The Assessments and Comparisons of RASCAL and EPZDose on Atmospheric Dispersion and Dose Consequences in Radioactive Material Release Accidents

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Abstract

RASCAL has been developed by NRC for making dose projections during radiological incidents and emergencies. It evaluates the atmospheric releases from nuclear power plants, spent fuel storage pools and casks, fuel cycle facilities, and radioactive material handling facilities. EPZDose is a dose assessment code designed and developed by NTHU. It calculates the dose consequences according to the input time-varying source term and the meteorology conditions and is capable of demonstrating the dose dispersion progress. In this study, we compared the atmospheric dispersion and the dose consequences evaluated by RASCAL and EPZDose. First, we used RASCAL to simulate a long term SBO accident for Maanshan NPP and exported the calculated released source terms. Then we converted the source term files generated by RASCAL to the input source term format of EPZDose. Finally, we used RASCAL and EPZDose to evaluate the dose consequences of the simulated accidents, respectively under two postulated meteorology conditions and then compared the assessment results at certain hours after the start of the release. The accumulated thyroid dose distribution image calculated by RASCAL and EPZDose appeared fairly consistent.

1. Introduction

Taiwan is located at the circum-Pacific seismic belt and experiences earthquakes frequently. A severe earthquake may cause damage to the nuclear power plants or the related facilities and incur different dangerous levels of radiation. While the severe nuclear power plant accidents that cause fission products to be released from the reactor core happen, the authorities will need to make a protective action decision shortly based on the evaluation of the dose consequences inside the planning zone. Therefore, a rapid assessment of dose projections tool is very important for responding to radiological emergencies.

RASCAL and EPZDose are two tools for dose consequences estimation. RASCAL is developed by the USNRC for rapid assessment of dose projections during radiological emergencies based on plant and environmental conditions. The RASCAL graphical user interface (GUI) consists of seven tools. The Source Term to Dose (STDose) primary tool is the main tool for the user to input information about plant conditions or accident conditions in order to estimate the projected radiation doses from a plume to people downwind.[2] It can evaluate the released source term caused by the accidents of nuclear power plants, spent fuel storage pools and casks, fuel cycle facilities, and radioactive material handling facilities.[1] EPZDose is an offsite dose assessment code designed and developed by NTHU. It can rapidly simulate the offsite radiation dispersion process and the dose results based on the input source terms and the meteorology conditions and display the dose dispersion progress with continuous animations.[5]

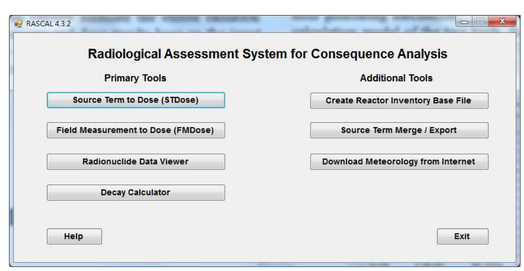

Fig. 1 RASCAL GUI

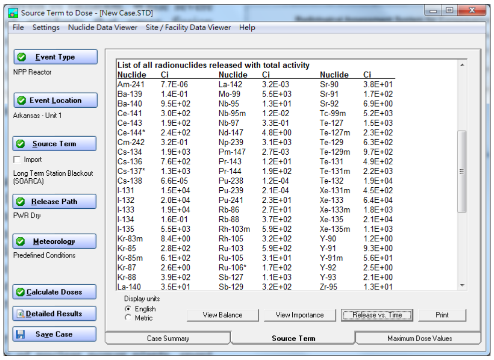

Fig. 2 RASCAL STDose GUI

In this paper, we compare the assessment results of ground level accumulated thyroid dose calculated by RASCAL and EPZDose for a Maanshan power plant LTSBO (long term station blackout) accident. Maanshan power plant is located at south Taiwan, equipped with a twin-unit Westinghouse 3-loop PWR (Pressurized Water Reactor), and currently operates at rated core thermal power of 2822 MWt for each unit.

We first used RASCAL to simulate an LTSBO event case for Maanshan nuclear power plant, and then exported the calculated source term and converted it to meet the input source term format of EPZDose. Next, we used EPZDose to do the simulation with the previously calculated source term and then compared the dose consequences evaluated results of these two codes under two different meteorology conditions.

Since the information of Maanshan nuclear power plant is not in the site database of RASCAL, there is no map of this site installed and the doses footprint result images generated for Maanshan are on blank backgrounds. To compare the dose consequence with the images, we exported the accumulated dose footprint images (gis shapefiles) of the simulated LTSBO event and displayed them using the free GIS software-QGIS.[2]

The following paragraphs will describe the source term generating mechanism, the dispersion and dose calculation models of these two tools, the description of the simulation case and finally the comparison results.

