ESTIMATION OF SOURCE TERM BY INVERSE MODEL IN EMERGENCY WITH ENVIRONMENTAL MONITORING AND ATMOSPHERIC DISPERSION IN KOREA NUCLEAR POWER PLANT

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Abstract: Lesson learned from Fukushima Dai-ichi Nuclear Power Station Accident caused by earthquake and Tsunami followed station black out and explosion of plant resulted in chaos over the world. Evaluation of source terms released to the environment is one of important decision making process in protective actions taken by utility to protect people as the progress of accident situations.
Korea Hydro & Nuclear Power Co., Ltd has developed a new inverse modeling compare measured environmental radiation with atmospheric dispersion modeling to reevaluate protective responses in early stage. New routines, collection of radiation monitoring data from Environmental Radiation Monitoring System and from Mobile Monitoring System, and assimilation of radiation data and optimization of source term estimations, are added to emergency response system K-REDAP(KHNP's Radiological Emergency Dose assessment Program) for Nuclear Power Plant in Korea.
Inverse modeling depends on atmospheric dispersion models used such as Gaussian Plume Model, Puff Model and particle-in-cell Model, and also depends on weather data such as observed local meteorological data at ground level and regional forecasting data used to estimate accident source term. Simulation of model carried out on Fukushima accident case, results shows well agreed with other research. Inverse model to estimate real source term in early stage is a useful tool to realize the response actions taken by utility.

***Key words:** Radiological emergency, dose rate, inversion model, atmospheric dispersion*

1. INTRODUCTION

In the case of radiological emergency in nuclear power plant accident with radioactive materials released to environment, estimation of the release duration and rates of source materials is one of important factors in selection of countermeasures deployed on time to protect the public.
Many lessons have been learned from the Fukushima Dai-ichi Nuclear Power Station Accident happened 11th March 2011. Radioactive materials release rates were evaluated based on the environmental radiation monitoring data by SPEEDI system(Chino M. 2011), and first estimation report provided on May 2011, almost two month later of accident occurred in Fukushima. Reevaluation of source term was performed on August, five month later from accident started and early stage protective actions were implemented.
It is recognized that readiness of tools, i.e. source term analysis based on operational conditions of nuclear power plant, inverse modeling based on radiation monitoring results etc., to estimate the release rates of radioactive materials from the nuclear power plant experienced from Fukushima accident. Unfortunately source term analysis based on operational conditions was impossible due to the blackout of nuclear power station, inverse modeling based on radiation monitoring results became a unique back-tracking solution in the Fukushima accident.
Korea Hydro & Nuclear Power Co., Ltd decided to develop a new source term evaluation routines based on inverse modeling with environmental radiation data assimilation, radionuclides concentration in air and air dose rate are calculated and compared to environmental radiation monitoring data until optimized results obtained, included in emergency response K-REDAP(KHNP's Radiological Emergency Dose assessment Program) system for Nuclear Power Plant in Korea as follows in figure 1.
Inverse modeling is a useful tool to identify the source strength and location essential to choose protective actions to minimize the radiological consequences. The solution requires data assimilation and a robust technique such as cost function algorithm in order to estimate the source that best optimizes the monitored receptor data with the forecast atmospheric dispersion model output.

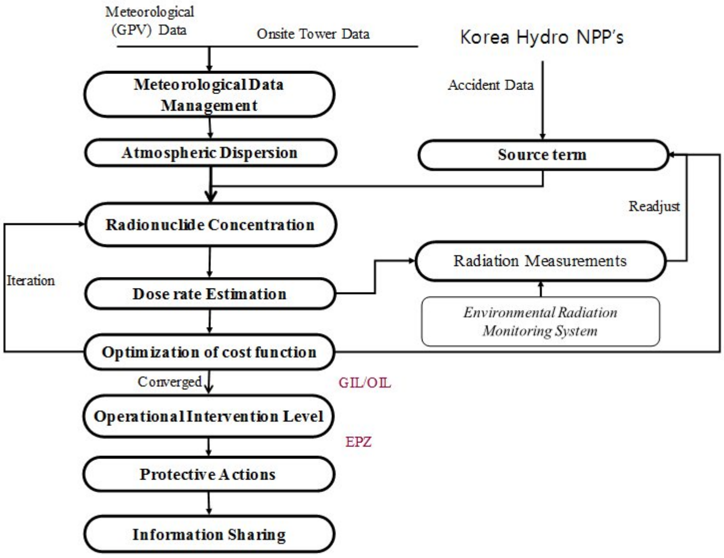

Figure 1. System diagram of modified KHNP's Radiological Emergency Dose Assessment Program(REDAP) included inverse model

2. METHODOLOGY

Inverse model is a useful method to estimate source term characteristics (amount, location etc.) from measured dose rates and radionuclide concentrations in air. First step project dose rates or radionuclide concentrations by atmospheric dispersion model using source term presumed and second step minimize discrepancy between measured and projected dose rates or radionuclide concentrations using data assimilation and optimization techniques, as following methods.

2.1 Atmospheric Dispersion Model

Atmospheric dispersion of radioactive materials is modeled by the Gaussian plume model to estimate radioactive concentration at the receptor point(x, y, z) in near field (~20km) assumed a ground level point source

$$C = \frac{Q}{\pi u \sigma_y \sigma_z} exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \quad (1)$$

where C is the concentration at receptor point, Q is the release rate, u is average wind speed y is height of receptor, σ, σ_y and σ_z are standard deviation of materials in a plume in the y- and z- directions respectively. Atmospheric dispersion parameters are functions of either distance from the release point or time since release, and also be function of atmospheric stability and surface roughness.

