

The study on spatial distribution features of radiological plume discharged from Nuclear Power Plant based on C4ISRE

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Abstract. When the nuclear emergency accident occurs, it is very important to estimate three-dimensional space feature of the radioactive plume discharged from the source term for the emergency organization, as well as for better understanding of atmospheric dispersion processes. So, taking the Hongyanhe Nuclear Power Plant for example, the study for three-dimensional space feature of the radioactive plume is accomplished by applying atmospheric transport model (coupling of WRF-HYSPLIT) driven by FNL meteorological data of NCEP (04/01/2014-04/02/2014) based on the C4ISRE (Command, Control, Communications, Computer, Intelligence, Surveillance, Reconnaissance, Environmental Impact Assessment). The results show that the whole shape of three-dimensional plume was about irregular cloth influenced by wind; In the spatial domain (height > 16000m), the distribution of radiological plume, which looked more like horseshoe-shaped, presented irregular polygons of which the total length was 2258.7km, where covered the area of 39151km²; In the airspace from 4000m to 16000m, the plume, covered the area of 116269 km², showed a triangle and the perimeter of that was 2280.4km; The shape of the plume was more like irregular quadrilateral, its perimeter was 2941.8km and coverage area of the plume was 131534km²; The overall distribution of the wind field showed a rectangular shape; Within the area along the horizontal direction 400m from origin to east and under height (lower than 2000m), the closer the distance coordinate (0,0), the denser the plume particles; Within the area of horizontal distance (500m-1000m) and height (4000m-16000m), the particle density were relatively sparse and the spread extent of the plume particles from west to East was relatively large and the plume particles were mainly in the suspended state without obvious dry sedimentation; Within the area of horizontal distance (800m-1100m) and height (>16000m), there were relatively gentle horizontal diffusion of plume particles with upward drift of particles in local area.



1. Introduction

The Fukushima Daiichi Nuclear Power Stations accident, occurred On March 11, 2011, caused the devastating effects of nuclear disasters all over the world. It was owing to prevailing western winds that the atmosphere nuclear pollution materials were mainly dispersed from Fukushima over the Pacific Ocean, then to North America, the Atlantic Ocean, Europe, Arctic, and back into Asia, apart from the contamination of the Japanese territory, the Japan Sea, and the Korean Peninsula. The released radionuclides were mostly deposited over the North Pacific Ocean (about 80%), about 20% was deposited over Japan, and less than about 1% was deposited over the Atlantic and Europe [1].

The System for Prediction of Environmental Emergency Dose Information (SPEEDI) was an essential system for preventing nuclear disasters by developing protection strategies in Japan. SPEEDI, as they were designed and expected to do, could quickly predict the atmospheric concentration of radioactive materials and radiation dose in the surrounding area of an emergency situation, including nuclear power stations, based on release sources, meteorological conditions and topographical data. Predicted results are shown with symbols and isolines on a map [2-3]. However, when the accident occurred, SPEEDI was not used when evacuation instructions were issued over several times. The gist of those instructions was simply “Just get out of the demarcated area!” Residents, not knowing how far to go to be safe, or in which direction, had no other option to take other than following decisions made blindly by the heads of their municipal governments [4-5].

Based on the experience and lesson of the Japan government emergency response, the spatial distribution characteristics of radionuclides plume were predicted by C4ISRE [6-8].

C4ISRE — Command, Control, Communications, Computer, Intelligence, Surveillance, Reconnaissance, Environmental Assessment, i.e. Environmental Protection Command Automation System. C4ISRE were a human-computer discrete event dynamic system which synthetically utilized modern information network technology and environmental science theory whose core was C4ISR theory in order to realize the relative EA information's automatic management on collection, transference and analysis. C4ISRE were the highly-efficient complicated system that could fulfill the control, management, simulation and forecast of the related information in EA.

