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A probabilistic approach for determining potentially affected areas for accidental releases

Astrid Kloosterman[1],Chris Twenhöfe1[1], Teun van Dillen[1], and Jasper Tomas[1]

[1] National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands

Abstract: Protective measures such as evacuation, sheltering, and iodine thyroid blocking can avoid or reduce health effects due to exposure to released radioactivity in the air during a nuclear accident. Preparation of these protective measures demands insight into the potentially affected areas. For this, a probabilistic approach is applied to calculate effects of potential releases and some characteristics of the resulting affected areas are studied. This contributes to the development of a robust method for identifying planning zones and provides insight into the relevant indicators for assessing the planning areas.

Key words: *radioactivity, atmospheric dispersion, emergency respons & preparedness, probabilistic calculations*

INTRODUCTION

An accident in a nuclear power plant can result in a release of radioactive materials into the atmosphere. This may lead to radiation exposure away from the release location due to dispersion of the radioactive material. When the radioactive cloud passes, external radiation from the cloud and inhalation of radioactive material in the air will result in a radiation dose. In addition, deposited radioactive material can further increase the dose after cloud passage by exposure to external radiation from the ground. Protective measures such as evacuation, sheltering, or iodine thyroid blocking can avoid or reduce health effects resulting from the radiation dose. The projected dose, received by the population can be compared to predetermined dose criteria and forms a basis for decisions on protective measures. Preparations for this are carried out in so called planning areas which requires a detailed knowledge of the potential affected areas.

Since meteorological conditions strongly influences the potential affected area, a wide range of realistic meteorological conditions need to be considered to identify these areas. For this purpose, probabilistic modelling is particularly well suited and involves the simulation of multiple releases of radioactive material under varying meteorological conditions, covering also the seasonal and day-to-night variations.

In this study, we applied probabilistic modelling using a range of atmospheric releases conditions. We studied some geometrical characteristics of the affected area and its dependance on the duration of the release and on the release height.

METHODS

Model chain

For all scenarios in this study we performed atmospheric dispersion model calculations of approximately 1000 model runs using varying meteorological conditions taken from a database covering three years of meteorological data. Releases were simulated with the dispersion model NPK-PUFF (Tomas *et al.*, 2017, 2019, 2021, De Meutter *et al.*, 2021*)* for every 26th hour between 2015 and 2017 using meteorological data from the numerical weather prediction model HARMONIE (Bengtsson *et al.*, 2017). This approach provides a representative picture of meteorological conditions including influences of the different seasons as well as day-to-night variations.

Each dispersion calculation is used to evaluate the resulting radiation doses in the effect area in the absence of any protective measures. These doses are then compared with established dose criteria for evacuation, sheltering, and iodine thyroid blocking. Areas above one of these three dose criteria are identified and characterized by its surface area and the maximum distance of its boundary to the release location. This results in a distribution of approximately 1000 distances and areas for each dose criterion for which 50th, 70th, 80th, 90th, and 95th percentiles are calculated. This methodology to determine and characterize the distances is visualized in Figure 1.