2. Source Term

A source term is defined as the activity of each radionuclide released to the environment as a function of time. RASCAL evaluates the source term based on the methods and information described in some publications such as NUREG-1228, "Source Term Estimation during Incident Response to Severe Nuclear Power Plant Accidents", NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants, Final Report," and NUREG/CR-6451 "A Safety and Regulatory Assessment of Generic BWR and PWR Permanently Shutdown Nuclear Power Plants" [1].

The calculation method of source terms in RASCAL includes four steps. First, it calculates the activity of each radionuclide that is present in the container (e.g., the nuclear power plant or spent fuel storage). Second, it calculates the release fraction of the inventory of each radionuclide for the accident being evaluated. Third, the product of the above two terms is multiplied by a reduction factor (e.g., for reduction by filters). Lastly, the source term of each radionuclide released to the atmosphere during a specific time step is obtained by multiplying the leakage fraction for that time step and the result from the third step[1].

EPZDose can calculate the contribution of doses for 52 nuclides and the source terms generated by RASCAL including more than 60 nuclides[1][5]. Although not every radionuclide generated by RASCAL is calculated for dose with EPZDose, according to the "Cumulative Importance to Dose" table in RASCAL, more than 99% of the doses are contributed by the nuclides calculated by EPZDose.

3. Dispersion Model

In a nuclear accident, the fission products are first released from the reactor core and then leak into the atmosphere and disperse, depending on the meteorological conditions such as the wind direction, wind velocity and stability category. Both RASCAL and EPZDose consider the radioactive materials to be released in a discrete manner and separated as a series of puffs that contain certain amount of activities(in Ci) associated with different kind of nuclides and describe the atmospheric dispersion of radioactive materials based on the Gaussian puff model[1][3]. The atmospheric dispersion parameters in the solution of Gaussian puff model are functions of either the distance from the release point or the time since release. They may also be functions of atmospheric stability and surface roughness. RASCAL uses dispersion parameters that are based on travel time and the turbulence parameters (stability class) that are responsible for dispersion[1]. EPZDose calculates the dispersion parameters of a puff based on the moving distance of it and the Pasquill's stability conditions. If a puff has been transported under different stability status, EPZDose will adjust the dispersion parameters of it according to its moving distance of each stability status.

3. Graphical Dose Assessment Display

For the doses calculation, RASCAL provides four choices for the calculation distance (16km, 40km, 80km, and 160km). After finishing the event conditions and meteorology setting, the user can select one of the four distance choices to set the assessment geography range. The code accomplishes all the calculations of an event for the selected distance and provides the assessment results display option in "Detail Result of Dose Calculations" GUI.

The user should always select 16km for the initial run. If the user is interested in the doses at distances beyond 16 miles, then he/she should run the calculations again using the other distance choices[2]. The assessment result can be displayed as footprint images or numeric tables. The footprint images are shown upon a map for only built-in sites. The user can export the images and display them using GIS software[2].

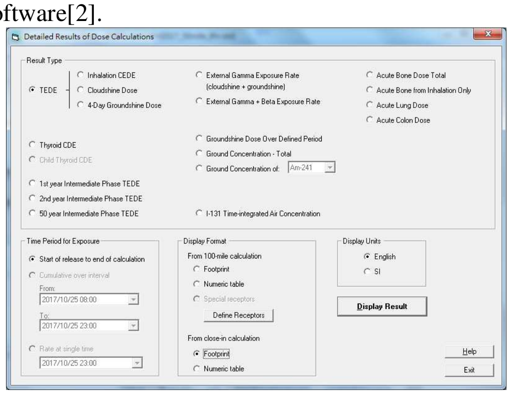

Fig. 3 Detailed Results of Dose Calculations GUI

EPZDose assesses the dose rates and accumulated doses of whole body and thyroid based on the input source term and meteorology conditions (e.g., the wind direction, wind velocity, Pasquill's stability conditions, and fallout fraction). The background map of the event sites can be retrieved through the internet for 8 different zoom levels of the map, from 3km to 367km, centered at the release point. EPZDose calculates and displays the result simultaneously[4]. The assessment results are shown using dose dispersion animations. While the dose dispersion process is displayed, it can automatically switch the zoom levels of the map according to the furthest transport distance of released puffs. The code also allows the user to manually switch the map zoom levels during or after the simulations.