2.2 Dose Rate Calculation Model

The total gamma exposure rate from the cloud shine and ground shine dose rates in $Gy\ h^{-1}$ is compared with field measurements

$$D_{gair} = \frac{(D_{cs}+D_{gs})}{DCF_k} \quad (2)$$

Where, D_{gair} is gamma exposure rate in air, D_{cs} is effective dose equivalent from cloud shine, D_{gs} is effective dose equivalent from ground shine, and DCF_k is conversion factor for kerma to organ dose.

The general expression of ground shine dose equivalent is

$$D_{gs} = RF \sum_n \left[DCF_n \int_t^{t+\Delta t} C_{gn}(t)dt\right] \quad (3)$$

Where, RF is surface roughness factor, C_{gn} is radionuclide concentration of surface contamination, DCF_n is ground shine dose conversion factor of radionuclide n, and t is time. Ground shine dose can be incurred after surface contaminated even if radioactive materials is not flow over the area.

Dose rate from ground shine was calculated by deposition rate at a receptor point sum of the dry and wet deposition rates.
The cloud shine dose equivalent is calculated from infinite slab line source

$$D_{cs} = \left[\frac{X(t)}{Q}\right] \sum_n Q_n DCF_n \quad (4)$$

Where, Q_n is radionuclide concentration in air, DCF_n is dose conversion factor of radionuclide n in air. When the plume dispersed sufficient to mixed, model changed to semi-infinite plume, the equation becomes

2.3 Data assimilation and optimization
Emergency radiation monitoring program of measuring radionuclide concentration and dose rate in environments is a unique tool in the Fukushima accident with black out of the nuclear power plant. It is difficulties to deal with the dose rate measurements because of a lots of factors such as plume dispersion, deposition rate, isotope constitutes. Inversion model used to evaluate source terms from the dose rate measurement with data assimilation method to atmospheric dispersion model.
The optimized estimation of source terms is minimize using the cost function J as

$$J = \frac{1}{2}\sum_{i=1}^{N} \frac{(C^o - C^m)^2}{\sigma_i^2} \quad (5)$$

Where, C^o is observed concentration, C^m is model predicted concentration, and σ_i is standard deviation of differences. First, set the release rates of source material assumed directly from high dose rate point and calculate gamma dose rates at a receptor point, weighed with corresponding differences of measurement and of calculations.
Second readjust the release rates of source material and calculate gamma dose rates and weighed with corresponding errors and iterate until minimization of the cost function is obtained as follow.(Figure 1)

3. RESULT AND DISCUSSION

The calculation of the atmospheric dispersion of radioactive materials is carried out by REDAP program with the GDAS numerical analyzed weather data from NCEP and measured onsite single point data. Air concentration and air dose rates were calculated in the domain of 80x80km grid, 1km resolution release duration from 09:00(JST) 15 March to 09:00(JST) 16 March 2011 for air dose rate calculations at the Fukushima Daiichi power plant.
The plume flowed toward the south to southwest direction from the plant and changed to west and northwest direction in the afternoon. The monitoring data (dose rates and concentration) on ground level were collected and compared with the calculated results to inverse source term evaluations. Local weather conditions to generate wind field and rainfalls within the local area from release point are key factors to estimate the calculated air dose rates.
The REDAP has been simulated for the large amount of radioactive materials released from Fukushima accident on 15 March. The radioactive plume discharged in morning was passed over western part of Fukushima site, and flowed to the northwest direction in the afternoon from the plant. Air dose rates are measured at Fukushima city, Minami-soma and Iwaki monitoring stations, and assimilated monitoring data to compare the calculated air dose rate map. Simulation of inversion model, first source term was set to a severe accident assumption, different source term values of each time intervals has been used for different runs.

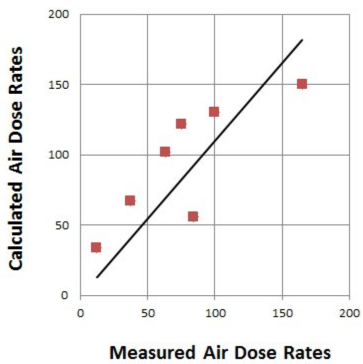

Figure 2. Distribution of air dose rates measured and calculated during 15 March at Fukushima Prefecture.

The air dose rates measured are compared with calculated air dose rates for 24 *hrs* duration of 15 ~ 16 March 2011, ^{137}Cs activity assumed 10 times lower than ^{131}I by the Chino's time variation study of concentration ratio of airborne ^{131}I to ^{137}Cs from 14 March to 25 March 2011.
Estimation of radionuclide source terms are minimizing discrepancies with inverse model, which will compare with 8.0×10^{13} ~ $4 \times 10^{15}\ Bqh^{-1}$ for ^{131}I and 8×10^{12} ~ $4 \times 10^{14}\ Bqh^{-1}$ for ^{137}Cs of Chino's Source Term estimations of the Fukushima accident. Preliminary study shows that local weather data is a key factor in atmospheric dispersion calculations.
And yet, the REDAP program is under development stage to deal with inversion modeling approach, works to improve dose rate calculation from dry and wet deposition on the ground.

4. CONCLUSION

In this paper, re-evaluation of sources from Fukushima accident was performed using inverse modeling. The efficient algorithm is developed which allows for source term adjustment with data assimilation of gamma dose rate and concentration measurements in the framework of REDAP atmospheric dispersion model. The proposed inversion model with the data assimilation method is successfully validated against the measurements in field on Fukushima accident.
Work is presently underway to treat meteorological data, measured data and to build improved atmospheric dispersions, interpolation algorithms, and successive correction methods. The parametric analysis and optimal minimization methods will also be developed in the future.

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