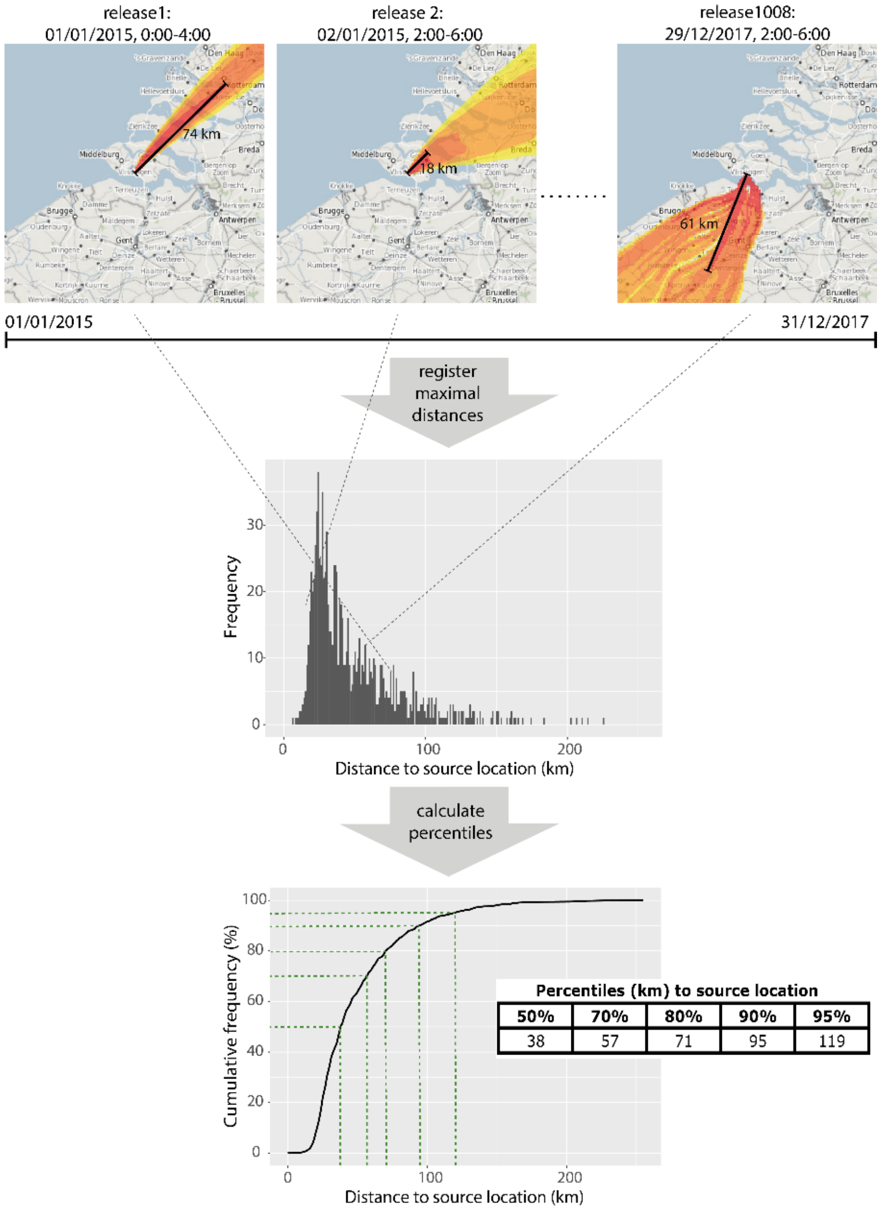

Figure 1. A release of radioactive material to the atmosphere is simulated for every 26th hour between 2015 and 2017. We determined the maximum distances (shown in this figure) and surface areas (not shown in this figure) where the calculated dose exceeds the criterionrelated to a certain protective measure. This results in a distribution of maximum distances for which several percentiles are tabulated.

Release scenarios (source terms)

We considered four scenarios for the release of the radioactive material. Two scenarios represent a large core meltdown accident and are used to study the effect of varying release durations of 4 hour (scenario 1a) and 96 hours (scenario 2b). To study the effect of release height, two scenarios are included having a release height of 25 m (scenario 2a) and 60 m (scenario 2b). More details on these scenarios can be found in ref. Tomas *et al.*, 2021.

Dispersion and dose model NPK-PUFF

We used NKP-PUFF (Gaussian puff methodology) for modelling the atmospheric dispersion of the released radioactivity and calculating the resulting dosimetric endpoints, which enables the subsequent comparison with dose criteria for the protective measures. These endpoints are the effective dose in the first seven days after start of release (evacuation, sheltering) and the thyroid dose for children due to inhalation of iodine radioisotopes in the first seven days after start of release (iodine tablets). The endpoints are calculated on three nested, square grids centered around the release location. The inner (smallest) grid measures 150x150 km with a resolution of 1x1 km, the second grid measures 300x300 km with a resolution of 2x2 km and the largest outer grid measures 600x600 km with a resolution of 4x4 km. This results in a high resolution of output close of to the release location and in lower resolutions further away, limiting calculation times. Due to the domain of the meteorological data, the distances where exceedance of the criteria may occur are limited to 250 km from the source location.