2. Experimental method

2.1. WRF (the weather research and forecast)

The Weather Research and Forecasting (WRF) model was a numerical weather prediction and atmospheric simulation system designed for both research and operational applications, flux-form Euler equations were as follows [9-14]:

$$\partial_t U + (\nabla \cdot V_u) - \partial_x (p\phi_\eta) + \partial_\eta (p\phi_x) = F_U \quad (1)$$

$$\partial_t V + (\nabla \cdot V_v) - \partial_y (p\phi_\eta) + \partial_\eta (p\phi_y) = F_V \quad (2)$$

$$\partial_t W + (\nabla \cdot V_w) - g(\partial_\eta p - \mu) = F_W \quad (3)$$

$$\partial_t \Theta + (\nabla \cdot V\theta) = F_\Theta \quad (4)$$

$$\partial_t \mu + (\nabla \cdot V) = 0 \quad (5)$$

$$\partial_t \phi + \mu^{-1} [(V \cdot \nabla \phi) - gW] = 0 \quad (6)$$

Where: ∂ represented a generic variable; p_0 was a reference pressure (typically 10^5 Pascals); F_U , F_V , F_W , and F_Θ represented forcing terms arising from model physics, turbulent mixing, spherical projections, and the earth's rotation.

2.2. HYbrid single-particle lagrangian integrated trajectory model

The HYSPLIT 4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) model (Version 4) was a complete system for computing simple trajectories to complex dispersion and deposition simulations

using either puff or particle approaches. Both the Central Europe and Fukushima used the HYSPLIT dispersion model to simulate the plume, equations were as follows[9-14]:

$$P'(t + \Delta t) = P(t) + V(P, t)\Delta t \quad (7)$$

$$P(t + \Delta t) = P(t) + 0.5[V(P, t) + V(P', t + \Delta t)]\Delta t \quad (8)$$

$$U_{\max} \Delta t < 0.75 \quad (9)$$

$$\sigma = \frac{Z_{\text{top}} - Z_{\text{msl}}}{Z_{\text{top}} - Z_{\text{gl}}} \quad (10)$$

Where: $P(t)$ represented the initial-position; $P'(t+\Delta t)$ represented the first-guess position; Δt represented the integration time step; $U_{\max}$ represented the maximum transport velocity; σ represented terrain-following coordinate system; Z represented height; top, msl and gl represented the top of the dispersion model's coordinate system, relative to mean-sea level, ground level.

2.3. The composition of C4ISRE system

Physical composition of C4ISRE system was shown in figure 1.

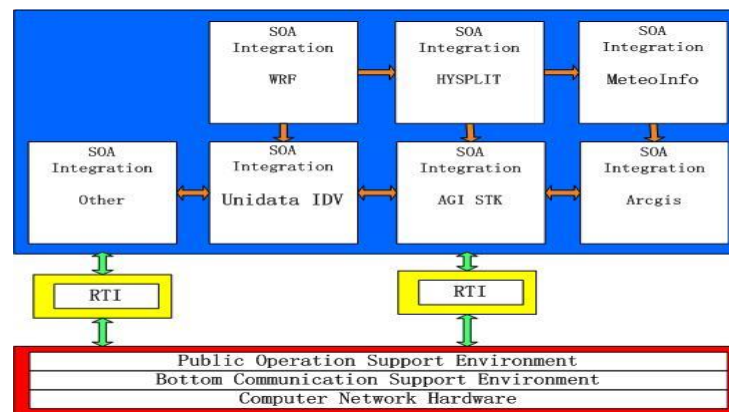


Figure 1. Physical composition for C4ISRE.

Service-Oriented Architecture was essentially a collection of services. These services communicate with each other. The communication can involve either simple data passing or it could involve two or more services coordinating some activity. Some means of connecting services to each other was needed. In SOA, services used protocols that describe how they passed and parsed messages using description metadata. This metadata describes both the functional characteristics of the service and quality-of-service characteristics. Service-oriented architecture aimed to allow users to combine large chunks of functionality to form applications which were built purely from existing services and combining them in an ad hoc manner. A service presented a simple interface to the requester that abstracts away the underlying complexity acting as a black box. Further users can also access these independent services without any knowledge of their internal implementation [15].

Run-Time Infrastructure (RTI) was a middleware that was required when implementing the High Level Architecture. RTI was the fundamental component of HLA. It provided a set of software services that were necessary to support federates to coordinate their operations and data exchange during a runtime execution. In other sense, it was the implementation of the HLA interface specification but was not itself part of specification. Modern RTI implementations conformed to the IEEE 1516 and/or HLA 1.3 API specifications. These specifications did not include a network protocol for RTI. It was up to components of an RTI to create a specification. Due to this, interoperability between RTI products and often, RTI versions, should not be assumed unless the vendor specifies interoperability with other products or versions [16].