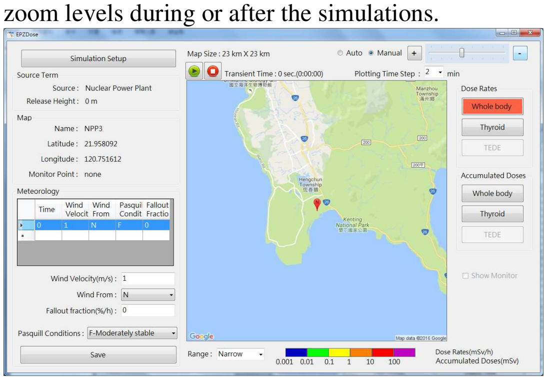

Fig. 4 EPZDose Main GUI

4. Assessment Results Comparison

Almost all the radioactive material at a nuclear power plant is in the fuel rods. The fuel rods keep producing heat by radioactive decay. If the cooling water no longer covers the fuel rods, the fuel cladding will start to be heated. Later, the fuel itself will start to melt and cause a large release. An LTSBO (long term station blackout) event is a very serious accident that leaves the fuel rods uncovered and causes large amounts of fission products to be released from the reactor core.

To compare the dose assessment results of RASCAL and EPZDose, we used RASCAL to simulate an LTSBO event of the Maanshan nuclear power plant. This event was assumed the Maanshan plant was shut down and scrammed due to an earthquake such that the offsite power was lost to leave the plant in a station blackout situation and the core became uncovered. Besides, the ECCS and RCIC were also not operable. Eight hours later, an SGTR (steam generator rupture) occurred and the fission product began to leak through it. The makeup flow was about 50 gpm; the rupture location was above the water level; the steaming rate was about 75,000 lbs/h and the release point was the safety relief valve. For this case, we assumed the core was not recovered.

Two kinds of meteorology conditions are calculated. For meteorology condition 1, we assume no rain, the condition remaining unchanged with the wind velocity of 2m/sec, the wind from the south-west, and the stability category of E (Slightly stable). Fig. 6 shows the accumulated thyroid doses assessment results, 10 hours after the release, calculate by RASCAL and EPZDose, respectively.

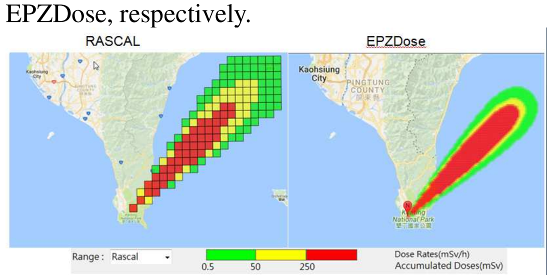

Fig. 5 Accumulated Thyroid Doses under meteorology condition 1 at 10 hours after the first release

For meteorology condition 2, we assume no rain, the initial wind velocity of 4m/sec, the initial wind from the south-west, and the stability category D. In 5 hours, the weather changes gradually with the wind velocity of 3m/sec, the wind from the west, and the stability category F. Fig. 6 and Fig. 7 show the assessment results of accumulated thyroid doses at 10 hours and 8 hours, respectively.

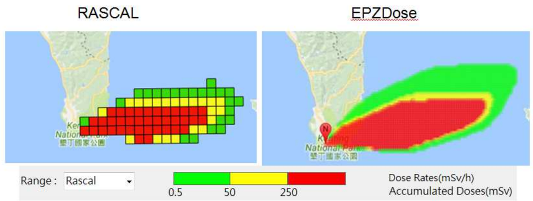

Fig. 6 Accumulated Thyroid Doses under meteorology condition 2 at 8 hours after the first release

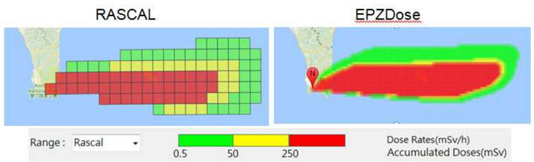

Fig. 7 Accumulated Thyroid Doses under meteorology condition2 at 16 hours after the first release

4. Conclusion

In this paper we introduced two dose consequence estimation tools - RASCAL and EPZDose. RASCAL can evaluate the source term of the user-defined nuclear power plant or of the related nuclear facilities accidents. We used RASCAL to simulate an LTSBO event of the Maanshan nuclear power plant and export the generated source term which is then used in EPZDose so that we can compare the assessment results calculated by these two tools. Two different meteorology conditions had been simulated. The footprints of the evaluated accumulated thyroid doses at some hours after the start of release of these two tools are pretty close. Since RASCAL calculates the decay of nuclides between the source and the receptors but EPZDose does not, the red regions indicating the accumulated thyroid dose value higher than 250 mSv in the footprint calculated by EPZDose are a little larger than those calculated by RASCAL, which thus also shows the assessment results are pretty consistent.

5. References

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