Measurements and Dispersion Calculations by the Deutscher Wetterdienst Regarding the Release of Radionuclides at Fukushima

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In Germany, surveillance of radioactivity in the atmosphere has been a special task of the Deutscher Wetterdienst (German Meteorological Service) since 1955. This also involves the computation of dispersion forecasts, which provide information about the transport, and the provision of measurements. The activity concentrations of airborne radionuclides are continuously measured at 48 measuring sites in Germany while precipitation samples are collected and measured at 40 sites. In addition, aircraft measurements supply information on radionuclide concentrations in the upper atmosphere.
Shortly after the release of radionuclides due to the explosions at the Fukushima Daiichi nuclear power plants, regular calculation of dispersion forecasts was started at the Deutscher Wetterdienst. The results were published on the Internet, with graphs describing the pathways of possibly contaminated air parcels. Two weeks after the event, the volatile radionuclides Xe-133, I-131, Te-132, I-132, Cs-134 and Cs-137 arrived in Europe and were measured over Germany at magnitudes of several mBq/m^3 using nuclide specific measuring systems. In addition, I-131 was also detected by aircraft measurements.

Key words: Trajectories, dispersion calculations, measurement of radionuclides, aircraft measurements

1. Release of radionuclides following the breakdown of the cooling system at the Fukushima Daiichi nuclear power plant

The devastating earthquake and ensuing tsunami that struck Japan on 11.03.2011, have destructed large parts of the infrastructure in the coastal areas of north-eastern Japan. This also concerned the four reactor units of the Fukushima nuclear power plant as well as the reactor fuel ponds. Due to the loss of the electrical power, cooling of the fuel elements was no longer possible so that three of the reactors overheated, which was followed by a partial core melt. The following explosions damaged the reactor buildings and radioactive reactor material was released into the environment. On 15 March, dose rates of up to 400 mSv/h were observed according to the information of International Atomic Energy Agency (IAEA). Evacuation of the population from the 20-kilometre zone around Fukushima Daiichi was directed by the Japanese authorities, and people within a 30-km radius were advised to take shelter indoors. Depending on the meteorological dispersion conditions, radionuclides dispersed differently in the eastern and northern sectors and caused significantly increased dose rates [1]. Protection measures for the population were taken according to Japanese regulations.

2. Monitoring of environmental radioactivity in Germany

Unlike the nuclear accidents of Harrisburg (1979) and Chernobyl (1986), the seriousness of the situation at the nuclear power plant site of Fukushima was a global media event from the first minute. All the world's eyes were on Japan when the explosions happened, could see and, at the same time, judge the measures taken for the protection of the people.
Far away from the events, in Germany, radiation experts from the respective authorities and ministries had to answer the public's questions:

- Where will the radioactively contaminated air be transported to?
- How long will it take?
- What activity concentrations are to be expected for Germany?
- Is such an accident also possible in German nuclear power plants?

The technical issues of radioactivity measurements are regulated by the provisions of the German Precautionary Radiation Protection Act. In consequence of the nuclear accident at Chernobyl (1986), the entire system for the monitoring of environmental radioactivity was reorganised and new laws were put in place [2,3]. All respective federal and regional authorities were included in an 'Integrated Measuring and Information System for the Surveillance of Environmental Radioactivity' (IMIS), which rules the distribution of tasks at times of normal operation as well as in the event of a crisis situation. There is a clear delineation and separation of measurement-taking institutions and those responsible for evaluation. The responsibility for the evaluation and presentation of results to the public lies with the Federal Office for Radiation Protection (BfS) and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

The monitoring of the atmosphere is assured by

- Deutscher Wetterdienst (DWD)
  Provision of dispersion forecasts, measurement of activity concentrations in the atmosphere and in precipitation at 48 measuring sites, trace measurements at the measuring sites Offenbach and Potsdam, aircraft measurements in the upper atmosphere;
- Federal Office for Radiation Protection (BfS)
  Measurement of gamma radiation dose rates at 1800 measuring sites, trace measurements at the measuring sites Freiburg/Schauinsland, helicopter measurements;
- Federal Institute of Physics and Metrology (PTB)
  Trace measurements at the measuring site Braunschweig.

In case of need, the DWD calculates trajectories and concentration distributions with the products being available 10 and 30 minutes later, respectively, in order to determine the direction and time of atmospheric transport as well as, provided that the source term is known, the order of magnitude of activity concentrations.