3. Simulation experiment design

3.1. Simulated region

The Hongyanhe Nuclear Power Plant was located in Donggang Town, Wafangdian in the Liaoning Province of China. The site was within the Prefecture-level city of Dalian, 104 kilometers north of Dalian City proper. The first Unit#1 located in the site (39.7969N, 121.473673E) [17]. For WRF simulating, the WRF-WPS domain consisting of three nested domains (figure 2), the inner domain represented location at (39°48'0N, 121°28'19"E).

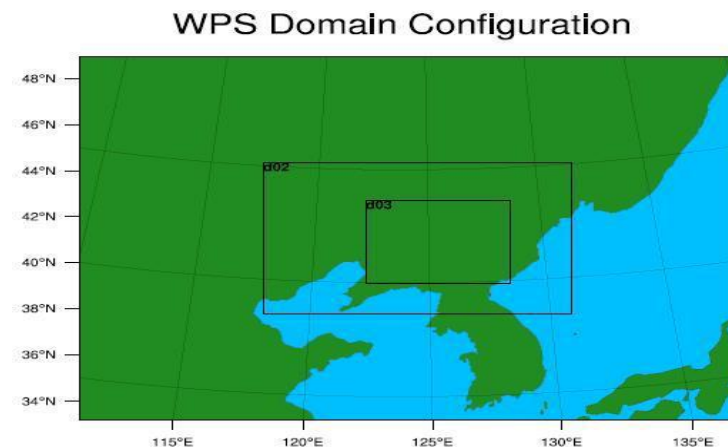


Figure 2. WRF model simulation area.

3.2. Simulation parameters setting

The physical and dynamical variables, which were same as Fukushima accident, were set up for HYSPLIT model (seen table1).

Table 1. The physical and dynamical variables for HYSPLIT model.

Variables	Values	Variables	Values
Height(m)	1200	Starting time	2014010100
Direction	forward	Particle or Gas	Gas
Total run time(hr)	24	Dry Deposition	Yes
Vertical Motion Method	sigma	Wet Deposition	Yes
Pollutant	I131	Velocity (m/s)	0.01
Emission rate(1/hr)	5.00E+15	Henry's (M/a)	3
Hours of emission (hr)	24	Radioactive decay half-life(days)	8

4. Results and discussion

4.1. Three-dimensional spatial characteristics of radiological plume

Three-dimensional spatial characteristics of radiological plume was simulated on basis of C4ISRE(as shown figure3 and figure 4).

As shown in figure 3 and figure 4, there were server main spatial features about the radiological plume. In the spatial domain (height > 16000m), the distribution of radiological plume, which looked more like horseshoe-shaped, presented irregular polygons of which the total length was 2258.7km (as shown in figure 4 (b)), the important coordinate points were as follows: (39°47'03.1423"N, 121°32'12.1965"E), (39°47'03.1423"N, 121°33'35.8413"E), (39°05'37.4379"N, 132°43'23.2403"E), (38°11'55.0085"N, 132°26'17.3745"E) where covered the area of 39151km². In the airspace from 4000m to 16000m, the plume, covered the area of 116269 km², showed a triangle (as shown in figure 4 (c)) and the perimeter of that was 2280.4km, the key points were as follows: (39°46' 54.5195" N, 121°30'43.4249" E), (39°47' 02.4885" N, 121°32' 12.0210" E), (37°55' 08.0465" N, 132°25'43.44" E),

(36°05'58.1862" N, 132°06'45.74" E). The shape of the plume was more like irregular quadrilateral (as shown in figure 4 (d)), its perimeter was 2941.8km and coverage area of the plume was 131534 km², the coordinate values of important points were as follows: (39°46' 46.8675" N, 121°30'03.8454" E), (37°58' 43.0689" N, 132°18'33.6133" E), (36°10' 01.0007" N, 131°54'12.2901" E), (38°26'51.9588" N, 121°29'33.3746" E).

