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SRDAAR-QNPP: a computer code system for the real-time dose assessment of an accident release for Qinshan Nuclear Power Plant

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Abstract—The paper presents a computer code system "SRDAAR-QNPP" for the real-time dose assessment of an accident release for Qinshan Nuclear Power Plant. It includes three parts: the real-time data acquisition system, assessment computer, and the assessment operating code system. In SRDAAR-QNPP, the wind field of the surface and the lower levels are determined hourly by using a mass consistent three-dimension diagnosis model with the topographic following coordinate system. A Lagrangin Puff model under changing meteorological condition is adopted for atmospheric dispersion, the correction for dry and wet depositions, physical decay and partial plume penetration of the top inversion and the deviation of plume axis caused by complex terrain have been taken into account. The calculation domain areas include three square grid areas with the sideline 10 km, 40 km and 160 km and a grid interval 0.5 km, 2.0 km, 8.0 km respectively. Three exposure pathways are taken into account: the external exposure from immersion cloud and passing puff, the internal exposure from inhalation and the external exposure from contaminated ground. This system is able to provide the results of concentration and dose distributions within 10 minutes after the data have been inputed.

Keywords: real-time; dose assessment; computer code system; nuclear power plant; accident.

1 Introduction

At present, the accident consequence assessment of nuclear facilities includes following categories: ACA, PCA, Real-time and over-event (UIF, 1990). "Real-time assessment", also known as the name of "Emergency response assisting systems", is mainly used for assessing consequences of a release that has actually taken place, and the assessment is more or less carried out simultaneously with the development of accident situation.

The main difference between real-time and accident consequences assessment (ACA) or probabilistic consequences assessment (PCA) is that ACA or PCA is used for

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assessment of potential accident. One of the main differences between real-time and over event is that the ingestion pathway is usually neglected in real-time, however, is main pathway in over-event. At the moment the most advanced system of real-time assessment in the world is the ARAC system developed by Lawrence Livermore National Laboratory of U.S.A. (Dickerson, 1985).

In addition, a computer code system is named "SPEEDI" developed in the early 1980s by JAERI (Imai, 1985).

In the middle October 1988, international workshop "Improved safety character of nuclear facility: developing the model of real-time dose assessment" was held by LLNL and IAEA at LLNL, U.S.A. Subsequently, a workshop on emergency of accident for nuclear power was organized by Bureau of Safety, Protection and Health of China National Nuclear Corporation at CIRP. In the workshop it is preliminary determined that a computer system of real-time dose assessment for accident emergency should be set up in the Qinshan Nuclear Power Plant (QNPP). In spring 1989, CIRP accepted the entrustment from QNPP, undertaking the research project on design, model, parameter and code of accident emergency assessment for the Qinshan Nuclear Power Plant. According to the conditions of our country and requirements by QNPP the computer assessment system could not only be used for real-time dose assessment but also for display several important parameters required by the plant operation and the environmental monitoring data.

2 Brief introduction of QNPP

Qinshan Nuclear Power Plant is PWR type and the total nuclear net capacity installed is 300 mW (e). It is located at the foot of Qinshan Mountain, Haiyan County, Zhejiang Porvince. The site is 87 km south-west of Shanghai and 67 km north-east of Hangzhou. It locates a complex topography, a hilly lands near the sea coast. The climate of the site belongs to that of subtopics moist area. The significant feature of the climate is that the wind direction changes obviously with seasons and most precipitations are concentrated in the summer. The general meteorological characteristics in the site and the surrounding area are described as follows: annual average temperature: 15.9℃ ; annual precipitation: 1124.6 mm; annual prevailing wind direction: east wind and the second, ESE wind; annual average wind speed; 3.4 m/s. Based on the census data in 1982, the total number of the population with the range of 80 km around the plant is about 10 million, the average density of population is 535 people/km^2.

