SOURCE TERM ESTIMATION BASED ON ENVIRONMENTAL RADIATION DATA IN QINSHAN NUCLEAR POWER PLANT OF CHINA

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Abstract: Achieving information of source terms is an import task in emergency response during a nuclear accident. Affected by large errors of atmospheric model, the reverse modeling of atmospheric dispersion faces great challenges. The traditional scaling method adopted in Fukushima nuclear accident is affected by deviation of the observed and predicted values. To cope with the deviations, an assimilation model based on Ensemble Kalman filter (EnKF) was established with consideration of model errors and observation errors. It was validated by 7 groups of tracer experiments. The result shows that the EnKF model could estimate the release rate of source term successfully. This scheme was applied to emergency response system of Qinshan nuclear power plant.

Keyword: atmospheric dispersion, source term estimation, nuclear accident

1. INTRODUCTION

The total amount of radionuclides released during nuclear accidents is generally obtained by the two methods, one method is to estimate the damage status of the reactor core, and the other method is estimating the source term released into the environment by radiation detected around the nuclear power plant.

In 2011 Fukushima nuclear accident, status of reactor core is unknown for a long time, along with the hydrogen explosion, the source term is difficult to estimate. In fact, for any nuclear accident, under the threat of strong radiation, the status of core damage is basically unknown. Researchers calculate the source term by the type of reactor and accident, such as the using the WASH-1400 pressurized water reactor prototype to simulate the accident and preset the source term to nine categories. However, due to a variety of types of accidents, fuel burn up depths, when the accident occurred, this 'pre-set' source term information and the actual accident source term is not consistent.

It will seriously affect the emergency response effect, so the second method as an important supplement, will play an important role in nuclear accident consequence assessment.

Source term estimation faces great challenges, Fukushima nuclear accident occurred with multi-reactors, and Japan's SPEEDI system did not work properly due to power loss, resulting in the early results cannot be effectively estimated(Katata et al. 2012).

With the development of data assimilation techniques, it is possible to use the external environmental radiation monitoring data to estimate the release parameters, adjusting the concentration field. It is proved to be an effective way. RODOS systems in Europe(Rojas-Palma et al. 2003), and the SPEEDI system in Japan(Nagai, Chino and Yamazawa 1999) are developing their own methods of source term estimation.

Because of the wind turbulence, topography, weather conditions and the observation error, the accuracy of estimation is difficult to ensure. More research work should be done to cope with the large errors in the analysis scheme.

2. METHOD

Ensemble Kalman filter (EnKF) is a low-rank solution of the standard Kalman filter. It employs an ensemble of state vectors propagating along the forecast model, and error covariance matrix can be estimated from the dispersion among these state vectors(Evensen 2003). To apply the EnKF, the basic formula of the inverse problem is:

The model state source release rate(RR) is set to constant with a random perturbations *q.*

$$RR_t = RR_{t-1} + q \quad (1)$$

q is the error source from model, and the measurements formula is:

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$$d = H\psi + \varepsilon \quad (2)$$

H is measurement operator related to dispersion model, the observations d is calculated by model state and measurement errors ε .
The aim is to estimate the q by the observations and the calculations of equation 2.
Define an ensemble of Ψ(including model state *RR*) with finite size N, converge to matrix $A^f = (\psi_1, \psi_1, \ldots, \psi_N)$, denote the model forecast and analysis as A^f and A^a.
Further, the respective covariance matrix for model forecast and measurements are denoted P^f and R.
Give a vector of measurements $d \in \Re^m$, with m being the number of measurements, we can define the N vectors of perturbed observations as

$$d_j = d + \varepsilon_j, j = 1, 2, \ldots, N \quad (3)$$

Which can be stored in the columns of a matrix:

$$D = (d_1, d_2, \ldots, d_N) \quad (4)$$

The analysis formula is:

$$A^a = A^f + P^f H^T (HP^f H^T + R)^{-1} (D - HA) \quad (5)$$

Where $\bar{\Psi}$ of ensemble A^a is the best estimation.
But for the dispersion problem, the measurement operator H is nonlinear, the traditional solution is to linearize and iterate. Here define the new ensemble member:

$$\hat{\psi}^T = [\psi^T, h^T(\psi)] \quad (6)$$

Form a new matrix as:

$$\hat{A} = (\hat{\psi}_1, \hat{\psi}_2, \ldots, \hat{\psi}_N) \quad (7)$$

The analysis can be written as:

$$A^a = A^f + A'\hat{A}'^T \hat{H}^T (\hat{H}\hat{A}'\hat{A}'^T H^T + R)^{-1} (D - \hat{H}\hat{A}) \quad (8)$$

Where $1_N \in \Re^{N \times N}$ is the matrix where each element is equal to 1/N, and $A' = A - A1_N$, $\hat{A}' = \hat{A} - \hat{A}1_N$,
The matrix P^f will never be calculated. With the state ensemble, the error covariance should be represented by the ensemble covariance.