On the basis of such information, the BfS decides on measures to be taken for protecting the population. The measurement configurations used for monitoring the atmosphere cover a relatively wide range of concentrations. For determining even minor activity concentrations in the air, as laid down in the General administrative provision for the surveillance of radioactivity in the air (AVV-IMIS)[4], the BfS, DWD and PTB operate sampling and measuring instruments suited for the analysis of low activity concentration. Four of the measuring sites are also part of the Sparse Network pursuant to Articles 35/36 of the EURATOM treaty: Schauinsland (BfS), Berlin (now Potsdam, DWD), Offenbach (DWD), Braunschweig (PTB).

For aerosol-bound gamma-emitting radionuclides, low activity concentrations of few 100 nBq/m^3 can be measured at high volume flow rates of 1000 m^3/h, measurement periods of > 24 hours and a sampling period of one week.

3. Dispersion calculations by the Deutscher Wetterdienst

As part of its tasks within the IMIS network [5], the DWD already calculated the first trajectories on 11 March 2011 and made them available in IMIS. The calculation results were transmitted to IMIS on a daily basis, after the 14.03.2011 even twice per day. From 15.03.2011 on, the results were also published on the DWD website (Fig. 1: Trajectory of 15.03.2011). Trajectories predict the movement of air masses up to about 172 hours ahead. The calculations gave rise to the assumption that the air masses would be transported towards northern Europe across the polar region.

From 18.03.2011, the trajectories were replaced by the more meaningful concentration forecasts. The dispersion calculations were initialised from the current numerical weather forecasting model and the Lagrange Particle Dispersion Model (LPDM). The data were available at 6:00 UTC and 18:00 UTC. The model assumes a continuous point source at the site of the Fukushima Daiichi plant, beginning at the respective starting date of the meteorological forecast model. There were no data available on the actual release of radioactivity. Therefore, the model was run with assumed values. The distribution of concentrations can be illustrated using a colour scale. In addition to the near-surface concentrations averaged over the lower 500 metres of the atmosphere, wet and dry deposition fields are shown, displaying the accumulated depositions from one forecast date to the next as well as being the model sink for the computed activity concentrations in the air (as the mean between two forecast dates). All values are available at 6-hour intervals, computed up to 120 hours into the future (Fig. 2: DWD dispersion calculation, beginning on 18.03.2011). Dispersion calculations are of higher information value due to the fact that they also simulate activity distributions and the depositions to be expected. The results from the dispersion calculations led to the assumption that air masses were expected to be carried over the Pacific and the Atlantic Ocean towards Europe as well as to arrive in northern Scandinavia across the polar region.