Meteorological data

We used meteorological data from the numerical weather prediction (NWP) model HARMONIE from the Royal Netherlands Meteorological Institute (KNMI) (Bengtsson et al., 2017). The domain covers the Netherlands. These data have a spatial resolution of 2.5 km in the horizontal directions and are available on five vertical levels: 10, 50, 100, 200, and 300 m measured from ground-level.

RESULTS & CONCLUSION

Tables 1-4 list percentiles of the distribution of maximum distances and the distribution of areas where exceeding of dose criteria occurs for the four release scenarios. The distance percentiles can be used as a measure for the distances of the planning areas. The area percentiles provide additional insight into the size of the affected regions. To study the relation between maximum distance and area in more detail, scatter plots of these quantities are shown in Figures 2 and 3.

Table 1. Percentiles of maximum distance and surface area for exceeding dose criteria in scenario 1a.

Measure	**Percentiles (km) distance**					**Percentiles (km^2) surface area**				
Dose criterion	**50%**	**75%**	**80%**	**90%**	**95%**	**50%**	**75%**	**80 %**	**90%**	**95%**
Evacuation (adults) *100 mSv effective dose*	4	6	8	11	14	3	5	7	12	18
Sheltering (adults) *10 mSv effective dose*	16	24	30	42	55	29	56	89	207	592
Iodine tablets (1-year-old) *50 mSv thyroid dose*	38	57	71	95	119	161	310	456	707	1007

Table 2. Percentiles of maximum distance and surface area for exceeding dose criteria in scenario 1b.

Measure	**Percentiles (km) distance**					**Percentiles (km^2) surface area**				
Dose criterion	**50%**	**75%**	**80%**	**90%**	**95%**	**50%**	**75%**	**80 %**	**90%**	**95%**
Evacuation (adults) *100 mSv effective dose*	2	2	3	3	3	2	3	3	4	5
Sheltering (adults) *10 mSv effective dose*	11	14	16	18	21	43	56	65	80	97
Iodine tablets (1-year-old) *50 mSv thyroid dose*	30	37	41	47	55	282	380	449	551	693

Table 3. Percentiles of maximum distance and surface area for exceeding dose criteria in scenario 2a.

Measure	**Percentiles (km) distance**					**Percentiles (km^2) surface area**				
Dose criterion	**50%**	**75%**	**80%**	**90%**	**95%**	**50%**	**75%**	**80 %**	**90%**	**95%**
Evacuation (adults) *100 mSv effective dose*	-	-	1	2	3	-	-	1	1	1
Sheltering (adults) *10 mSv effective dose*	6	8	10	13	17	5	9	13	19	29
Iodine tablets (1-year-old) *50 mSv thyroid dose*	11	16	19	26	33	15	28	44	74	103

Table 4. Percentiles of maximum distance and surface area for exceeding dose criteria in scenario 2b.

Measure	**Percentiles (km) distance**					**Percentiles (km^2) surface area**				
Dose criterion	**50%**	**75%**	**80%**	**90%**	**95%**	**50%**	**75%**	**80 %**	**90%**	**95%**
Evacuation (adults) *100 mSv effective dose*	-	-	-	-	-	-	-	-	-	-
Sheltering (adults) *10 mSv effective dose*	5	7	9	12	15	4	5	7	12	16
Iodine tablets (1-year-old) *50 mSv thyroid dose*	11	16	19	26	33	14	24	37	67	91

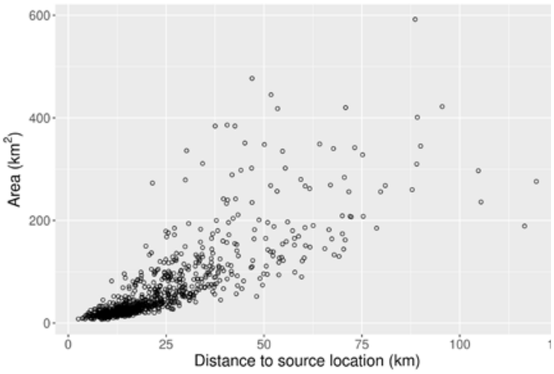

Figure 2. Scatter plot of the maximum distance and area for exceeding dose criterion for sheltering for scenario 1a (4 hours release time).

