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TECHNICAL MATERIAL

Design and development of nuclear accident offsite consequence assessment system (NAOCAS_V3.0)

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Based on decades of development experience and condition with current international and development technology and trend, China Institute for Radiation Protection (CIRP) developed a new nuclear accident offsite consequence assessment system (NAOCAS_V3.0). The system architecture adopts Client/Server (C/S) combined with Browser/Server (B/S). Geographic information platform for 2D and 3D spatial analysis technology and physical module chains are both derived from independent innovations with proprietary intellectual property rights. The physical modules in the system are verified by field tracing experiments and are compared with similar systems such as InterRAS, Rascal and JRODOS (Java Real-time On-line Decision Support System). The preliminary results of model-evaluation and system-system intercomparison demonstrate that the numerical methods used in the NAOCAS system are accurate. Through the interaction between users and systems, users can further enhance the ability of space analysis and application of the consequences of nuclear accidents. This paper introduces architecture and functions and applications of the system (NAOCAS_V3.0), it had been successfully applied in the "2015-Aegis" national nuclear emergency exercises and ConvEx-3 (2017) International Convention emergency exercises, as nuclear emergency evaluation resources for the national nuclear emergency response center.

Keywords: nuclear accident; consequence assessment; geographic information; 3D spatial analysis; B/S; C/S

1. Introduction

Real time consequence assessment model is a valuable tool for emergency response, because it can predict the impact on the environment and public health before the arrival of radioactive substances, therefore, nuclear accident consequence assessment and decision support system is an important part of nuclear emergency preparedness and is a necessary technology in the process of decision making.

A balance should be found between selecting appropriate physical models to obtain reliable prediction and decreasing calculating time. Nuclear accident consequence assessment and decision support system has developed for thirty or forty years. At present, in terms of scope of application and influence, there are already some representative real-time consequences assessment/decision support systems, such as ARAC/NARAC [1], EC RODOS [2], Japan SPEEDI/WSPEEDI [3], Denmark ARGOS [4] and so on. The structure and function of these systems are different, but they have the ability of atmospheric diffusion and radiation dose real-time simulation, and the decision support system (RODOS and ARGOS) also has the function of simulating the intervention and making the decision analysis.

With the development of numerical simulation technology, computer, internet, database and geographic information technology, the technical level of the corresponding assessment system and model development and application are also constantly improved and perfect. In the meantime, the evolution of radiation protection system also makes the relevant changes of nuclear emergency concepts. For example, in the current protection system [5], the concept of ‘intervention levels’ is replaced by ‘reference level’.

CIRP developed the real-time dose evaluation system (SRDAAR - QNPP) [6] for Qinshan nuclear power plant in 1991, which is the first nuclear power plant real-time dose evaluation system in China. With the development of more than 20 years, CIRP has gradually developed and perfected multi-scale atmospheric dispersion simulation technology and water environment diffusion simulation technology based on the requirement of nuclear accident consequence assessment and emergency response. NAOCAS is appropriate for mesoscale nuclear accident consequence assessment.

In this paper, a review of the development of

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NAOCAS was given, and other nuclear accident consequence assessment system developed by CIRP was given a brief introduction. Then the architecture and models applied in NAOCAS_V3.0 was introduced. Final some issues of verification of migration and dispersion models should be paid close attention and future progress on nuclear accident consequence assessment of CIRP was discussed.

2. Overview of NAOCAS system

2.1. Development of NAOCAS

After the application of SRDAAR in Qinshan NPP, CIRP also focus on the research of nuclear accident consequence assessment technology. According to the development needs of emergency work, the nuclear accident consequence assessment system experienced a number of versions of the upgrade.

NAOCAS_v1.0 can response to the single source and the Geographic Information System (GIS) is based on Arc GIS 8.0 which is manufactured by ESRI Inc. (California, USA) was finished in 2003. In 2008, NAOCAS_v1.2 was developed to respond to mobile nuclear facility accidents and to validate the model using a large number of on-site tracer test data. NAOCAS_v2.0 is designed at the end of 2011, after the Fukushima nuclear accident, and developed in December 2012. It can response to nuclear facilities accident with multiple sources, any time to release. At present, the system has been successfully applied to nuclear power plants such as Tianwan, Fuqing, Changjiang, Taishan and so on. Also widely used in China's other nuclear facilities and forces.