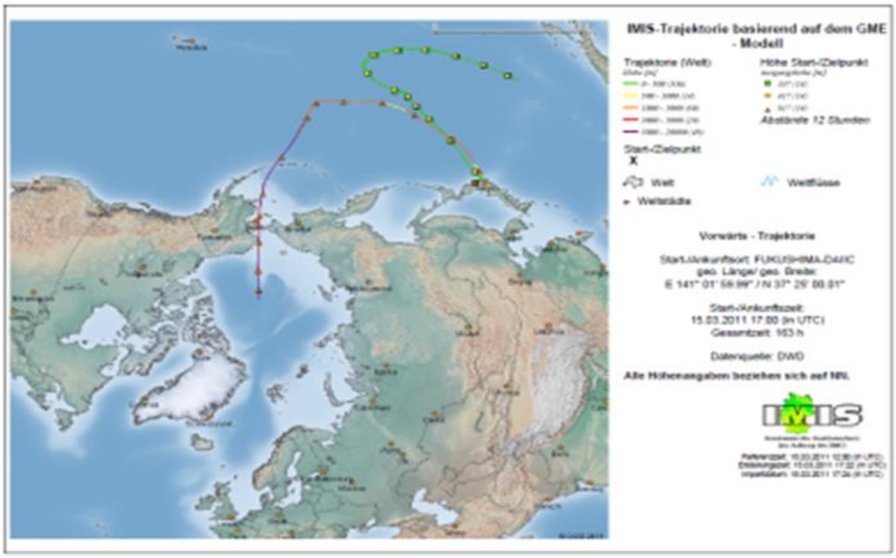

Figure 1: Trajectories starting from Fukushima 15 March 2012, 17 UTC

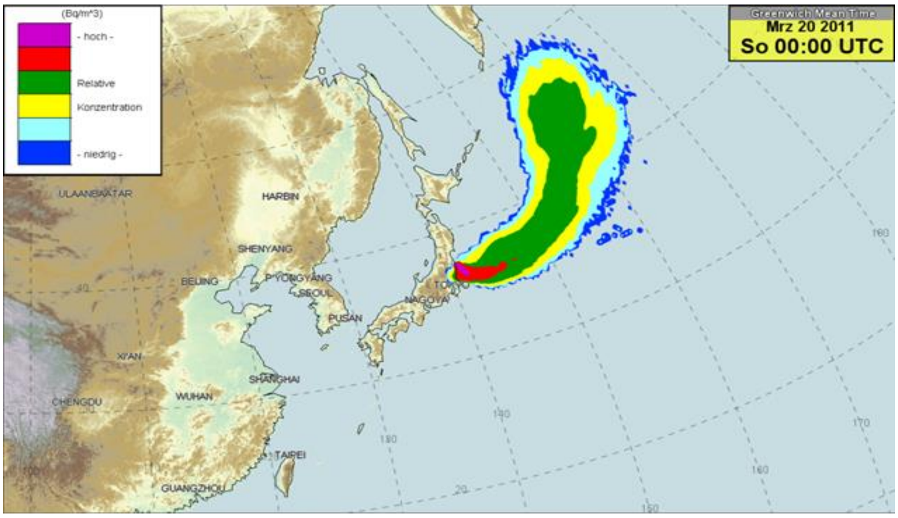

Figure 2: Dispersion calculation 48 hours after an assumed release of radionuclides

Information obtained through international collaboration

As agreed internationally, dispersion calculations were carried out by 'Regional Specialized Meteorological Centres' (RSMC) and the results made available to the International Atomic Energy Agency (IAEA). The data were furthermore distributed by the DWD, in its role as a communication hub of the World Meteorological Organization (WMO), to the meteorological institutions around the world [6]. The RSMCs responsible for the Japanese region are located in Obninsk (Russia), Peking (China) and Tokyo (Japan).

The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) operates a global network of (currently) 60 operational radionuclide measuring stations, where the air is analysed for γ-emitting radionuclides attached to aerosols on a daily basis. In addition 27 of these are equipped with systems for measuring radioactive xenon isotopes. Thanks to this global network, the BfS received timely information at an early stage [7]. As early as on 14.03.2011 and 15.03.2011, the measuring stations of Petropavlovsk (Kamchatka) and Takasaki in Japan, respectively, recorded artificial radionuclides originating from Fukushima. It was possible to verify the dispersion calculations using the data provided by the CTBTO network. There were not many records of radionuclides from Fukushima in the southern hemisphere, which can be explained by the very little exchange of air masses between the northern and the southern hemispheres. Only New Guinea and the Fiji Islands, which then were still under the influence of air masses from the northern hemisphere (spring position of the intertropical convergence zone) shortly recorded traces of radioactivity from Fukushima.

The measurements as well as the continued dispersion calculations made it possible to relatively precisely predict the middle/end of the twelfth calendar week as the time when contaminated air was to arrive in Europe and to prepare the measuring sites as well as to initiate aircraft measurements.

The network of trace measuring sites in Europe (Ring of Five, ro5) provided first measurements of I-131 in Iceland as early as 20.03.2011, thus making reliable forecasts possible on the arrival of radioactively contaminated air masses in central Europe. Nearly all results of measurements taken in Europe were collected together and published [8]. Simulations were computed using the various meteorological data available and an emission scenario which was provided by IAEA in co-operation with the WMO and the Canadian Meteorological Center (CMC). For Wednesday, 30.03.2011, these 'hindcast' simulations produced daily mean I-131 concentrations in the range of few mBq/m^3 (vertical mean 0–1,500 m). For computing the scenario, source term estimates based on varying emission strengths were taken into consideration. The computed values agreed relatively well with the measurements.

4. Trace measurements at the measuring sites of the Deutscher Wetterdienst

The DWD's nuclide-specific measurement equipment is operated all day round at 41 measuring sites. Aerosol particles are accumulated on a filter tape at a volume flow rate of 10 m^3/h and are measured by means of gamma spectrometry. During alarm operation, the filter tape is conveyed every two hours so that a fresh filter area is available. Increased activity concentrations of aerosol-bound radionuclides, such as I-131, can be determined within 2 hours with a detection limit of 10 mBq/m^3. In normal operation, the data are transmitted to the DWD headquarters on a daily basis, whereas in alarm operation the data are transmitted every two hours.

