Journal of Environmental Radioactivity 178-179 (2017) 36–47

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Automatic plume episode identification and cloud shine reconstruction method for ambient gamma dose rates during nuclear accidents

Xiaole Zhang [a, b, *], Wolfgang Raskob [a], Claudia Landman [a], Dmytro Trybushnyi [a], Christoph Haller [a], Hongyong Yuan [b]

[a] Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology, Karlsruhe, D-76021, Germany

[b] Institute of Public Safety Research, Department of Engineering Physics, Tsinghua University, Beijing, 100084, PR China

A R T I C L E I N F O

Article history:
Received 29 December 2016
Received in revised form
6 July 2017
Accepted 20 July 2017

Keywords:
Gamma dose rate
Cloud and ground shine separation
Atmospheric dispersion modeling
JRODOS
The Fukushima Dai-ichi accident

A B S T R A C T

Ambient gamma dose rate (GDR) is the primary observation quantity for nuclear emergency management due to its high acquisition frequency and dense spatial deployment. However, ambient GDR is the sum of both cloud and ground shine, which hinders its effective utilization. In this study, an automatic method is proposed to identify the radioactive plume passage and to separate the cloud and ground shine in the total GDR. The new method is evaluated against a synthetic GDR dataset generated by JRODOS (Real Time On-line Decision Support) System and compared with another method (Hirayama, H. et al., 2014. Estimation of I-131 concentration using time history of pulse height distribution at monitoring post and detector response for radionuclide in plume. Transactions of the Atomic Energy Society of Japan 13:119–126, in Japanese (with English abstract)). The reconstructed cloud shine agrees well with the actual values for the whole synthetic dataset (1451 data points), with a very small absolute fractional bias (FB = 0.02) and normalized mean square error (NMSE = 2.04) as well as a large correlation coefficient (r = 0.95). The new method significantly outperforms the existing one (more than 95% reduction of FB and NMSE, and 61% improvement of the correlation coefficient), mainly due to the modification for high deposition events. The code of the proposed methodology and all the test data are available for academic and non-commercial use. The new approach with the detailed interpretation of the in-situ environment data will help improving the ability of off-site source term inverse estimation for nuclear accidents.

1. Introduction

Emergency management and response is the last line of defense in case of a nuclear accident to minimize the consequences for the affected population (NEA/OECD, 1994). Timely and reliable estimation of radioactive releases (the "source term") is of utmost importance for the assessment of the dose distribution and the planning and conducting of appropriate countermeasures during an ongoing emergency (NEA, 2002). Inverse estimation using off-site environmental measurements is an effective method to reconstruct the releases (Chino et al., 2011; Stohl et al., 2012a, 2012b; Terada et al., 2012), especially for situations where the in-plant monitoring systems are unavailable, as was the case for the Fukushima accident.

Effective source term estimation mainly depends on three components: observation data, environmental transport models, and an inverse assessment methodology. There has already been a long history in developing sophisticated atmospheric dispersion models for nuclear emergency management (Benamrane et al., 2013; Holmes and Morawska, 2006). After the Fukushima accident, a lot of effort has also been spent in developing inverse estimation methods (Bocquet, 2012; Chino et al., 2011; Hirao et al., 2013; Winiarek et al., 2011). Source term estimation and data assimilation methods based on Ensemble Kalman Filter have also been proposed (Zhang et al., 2013b, 2014, 2015a, 2015b). Most of the methods utilize activity concentration measurements of radionuclides which are usually not available during the critical early

* Corresponding author. Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology, Karlsruhe, D-76021, Germany.
E-mail address: zhangxiaole10@outlook.com (X. Zhang).

http://dx.doi.org/10.1016/j.jenvrad.2017.07.014
0265-931X/

phase of an accident. Samples have to be collected in the field, and brought to a laboratory to analyze its composition, which is usually time consuming (Zhang et al., 2013a) and hardly fits the requirements of emergency response.

The primary observation data, however, is the ambient gamma dose rate (GDR), due to its relatively high acquisition frequency and dense spatial deployment (Saunier et al., 2013). There exist studies trying to reconstruct the source term based on GDR (Tsiouri et al., 2012a, 2012b) with *a priori* knowledge of the source term (Hofman et al., 2015; Saunier et al., 2013; Zhang et al., 2017). Recently, Kovalets et al. (2016a; 2016b) has developed a new method for source term estimation using GDR data. However, there are still some obstacles when using the GDR data to estimate the release, and few studies have investigated how to interpret the ambient GDR measurements, in order to make more effective use of the data during the ongoing accident.