Thus in every compute step the updated $\bar{\Psi}$ is calculated and the parameters are estimated on-line.

3. EXPERIMENT

3.1 Tracer Experiment

In order to obtain the diffusion parameters of the Qinshan nuclear power plant, the SF_6 tracer experiments were implemented at June 27, 2005. Source estimation system was validation by this experiment. Total 5 arcs of sampling points were arranged at the position shown in Fig.1.

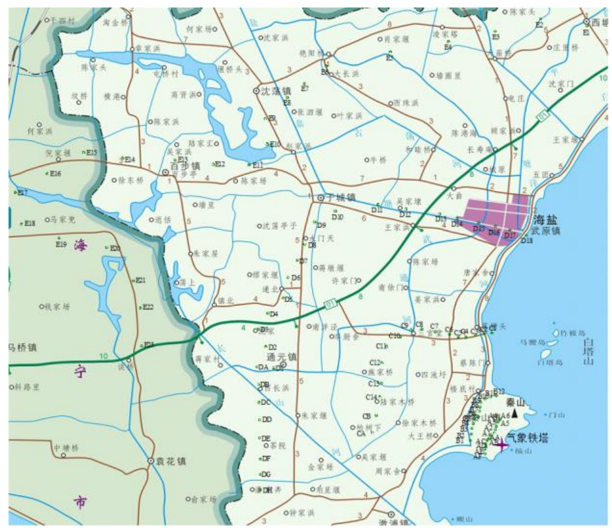

Fig. 1. 5 arcs of sampling points around Qinshan nuclear power plant.

About 50kg SF_6 was hanged to 30m height to release. Each experiment case was shown in Tab.1.

Tab. 1. Parameters of each case in Qinshan SF_6 tracer experiment.

NO.	Date	Time	Total Relase (kg)	Wind Direction	Wind Speed (m/s)	Stability	RR (10^{-4}mg/s)
1	05.07.07	12:20-13:20	46.5	111°-133°	5.0	C	1.29
2	05.07.07	16:20-17:20	22.0	97°-110°	3.4	D	0.61
3	05.07.16	10:00-11:00	43.6	N/A	2.9	C	1.21
4	05.07.16	13:40-14:40	49.6	80°-90°	8.0	C	1.38
5	05.07.16	16:50-17:50	51.0	98°-115°	9.2	D	1.42
6	05.07.17	7:00-8:00	48.0	118°-138°	6.4	D	1.33
7	05.07.17	10:40-11:40	50.4	104°-123°	8.9	B	1.40

3.2 Analysis Result

By measuring the value of dozens of observation points, EnKF scheme was used to estimate the release rate value. A great error is introduced into the inversion model, the final estimated value are shown in Tab.2. Although the estimated value has a certain error, but is in the same order of magnitude of the true value.

Tab. 2. Estimation result of Qinshan SF_6 tracer experiment.

NO.	Release(g/s)	Estimated(g/s)
1	12.9	4.42
2	6.1	2.08
3	12.1	38.24
4	13.8	11.06
5	14.2	9.87
6	13.3	3.72
7	14	3.02

4. APPLICATION

Qinshan Source Term Estimation System(QSTES) including a data acquisition module, atmospheric dispersion module and source term estimation module. They can use a text file as input, an alternative network data to ensure it works in case of an accident. Qinshan data acquisition module acquire three real-time data, including:

- Emergency System Database: Get accident data information from the database, including sequence of the accident, the accident reactor information, etc.;
- Meteorological Database: Get wind speed, wind direction, etc. from 5 meteorological station every 1 minute.
- Environmental γ dose rate Database: Get environmental γ dose rate at ground surface from 12 detection station every 5 minutes.

The system will collect all the data and estimated the source term release rate coupling all the parameter errors. The output is transferred to the Qinshan Emergency Management System as Fig.2. The system is able to get a comprehensive information source term, but there will still be errors source from:

- there may be errors item predefined initial source term
- readings has representative error
- atmospheric turbulence effects and error in atmospheric dispersion model itself.

The completely elimination of the above errors is difficult. In the downwind area, increase the number of observation points can effectively improve the estimation accuracy, we recommend mobile detection stations should be set up in the downwind area in a nuclear accident.

Fig. 2. Estimation result displayed in the Qinshan Emergency Management System.

5. CONCLUSION

To estimate the source term in nuclear accident, an assimilation model based on Ensemble Kalman filter was established with consideration of model errors and observation errors. It was validated by 7 groups of tracer experiments. The result shows that the EnKF model could estimate the release rate of source term successfully. This scheme was applied to Qinshan Source Term Estimation System, for Qinshan nuclear power plant.

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