 15 to 16 GBq/day for the period from 8 to 10/04/2020 and lower daily releases before 8/04 (around 4 GBq/day).

Also information was obtained via Ro5 on Cs-137 ultra-low level detections in Milano, Prague and Bilthoven: no abnormal detections were observed.

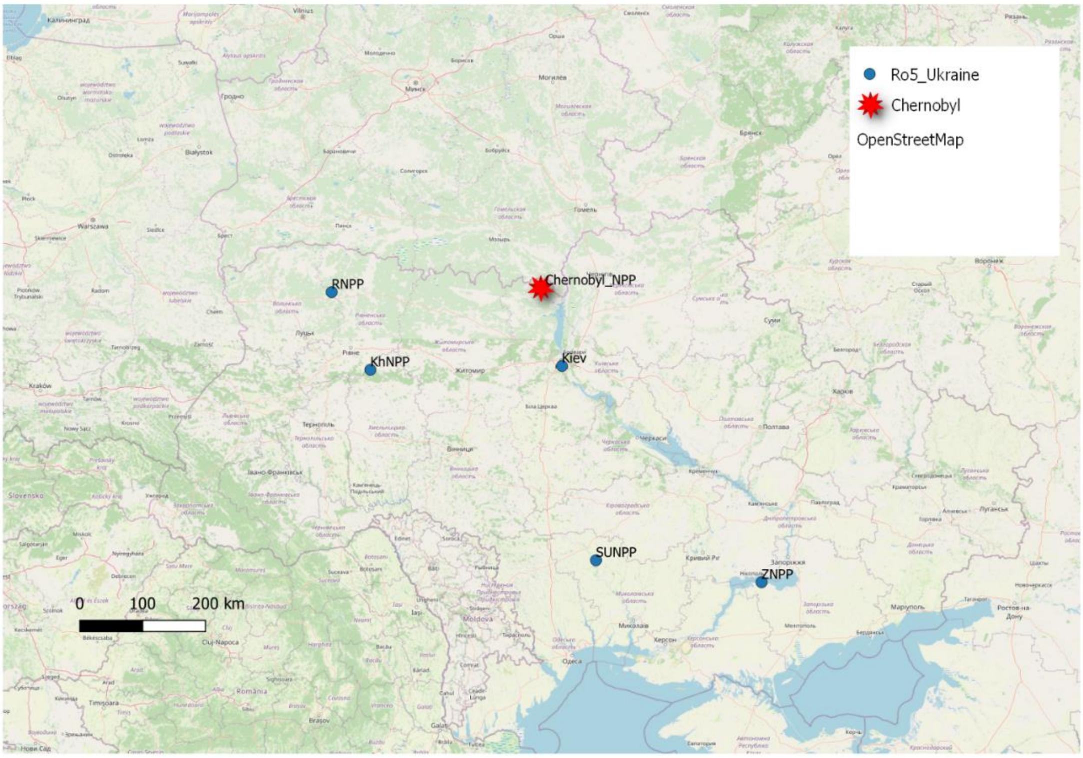


Figure 7 – Location of the measurements of radioactivity in the air in Ukraine as reported through the Ro5.

Using the activity concentration measurements distributed through the "Ring of Five" and high resolution atmospheric transport modelling, we performed an accumulated release estimate by using Bayesian inference. The result is shown in Figure 8. The accumulated release is estimated to be between 86 GBq and 2.9 TBq. These results will be refined in the next days, as more data will be integrated in the analysis. The lower bound of the estimate is in line with what the Ukrainian colleagues reported.

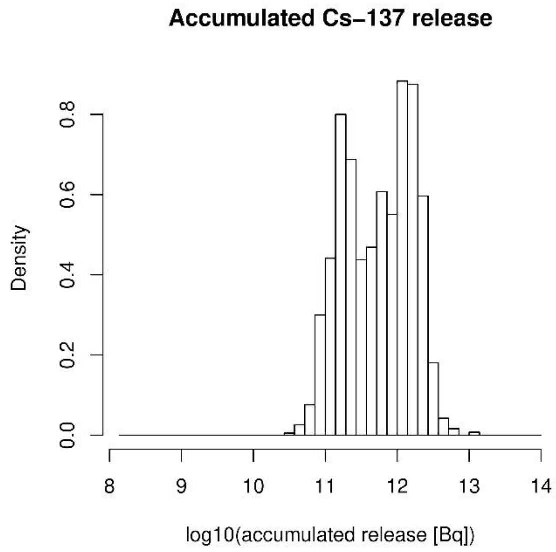


Figure 8 – Accumulated release, on a logarithmic scale, estimated using Bayesian inference.

References

UNSCEAR. (2000). *Exposures and effects of the Chernobyl Accident.* UNSCEAR.

[1] http://apps.ecmwf.int/datasets/licences/copernicus/

[2] http://atmosphere.copernicus.eu/sites/default/files/repository/CAMS_data_license.pdf