Ambient GDR contains the contributions from both cloud and ground shine (Saunier et al., 2013). However, current approaches of modelling the deposition of radionuclides still have large uncertainties (Sportisse, 2007). The deposition process strongly depends on the environmental conditions, in particular precipitation, which is difficult to accurately predict or measure with high spatial and temporal resolution (Cuo et al., 2011). Considering these uncertainties, the direct usage of GDR data is problematic. The separation between cloud and ground shine contributions may improve the accuracy of the release estimation. As a consequence, Tsiouri et al. (2012a; 2012b) only uses the measured cloud shine (noble gas without significant deposition) to reconstruct the release. Saunier et al. (2013) tried to identify particular plume episodes, extract the cloud shine information from the GDR data, and reconstruct the source term by comparison of the model results with the reconstructed cloud shine. But only an approximate identification and separation method was adopted without sufficient evaluation. Hirouchi et al. (2013) has used a simplified method, similar to Saunier et al. (2013), to separate the cloud and ground shine. The composition of the radionuclides deposited to the surface was estimated from radioactive decay information, and finally used to reconstruct the release history with the derived data.

Recently, Hirayama et al. (2014, 2015) has proposed a methodology to estimate the ^{131}I activity concentration by separating the cloud shine from the peak count rates data of NaI(Tl) detectors. Hirayama's method will surely improve the interpretation of the available information during a nuclear accident, and contributes to the release reconstruction. However, the method itself can be further enhanced: firstly, there is no automatic plume identification procedure in the method, and secondly, the ratio between ground and cloud shine is assumed to be below a factor of one (Hirayama et al., 2014), which may be not valid for some events with strong precipitation. In addition, the GDR due to the deposition is estimated based on only one GDR measurement (Hirayama et al., 2014). It seems more reasonable, however, to estimate the ground shine taking into account two successive GDR measurements.

The objective of this study is to develop an automatic plume episode identification and cloud shine reconstruction method for GDR data. Specifically, an adaptive Gaussian noise model with dynamic thresholds is adopted to characterize the background GDR rate of change and to detect the arrival and departure of radioactive plume. The cloud shine is reconstructed from the identified plume episode by minimizing a proposed cost function. The proposed method is firstly demonstrated and evaluated by comparing the reconstructed cloud shine values with simulated "real" base values for the analysis, using a synthetic GDR dataset (observation sites shown in Fig. 1) that was generated with the Decision Support System for Emergency Management after Nuclear Accidents JRODOS (Raskob et al., 2011). The proposed method is also compared

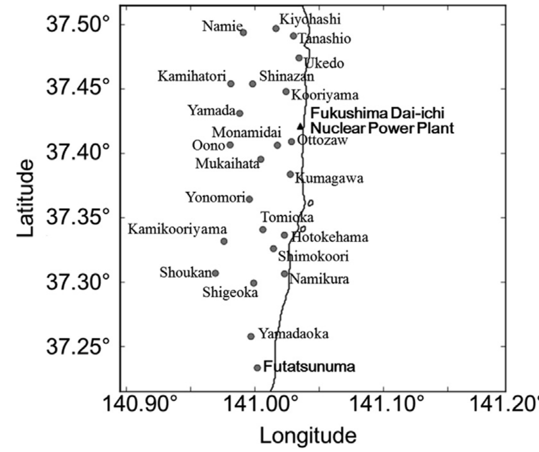

Fig. 1. Ambient gamma dose rate observation sites (23 sites) within about 20 km around Fukushima Dai-ichi power plant during the Fukushima nuclear accident.

with the method of Hirayama et al. (2014) to show the performance improvement. Finally, the method is applied to in-situ GDR measurements at Futatsunuma and Fukushima City (Momijiyama) to demonstrate and analyze its performance for real cases. The reconstructed cloud shine can be used to correct the errors in the wind data adopted in the dispersion model. The code of the proposed methodology and all the test data are all available for academic and non-commercial use.

2. Material and methods

2.1. Plume passage identification

In order to interpret a GDR measurement, it should be firstly identified when the radioactive cloud has passed over the location under consideration. The time span(s) of the plume passage(s), along with the coordinates of the observation site(s), will capture both the temporal and spatial characteristics of the radioactive cloud, which can be used to correct the errors in the wind data adopted in the dispersion model. An automatic, adaptive algorithm is proposed for a sequential identification of plume episodes.

The chosen example observation site is Futatsunuma, which is located about 21 km south of the Fukushima Dai-ichi Nuclear Power Plant, see Fig. 1. Fig. 2 shows typical in-situ GDR measurements obtained between 2:00 UTC, March 14 and 5:00 UTC, March 17, 2011, (75 h in total) at this site. The start time (0 h) of all measurements in this article is set to 00:00 UTC, March 12, 2011. The equivalent gamma dose rate (Sv h^{-1}) is assumed to be equal to the air absorbed gamma dose rate (Gy h^{-1}) (Katata et al., 2012). In general, the GDR dramatically increases during the plume passage episodes, shown as several peaks in the upper panel. After the passage of the plume, the ambient GDR still remains at a higher level compared to the time before the plume passage. This is caused by the deposition of radioactive material. The middle panel shows the GDR change rate (the first derivative of GDR). The arrival and departure of plume respectively leads to a rapid positive and negative pulse and the GDR change rate remains at a substantial low level (almost 0 μSv h^{-2}) for the remaining time. This suggests that the first derivative of the GDR is an appropriate indicator for identifying the arrival and departure time of the plume when a suitable threshold value is defined.

The plume episodes are detected by distinguishing the GDR change rate signals caused by the passage of the plume from the background signals, which are caused by decay of previous