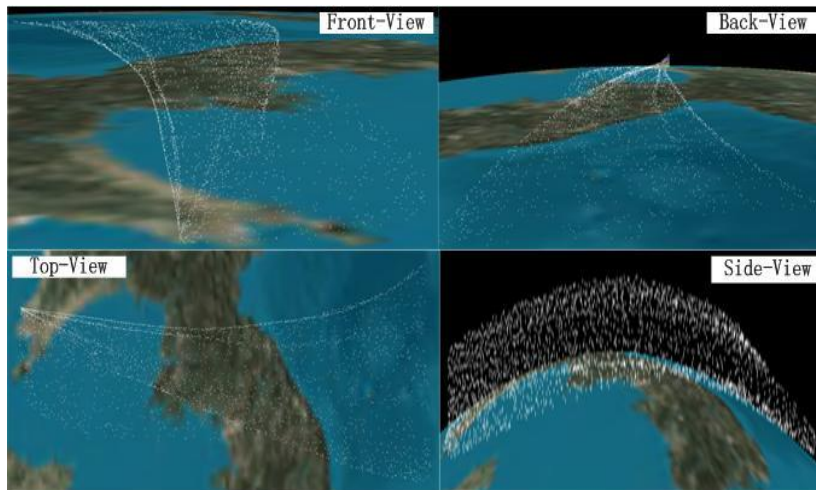


Figure 3. Comprehensive analysis of radiological plume by C4ISRE.

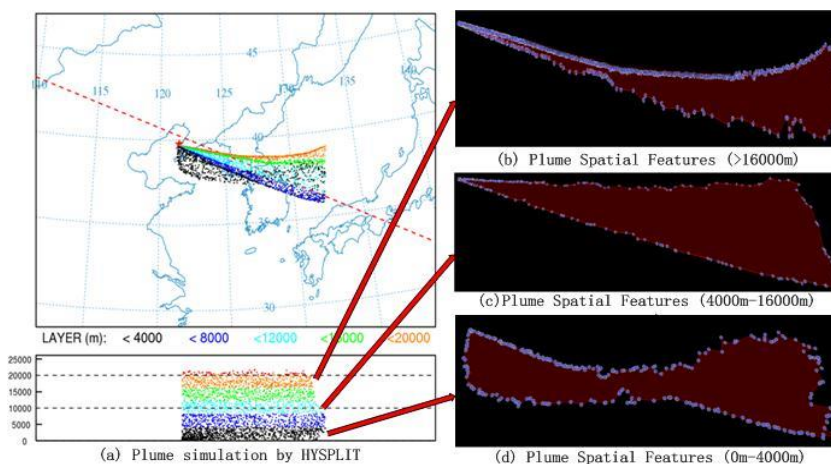


Figure 4. Radiological plume spatial features simulation by HYSPLIT.

4.2. Usal analysis for radiological plume spatial features

Causal Analysis for Radiological Plume Spatial Features was accomplished on basis of C4IRE integrated Unidata IDV, the simulation effect were shown in figure 5 and figure 6.

The overall distribution of the wind field showed a rectangular shape as shown in figure 6(a). The origin (0,0) of coordinate system represented the Source term (Unit #1 reactor) actually (see figure 6(b)). Due to dense wind lines and the change about angle of direction wind from 40 degrees to 65 degrees, so within the area along the horizontal direction 400m from origin to east and under height (lower than 2000m), the closer the distance coordinate (0,0), the denser the plume particles. Within the area of horizontal distance (500m-1000m) and height (4000m-16000m), because there were uniform wind distribution and strong wind power and the main wind direction changed from 32 degree to 38 degrees in a clockwise way in that area, so the particle density were relatively sparse and the spread extent of the plume particles from west to East was relatively large and the plume particles were mainly in the suspended state without obvious dry sedimentation. Within the area of horizontal distance (800m-1100m) and height (>16000m), the wind field had following characteristics: uniform wind distribution, moderate wind power and the main wind direction change from 32 degree to 38 in a

clockwise way, all that, in turn, led to relatively gentle horizontal diffusion of plume particles with upward drift of particles In local area.