In view of the events of the accident and the long transport distance, highly volatile radionuclides with activity concentrations in the range of few mBq/m^3 had to be expected. From 23.03.2011, the sampling frequency at the four German trace measuring sites was therefore increased from weekly to daily sampling in order to obtain data of higher temporal resolution, but with an increasing limit of detection. In addition to the monitoring systems, filters were exposed for more than 24 hours to a volume flow rate of approximately 1000 m^3/h and then subjected to gamma-spectrometry with a detection limit of approximately 10 $\mu Bq/m^3$. The resulting measurements were summarised by the co-ordination centre for trace analyses at the BfS, transmitted to the BMU and IAEA as well as the European Union (EU) and entered into the Electronic Situation Display System for Emergency Preparedness (ELAN) of the BfS. As agreed between the BMU and the trace measuring institutes, the measurement results were centrally published through the BfS' website. In addition, the institutes published co-ordinated versions of their measuring results on their own websites. The measurements from the trace measurement sites in Germany were presented in the German professional journal 'StahlenschutzPraxis [7], together with the I-131 and Cs-137 data recorded in Switzerland and Austria.

On 23/24 March, the DWD's measuring stations recorded increased values for I-131: 130 µBq/m^3 at Offenbach and 230 µBq/m^3 at Potsdam. In addition to I-131, the radionuclides Te-132, I-132, Cs-134, and Cs-137 were also detected. The activity concentrations for I-131, Cs-134 and Cs-137 at Potsdam in dependence of the daily sampling periods are shown in figure 3. The activity concentration of gaseous radioactive iodine could not be measured because of the high detection limit provided by the measurement configuration (1 mBq/m^3). Selected samples were analysed by radiochemical procedures but no alpha-emitting radionuclides and strontium isotopes were detected.
A selection of air samples was analysed by the DWD to determine the activity concentrations for the radioactive noble gas Xe-133. At first, the samples were analysed on a daily basis. Later on, the sampling intervals were increased to 2 and 3 days. The maximum value recorded at Offenbach for Xe-133 was 2.5 Bq/m³ (fig. 4). The temporal development corresponds to the measurements recorded for the highly volatile radionuclides I-131 and Cs-137.

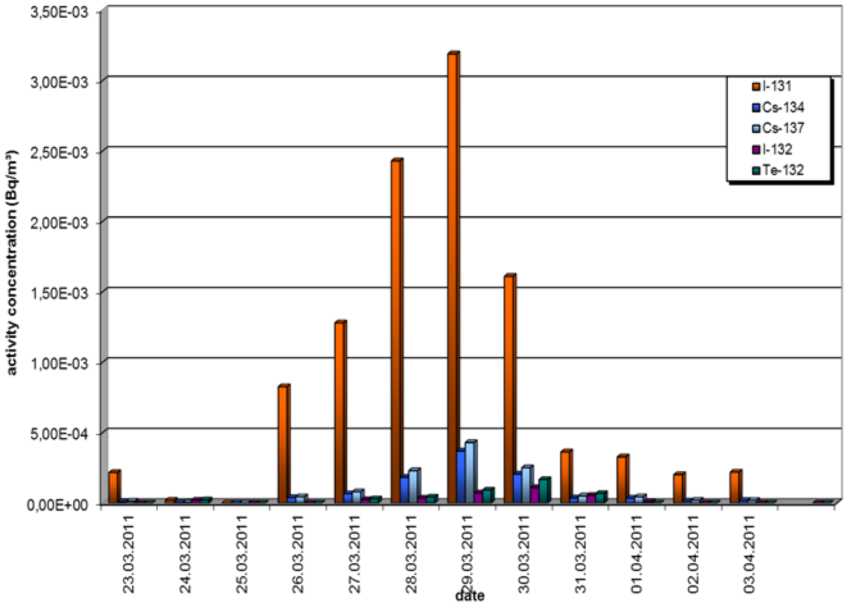

Figure 3: Activity concentration of volatile radionuclides at the Potsdam measuring site (DWD