NAOCAS_v3.0 is designed in 2014, system platform testing work is completed in June 2016. The system is a contingency platform of C/S and B/S combined architecture, which integrates geographic environment information, source item estimation, meteorological forecast and diagnosis model, mesoscale diffusion simulation model, dose evaluation module including food chain model and countermeasure model. As a national nuclear emergency response technical support center technology, NAOCAS_v3.0 was successfully used in 2015 - Aegis national emergency drills (for Taishan nuclear power version) and ConvEx-3 (2017) International Convention emergency exercises.

Also, to meet the evaluation requirement of long range migration and diffusion of radioactive nuclides in the atmospheric, CIRP developed the Radioactive Consequence Assessment System for Overseas Nuclear Explosion - RADCON. The system can predict and evaluate the long distance migration of atmospheric radioactive pollutant and its radiation effect in the domestic and surrounding countries and regions. The system has been successfully applied to the Wenchuan earthquake, the North Korean nuclear test, Fukushima nuclear accident and ConvEx-3 (2017) International Convention emergency exercises to provide the technical support for national decision-making and public safety. CIRP established numerical simulation techniques for the migration and diffusion of local scale assessment, including meteorological and Computational fluid dynamics (CFD) models.

2.2. Characteristic of NAOCAS_v3.0

The overall architecture of the system adopts the combination of C/S and B/S, based on the concept of Service Oriented Ambiguity (SOA), and absorbs the advantages of GIS for spatial data management. It ensures the shared access of data between different users and different applications demand. The system can quickly predict and evaluate the consequences caused by the release or potential release of radioactive substances into the environment in the event of a nuclear accident. It can provide decision makers with a strong visual of 2D and 3D consequence assessment graphical results, also with protective action decision recommendation reports, thus to assist the decision-making section to complete the implementation of emergency action plans and programs.

CIRP has independent intellectual property rights of the geographic information and physical modules. The graphical display enables all the functions of the current commercial GIS, while enabling the management and updates of the data. Geographic information can be externally imported as tif, dem, shp, png, CAD and other commonly used file formats. Also, NAOCAS can rapid automated 3D modeling which is beneficial to the accuracy and efficiency of the small scale modeling evaluation calculation, and the visualization effect in the emergency treatment process is improved. Users can customize physical model chain and interact with the system, such as set the evacuation route in real time and optimize the dose received on the evacuation route to meet the needs of emergency response.

2.3. Models

In this system, the acquisition of meteorological data provides three options: the use of provincial meteorological center numerical weather forecast products, weather station observation data; global numerical meteorological forecast data (NMC, NCEP, ECMWF). Non-hydrostatic wind field forecast model and wind field diagnostic model are adopted.

The Lagrangian puff model and the Monte Carlo particle diffusion model are adopted for the atmospheric diffusion model. In the puff model, when the complex topography or plume clusters increase to a certain extent, the puff's 5 splitting technique is adopted. The radioactive decay of nuclide, dry and wet deposition are considered. 3D particle trajectories can be more intuitive to show the distribution range of pollution influenced by the complex terrain.

In the intervention and dose calculation module, in the early stages of the accident, the irradiation pathways include plume immersed external irradiation, ground deposition external exposure and inhalation exposure, middle and late for food ingestion. The effects considered include acute deterministic effects and randomized health effects. The dose includes the expected dose, prevented dose and the remaining dose. By comparing the dose to the level of intervention, the interventions taken is determined. At the same time, the emergency evacuation route can be preset or plotted on the geographic information in real time, combined with the concentration of the spread of the grid data to analyze the rationality of the evacuation route.