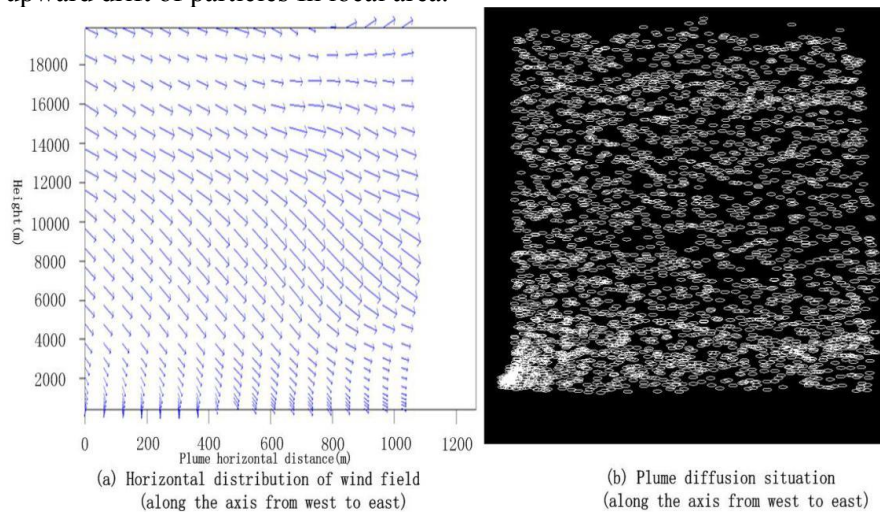


Figure 5. Radiological plume particles spatial distribution integrated pressure field.

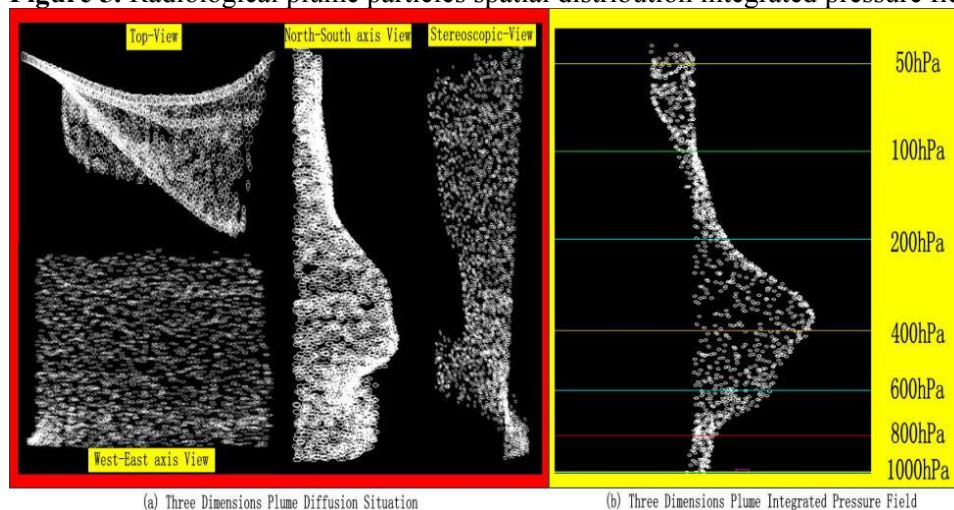


Figure 6. Comprehensive analysis of radiological plume particles spatial features simulated by C4ISRE integrated Unidata IDV.

5. Conclusions

a) In the spatial domain (height > 16000m), the distribution of radiological plume, which looked more like horseshoe-shaped, presented irregular polygons of which the total length was 2258.7km, where covered the area of 39151km². In the airspace from 4000m to 16000m, the plume, covered the area of 116269 km², showed a triangle and the perimeter of that was 2280.4km. The shape of the plume was more like irregular quadrilateral, its perimeter was 2941.8km and coverage area of the plume was 131534km².

b) The overall distribution of the wind field showed a rectangular shape. Within the area along the horizontal direction 400m from origin to east and under height (lower than 2000m), the closer the distance coordinate (0, 0), the denser the plume particles.

c) Within the area of horizontal distance (500m-1000m) and height (4000m-16000m), the particle density were relatively sparse and the spread extent of the plume particles from west to East was relatively large and the plume particles were mainly in the suspended state without obvious dry sedimentation.

d) Within the area of horizontal distance (800m-1100m) and height (>16000m), there were relatively gentle horizontal diffusion of plume particles with upward drift of particles in local area.