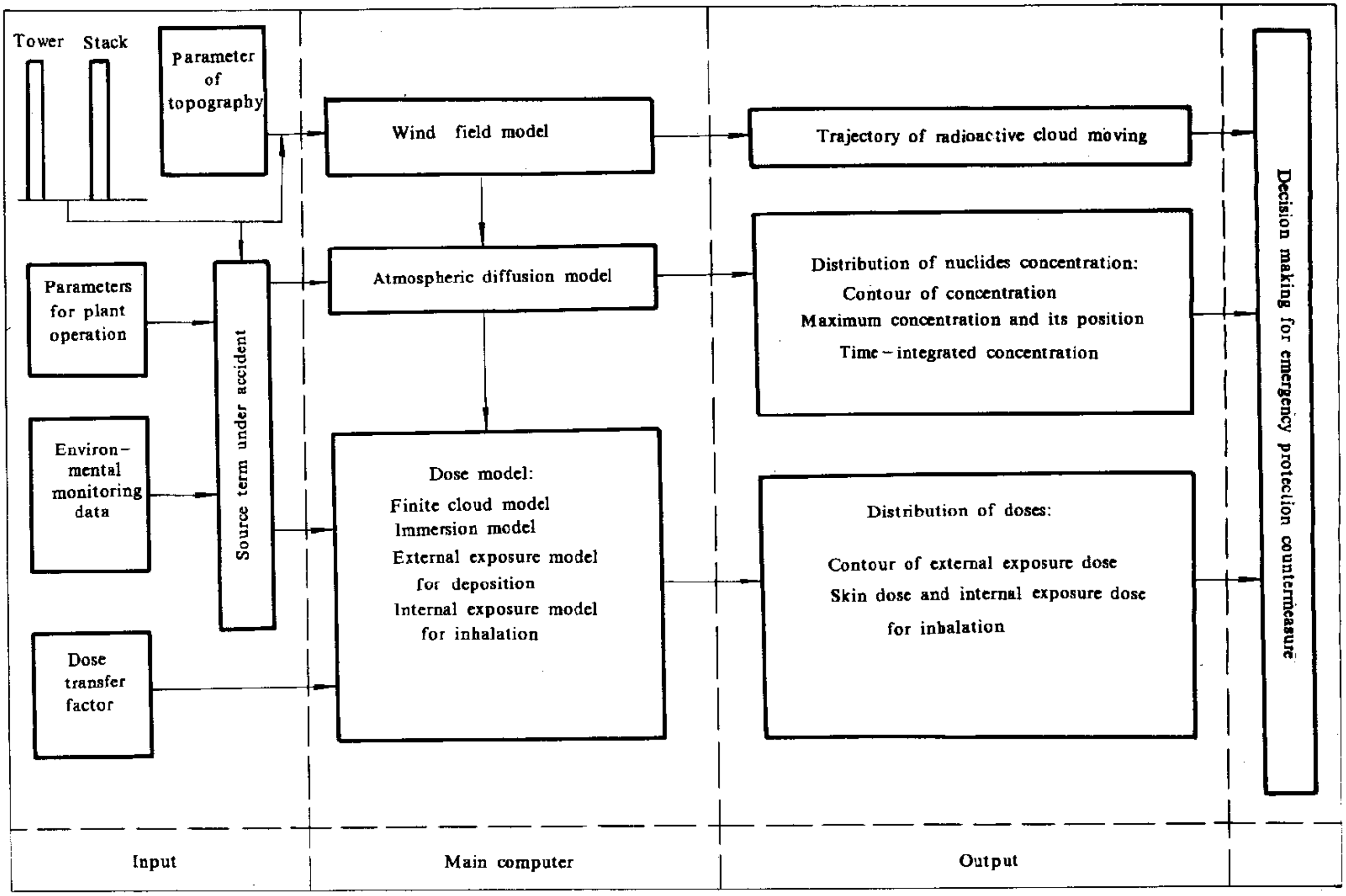

Fig.1 Schematic diagram of principal configuration of SRDAAR-QNPP

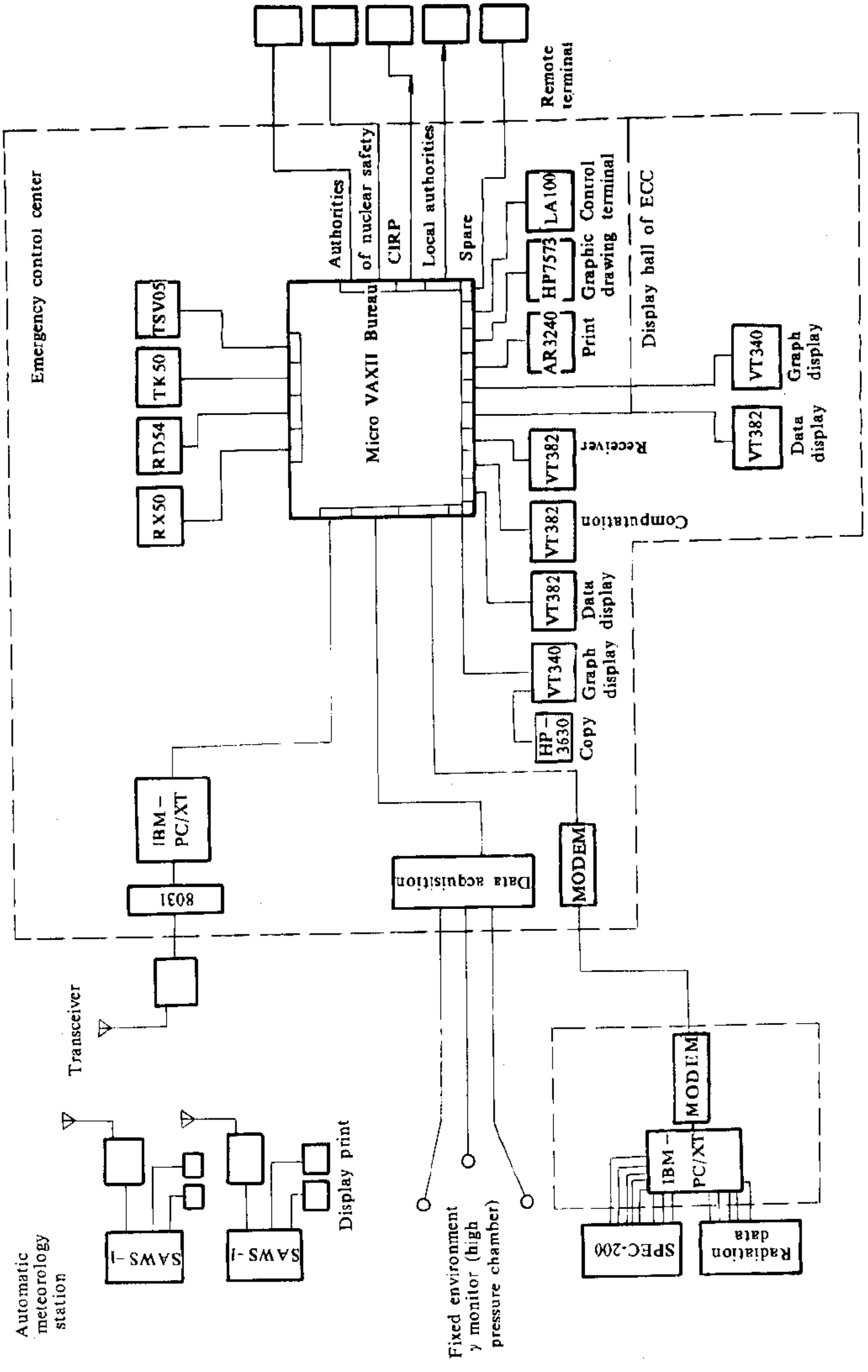

Fig.2 A brief description of the hardware of SRDAAR-QNPP

3 Construction of SADAAR-QNPP

SRDAAR-QNPP consists of the following three parts: real-time data acquisition system, assessment computer and code system of calculation and assessment. Fig. 1 shows schematic diagram of principal configuration of SRDAAR-QNPP. A brief description of the hardware of SRDAAR-QNPP is given in Fig.2

3.1 Real-time data acquisition system

Plant operation parameter from SPEC-200 unit of main-control chamber and radiation data from radiation monitoring system in dose-control chamber are processed by a IBM-PC/XT computer, which synchronously transmits real-time and historic data to the MV II assessment computer with a set of modem, according to the command of the acquisition subsystem.

Six meteorological elements from two automatic meteorology station are stored by a microprocessor 3031. Then the results are subsequently transmitted through wireless to the front unit IBM-PC/XT meteorological computer. Then IBM computer transmits required data to MV II according to command and requirements of acquisition system.

Environment monitoring data (average for 5 minutes) from 3 high pressure chamber are transfer processed and stored by a data-acquisition unit. Through the telephone wire and the modem, the data transfer from high pressure chamber to the unit. Then relevant data are transfered to the MV II by the wires.

Above three kinds of data are stored in the database of the system for assessing and displaying .

3.2 System of assessment computer

The assessment computer is the program operating environment. The main computer of SRDAAR-QNPP is a set of MICRO VAX II computer with 9 MB memory.

3.3 Code system of assessment and calculation

Code system of assessment and calculation is the most critical part of SRDAAR-QNPP. Its main function is as follows: acquisition and storage of data, atmospheric diffusion, dose calculation, and the output display.

It consists of the following 5 subsystems (Fig. 3): (1) Real-time data receiving subsystem; (2) subsystem of atmospheric diffusion and dose calculation; (3)subsystem of data output; (4) database subsystem; (5) subsystem of graphic output.