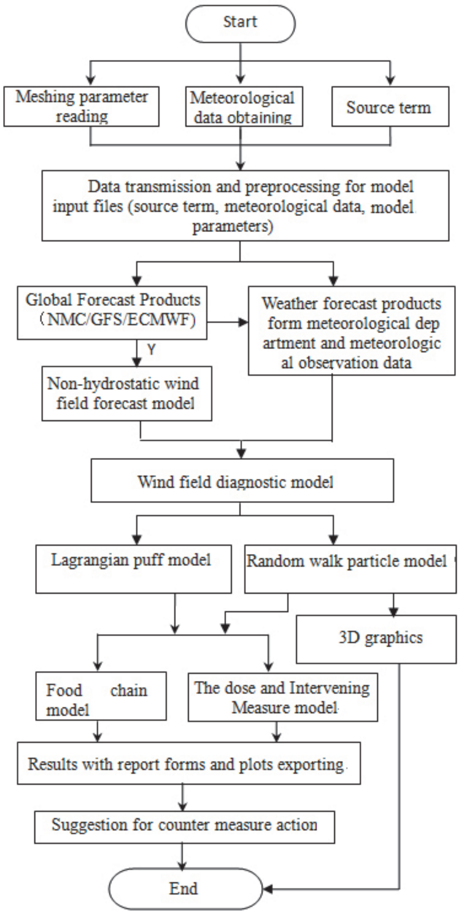

Figure 1. Model chains and data stream of NAOCAS system in the automatic manner.

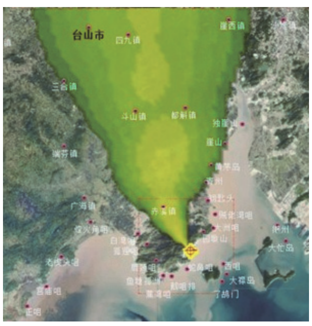

Figure 2. Instantaneous air concentration (puff).

2.4. Model verification and evaluation

During the development process, the project team is concerned with the selection and verification of the physical model, including the representative analysis of the station distribution under different meteorological

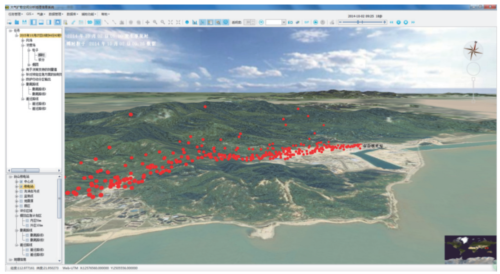

Figure 3. Instantaneous air concentration (particle).

observation data acquisition, using the observation data to verify the wind prediction mode, using the wild field SF_6 tracer experiment results to verify the atmospheric diffusion model, and comparison with commonly used evaluation software (such as Interas, Rascal and JRODOS). From the NAOCAS_v1.0 to the development of NAOCAS_v3.0, a lot of verification work have done to the physical module, the overall verification results show that the system used in the physical model is effective and reliable.

2.4.1 Verification of dispersion model

Ten releases of SF_6 tracer experiments were used to test the ability of our modeling system to simulate microscale dispersion. The radius of the evaluation range is 20km. Usually, the scatter diagram is a graph where predicted concentrations are plotted versus measured ones. **Figure 4** shows the distribution of ratios of predicted concentrations and measured ones, where the dot lines mean the limit of ratios of 3.5 and the broken lines of 10.

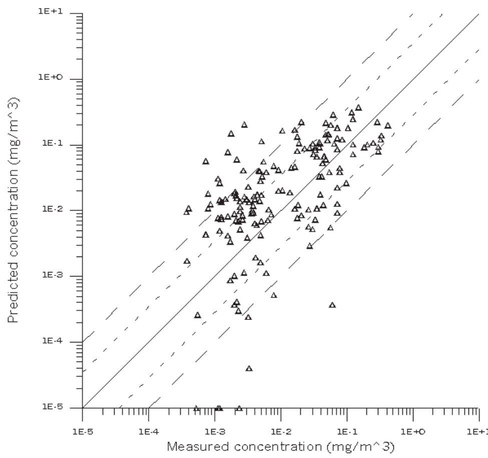

Figure 4. The distribution of ratios of predicted concentrations and measured ones (153 samples).