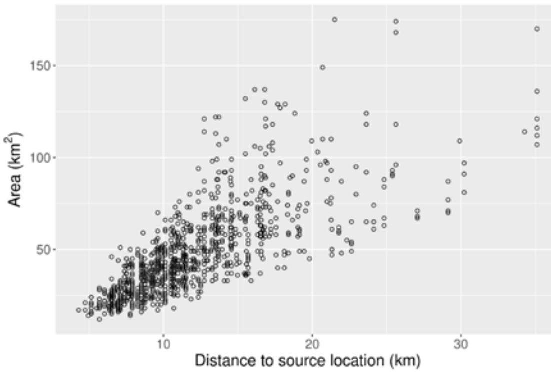

Figure 3. Scatter plot of the maximum distance and area for exceeding dose criterion for sheltering for scenario 1b (96 hours release time).

Release duration

Comparing the results of scenarios 1a and 1b shows that scenario 1a, with a shorter release duration for the same amount of radioactivity, has larger maximum distances and areas. This is a natural consequence of the variability in the meteorological conditions during the 96 hours interval as compared to the 4 hour interval. Also, the difference between the 50th percentiles and the 95th percentiles are relatively larger for scenario 1a. This holds for all dose criteria and for both maximum distances as well as for surface areas. This implies that a potentially affected area has more variations and uncertainties in size and distance for shorter release durations.

Release height

When the release height is increased, the concentration of radioactivity at ground level close to the source will be less. The corresponding dosimetric effect leads to maximum distances that are slightly lower for heigher release for effective doses. This effect is less pronounces for the maximum distances for the thyroid doses.

Concluding remarks

This study presents a methodology for identifying characteristics of planning zones for nuclear accidents. It gives results for two specific scenarios but it also provides insight into indicators that can be applied in deriving planning areas. Furthermore, the methodology can be applied to a wide range of cases where the current meteorological conditions are for example unknown or rapidly changing.

REFERENCES

Bengtsson, L., et al. 2017: The HARMONIE–AROME Model Configuration in the ALADIN–HIRLAM NWP System. Monthly Weather Review **145**(5): 1919-1935.

Tomas, J, A. van Dijk, C. J. W. Twenhöfel, 2017: Modelling atmospheric dispersion of radioactivity with NPK-PUFF using meteorological data from HIRLAM and Harmonie-AROME. 18th Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. Bologna, Italy, 2017:877-81.

Tomas, J. and C. J. W. Twenhöfel, 2019: The effects of uncertainties on the radiological assessment in the (pre-) release phase of a nuclear accident. 19th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, June 2019, Bruges, Belgium.

Tomas, J., V. Peereboom, A. Kloosterman, A. Van Dijk, 2021: Detection of radioactivity of unknown origin: Protective actions based on inverse modelling. Journal of Environmental Radioactivity, 235-236.

Tomas, J, A. Kloosterman, C. J. W. Twenhöfel, T.van Dillen, 2021: Radiologische gevolgen van mogelijke ongevalsscenario's voor Kerncentrale Borssele. RIVM report 2021-0047.

De Meutter, P, C. Gueibe, J. Tomas, P. den Outer, A. Apituley, M. Bruggeman, J. Camps, A. Delcloo, GJ. Knetsch, L. Roobol and L. Verheyen, 2021. The assessment of the April 2020 Chernobyl wildfires and their impact on Cs-137 levels in Belgium and The Netherlands. Journal of Environmental Radioactivity, 237.