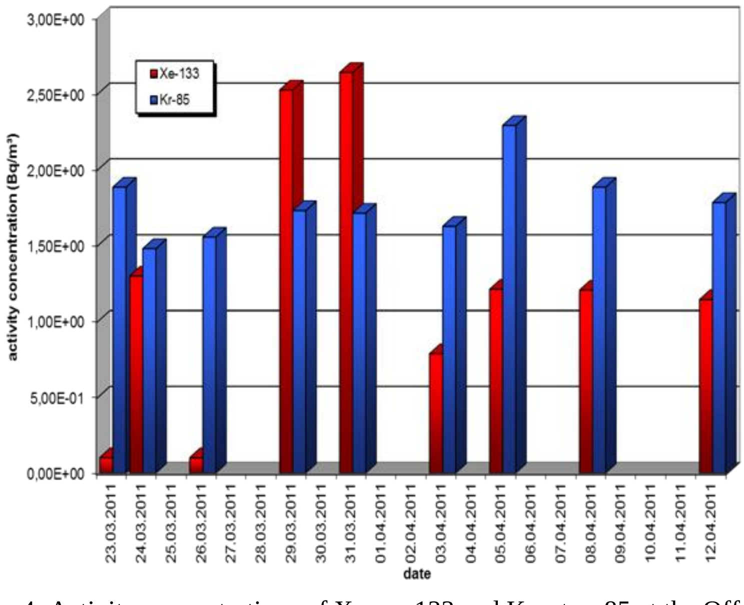

Figure 4: Activity concentrations of Xenon-133 and Krypton-85 at the Offenbach measuring site (DWD)

Between 27.03.2011 and 29.03.2011, the continuously measuring air monitoring systems at some of the DWD's measuring sites, too, showed significantly increased values of 10 mBq/m^3 to 20 mBq/m^3 for I-131 in 2-hour sampling intervals, with measurement uncertainties of approximately 30%.

The near-ground measurements were complemented by aircraft measurements of the DWD [9]. There is a Learjet available, which is equipped with a sampling device for aerosol particle and air as well as a transportable gamma-spectrometer, a system for measuring artificial alpha and beta activity and a dose rate meter. The aircraft measurements were carried out on 23.03.2011 by the German company enviscope GmbH and the air company Gesellschaft für Flugzielerfassung (GFD, Corporation for Airborne Target Representation), in co-operation with the German Aerospace Center (DLR) and their research aircraft FALCON 20E. A second measurement flight took place on 30.03.2011, this time without the DLR. The measurements taken on 23.03.2011 revealed no activity concentrations above the detection limits. As expected, increased dose rates were not detected. During the second measurement flight carried out on 30.03.2011 over northern Germany I-131 activity concentrations of 1.7 mBq/m^3 were measured at a height of 10,000 m; another flight at 4,000 to 5,000 m revealed an activity concentration of about 2.6 mBq/m^3 for I-131. This agrees with the results from measurements taken on 30.03.2011 in Switzerland where an activity concentration of approximately 1.9 mBq/m^3 for I-131 was recorded at 7,900 m.

Figure 5: Aircraft sampling system for aerosols

From 21.04.2011, in agreement with the BMU, the sampling intervals were changed from daily to every two or three days and from 09.05.2011 onwards back to the weekly interval of normal operation as the activity concentrations for I-131 were almost at the limit of detection or even below at times.

5. Lessons learnt from Fukushima

International agreements among the meteorological partners within the WMO as well as between the WMO and IAEA regulate the provision of dispersion forecasts. The meteorological data are made available to any of the meteorological services. Thanks to this, the DWD was in the position to run and then publish its dispersion calculations, harmonized with BMU. A somewhat problematic task in this context is evaluation of the results under radiation protection aspects and, ensuing therefrom, in the light of civil protection aspects. At first, there had been no reliable source term available from the Fukushima site. Hence, the concentration forecasts were always mentioned to be assumptions. However, this is not always understood in the right way. The population in Japan appreciated greatly the publication of the German dispersion forecasts on the Internet, which were mainly meant to inform the people in Germany about possible global atmospheric transports.

At almost two weeks, the lead time for the measurements in Germany was quite long. It was proven that Germany has provided for a measurement infrastructure which is capable of detecting even smallest activity concentrations in the atmosphere or identifying activity concentrations in the range of only few mBq/m^3 for I-131 and Cs-137 within 2 hours.
The most outstanding experience, however, was to see that the population's need for information - and thus that of the media - is higher than thought within the concept of IMIS. The presentation of information on the Internet or via social networks, such as Facebook, requires urgent revision. In contrast to the provisions of IMIS, it was agreed with the BMU to also publish the measurements nearly simultaneously on the websites of the institutions taking the measurements, with the proviso that the radiological assessment by the BMU was published on the BMU's and BfS' own websites. Therefore, the possibilities for rapid provision of dispersion forecasts and publishing of measurements (including explanations for the public) must be improved for the future.

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