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References

- [1] Pavel P, Katsumi Hirose, Michio Aoyama, 2013 Fukushima Accident Radioactivity Impact on the Environment [M] *Elsevier: British Library Congress* 132-230
- [2] Makoto M, Fumio N, 2008 System for prediction of environmental emergency dose information network system[J] *Fujitsu scientific & technical journal* **44(4)** 377-388
- [3] Chino M, Ishikawa H, Yamazawa H, 1993 SPEEDI and WSPEEDI: Japanese Emergency Response Systems to Predict Radiological Impacts in Local and Workplace Areas due to a Nuclear Accident[J] *Radiation Protection Dosimetry* **50(2)** 145-152
- [4] 2011 Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company. Executive Summary of the Interim Report[R]. <http://www.cas.go.jp/jp/seisaku/icanps/eng/interim-report.html>, 9-13
- [5] Herviou K, 1999 Final report of the STEPS project[R]. *IPSN-Report* 25-30
- [6] Ma Yunfeng, 2011 The system simulation research for the Environmental Impact Assessment based on C4ISR theory[D]. *Doctoral Dissertation of Northeastern University* 30-72
- [7] Ma Yunfeng, Hu Xiaomin, 2009 The research on the Environmental Assessment Automation System-C4ISRE based on C4ISR theory[C]. *6th International Conference on Information Technology : New Generations, Las Vegas, Nevada, IEEE Computer Society* 1485-1491
- [8] Yunfeng Ma, Qi Wang, Xiaofei Shi, 2015 Research on System Simulation Technology for Joint Prevention and Control of Environmental Assessment Based on C4ISRE[C]. *Geo-Informatics in Resource Management and Sustainable Ecosystem Communications in Computer and Information Science* 699-706
- [9] Lin Xueqing, Cao Jianzhu, Ou Jingyuan, 2006 DESIGN AND DEVELOPMENT OF CONSEQUENCES ASSESSMENT AND FORECAST SYSTEM FOR NUCLEAR ACCIDENTS FOR STATE ENVIRONMENTAL PROTECTION ADMINISTRATION[J]. *Radiation Protection* **26(2)** 70-77
- [10] FONG NGAN, ARIEL STEIN, ROLAND DRAXLER, 2015 Inline Coupling of WRF-HYSPLIT: Model Development and Evaluation Using Tracer Experiments[J]. *JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY* **54** 1162-1176.
- [11] A.F.Stein, R.R.Draxler, G.D.Rolph, 2015 NOAA'S HYSPLIT ATMOSPHERIC TRANSPORT AND DISPERSION MODELING SYSTEM[J]. *AMERICAN METEOROLOGICAL SOCIETY* **12**:2059-2077
- [12] XIN Yujie, WANG Guochen, CHEN Li, 2016 Identification of Long-Range Transport Pathways and Potential Sources of PM₁₀ in Tibetan Plateau Uplift Area: Case Study of Xining China in 2014[J]. *Aerosol and Air Quality Research* **16** 1044-1054
- [13] Galina I.Yotova, Roxani Tsitouridou, Stefan L.Tsakovski, 2016 Urban air quality assessment using monitoring data of fractionized aerosol samples chemometrics and meteorological conditions[J]. *JOURNAL OF ENVIRONMENTAL SCIENCE AND HEALTH* **51(7)** 544-552
- [14] Carlos J, Valle-Díaz, Elvis Torres-Delgado, 2016 Impact of Long-Range Transported African Dust on Cloud Water Chemistry at a Tropical Montane Cloud Forest in Northeastern Puerto Rico[J]. *Aerosol and Air Quality Research* **16** 653-664
- [15] https://en.wikipedia.org/wiki/Service-oriented_architecture#cite_note-5
- [16] [https://en.wikipedia.org/wiki/Run-time_infrastructure_\(simulation\)](https://en.wikipedia.org/wiki/Run-time_infrastructure_(simulation))
- [17] Song Lu, 2014 Nuclear Power Plant Landscape Design-A Case Study of Nuclear Power Plants Along the Hong Yan He[D]. *Master Degree thesis of Dalian Polytechnic University* 19-25