A factor, α, of goodness-of-fit is defined as the distribution function of the ratios of measured and calculated concentrations concentrated within the interval from 1/α to α. When the ratio is invariable, the smaller the factor is and the better the goodness-of-fit is. It is good that 68% of the total number of the points in scatter diagram is concentrated within the interval from 1/3.5 to 3.5 [7].

The result analysis indicates that, the percentage of predicted concentrations within factors of 3.5 and 10 of measured near-surface concentrations were 50.0 % and 81.3 %, respectively. In general, the concentrations are over-predicted. In addition, each release continued for near one hour and time interval of meteorological observations is one hour, so that it is expected that the precision of model will be improved with higher quality meteorological data. Thus, it is viable of the Lagrangian mesoscale puff dispersion model used in this system.

2.4.2 System-system intercomparison

In order to further test the validity of NAOCAS, typical cases were selected to compare the potential doses predicted by this system with those by InterRAS version 1.3, RASCAL version 2.1 and JRODOS (2016). **Table 1** and **Table 2** gives the comparison results.

(a) case No.1 (without precipitation): nuclide, 137Cs, 131I, 133Xe; duration of release, 10 hours; height of release, 30 m; the total amount of radioactivity released during 10 h, 1E+18 Bq; beginning time, 0800 BT.

(b) case No.2 (without precipitation): nuclide, 85Kr, 131I; height of release, 10 m; the total amount of 85Kr and 131I released during 0-8h is 1.45E+13 and 1.46E+14 Bq, and during 8-24h is 3.45E+13 and 6.48E+12 Bq.

It is shown that the difference of results of NAOCAS and InterRAS are almost less than 5 times. The trend of potential doses predicted by these two systems is consistent and the difference between the two systems is intelligible because of different wind field and dispersion models adopted. The ratios of NAOCAS and JRODOS are almost less than 3 times.

Table 1. The comparison of NAOCAS and InterRAS (mSv).

Case	System	1km	2km	5km	25km
No.1	InterRas	3.9E+02	1.7E+02	5.4E+01	3.4E+00
	NAOCAS	6.9E+02	3.3E+02	8.7E+01	4.2E+00
No.2	InterRas	1.4E+02	5.5E+01	1.1E+01	3.6E-01
	NAOCAS	1.8E+02	3.0E+01	3.9E+00	2.2E-01

Table 2. The ratio[a)] of NAOCAS and JRODOS.

Case	0.5km	1km	3km	5km	10km	20km
No.1	0.48	0.66	1.53	1.12	1.04	1.35
No.2	0.97	1.34	1.64	2.23	1.53	1.83

a) The ratio means the value predicted by JRODOS to one by NAOCAS.

3. Conclusion

NAOCAS_v3.0 provides a mean for quickly determining the concentration distributions of radioactive materials, various dose levels and areas by dose intervention levels during the early or later phase of the release after accident. The results discussed above demonstrate that the numerical methods used in the system are accurate. But it is necessary to further quantify model accuracy by comparing to much more experimental data, and use of a wider range of space/time, meteorological conditions, and source characteristics.

Based on the experience on the development of NAOCAS and RADCON, the CIRP project team is ongoing the research and development of the national nuclear accident consequence evaluation and decision support system, which will be applied to the state-level technical support units, the involved nuclear provinces and the operating units of the nuclear facilities. The system contains a multi-scale evaluation model chain, can response to the scope of all nuclear facilities, nuclear accident site in China and nuclear accident occurred at any position of the global, and regulate the China three levels of nuclear emergency organization in the nuclear accident consequence assessment and decision support technical system, to enhance the overall national nuclear emergency response capability.

The system will integrate the source analysis (including source inversion), multi-scale airborne radioactive substance diffusion model, water environmental radioactive material migration and diffusion model (rivers, lakes / reservoirs, ocean), dose estimation (including a dynamic food chain model), and decision support model of protective action. The data assimilation technology, Ensemble Dispersion Modeling (EDM), model validity and reliability verification are deeply studied.

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