4 Source term of serious accident

Nine kinds of serious source term proposed in WASH-1400 is temporarily

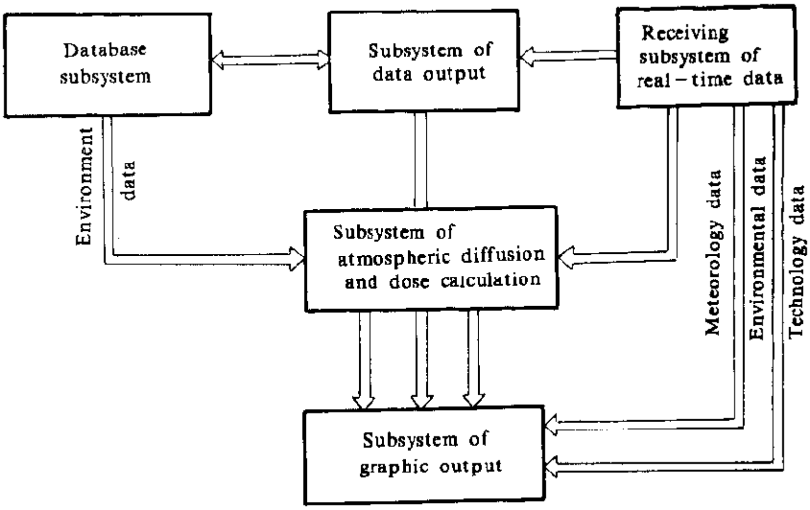

Fig.3 Construction of the computer code system of assessment and calculation

adopted as reference. Based on operation situation, i. e., degree of core damage and integrity of container, one of 9 kinds of serious source terms PWR 1-9 multiplied by a proper coefficients are selected and used in the environment consequence assessment. All parameters relevant to the source terms of PWR 1-9 are pre-stored in the database for recalling at any time.

5 Model of atmospheric diffusion and dose calculation

5.1 Model, parameters and code of atmospheric diffusion (Desiato, 1980)

Safety series No. 86 (IAEA, 1987) points out that atmospheric diffusion model for evaluating the consequence of a release of radioactivity to the atmosphere can be divided into three types according to its complexity: Gaussian plume model, Lagrangin puff model, three-dimensional numerical model.

Research report (Lowellen, 1985) indicates that the performances of above three kinds of model are similar in local area (within 10 km around source point), however, the performance of the two latter models superior to that of the first one at larger area (within 40 km around source point) and performance of puff model and three-dimensional numerical model are nearly similar. Based on above result and taking into account that the terrain of QNPP site is neither smooth nor very complex, a Lagrangin puff model under changing meteorological condition is adopted, in which the dispersing plume is simulated by a sequence of Lagrangin puff whose trajectories are determined by the wind speed and direction at each time step. Wind field is determined by a mass-consistent three dimensional diagnosis model with the topographic following coordinate system.

5.1.1 Grids

The shorter the interval of grid is, the higher the accuracy of spatial resolution is, but much more time will be spent for computation and so a compromise between computed time and its accuracy must be taken into account. In addition, if grid interval is too large the dimension of puff may be so small that it could pass through the interval of grid within near area closed source, which may cause underestimating of concentration. Therefore the area within 80 km is decided three square grid area of small, intermediate, lager scale. The lengths of sideline of these square are 10 km, 40km and 160 km with grid interval 0.5 km, 2 km and 8 km respectively.

5.1.2 Wind field

An automatic meteorology station is installed in Qinlian Village 2 km WNW away from QNPP, it transmits meteorological data of wind direction, speed, temperature, humidity, air pressure and precipitation to MV II in the form of real-time on line. There are 11 surface meteorology stations around QNPP within 50 km. In case of accident the meteorological data (wind direction and speed) will be acquired by specific wireless telephone as soon as possible. Wind field of the surface and the lower levels are determined hourly by using a mass consistent three-dimension diagnosis model with the topographic following coordinate system.

5.1.3 Puff release

The duration of release for PWR 1－9 accident could be changed from half hour up to 10 hours. Different time intervals between successive puffs should be selected for different type of accident in order to ensure an enough number of puff released within a certain duration of release which is required for a proper accuracy. In addition, a certain amount of puffs should be released during early stage of accident (such as first 30 min) in order to obtain a fairly accuracy of predicting consequences for early stage. A set of puff release with different time interval at different stage are developed to simulate the release of various type of accident. The detail of release form is shown in Table 1.

5.1.4 Puff trajectory

The trajectory of puff transportation is changed with the time. Fig. 4 illustrates puff trajectory at end of third time-step after beginning of an accident. Supposing the length of time step $dt = t_k - t_{ki}$, the coordinate of *i*th puff center at end of wth time-step is given as follows:

$$X^{(i)}_{o,w} = \sum_{k=1}^{w} U_{x,k}(t_k - t_{k-1}), \tag{1}$$

Table 1 **Puff release way for different duration accident release**

Puff parameter		Release time			
		0–0.5 h	0.5–4.0 h	4.0–8.0 h	>8h
Time interval between puffs		$\Delta t_1=5$ min	$\Delta t_2=10$ min	$\Delta t_3=30$ min	$\Delta t_4=60$ min
Total number of released puff		$N_1=6$	$N_2=21$	$N_3=8$	$N_4<40$
Number of released puff		n_1	n_2	n_3	n_4
Source strength	0–0.5 h	Q/n_1			
for	0.5–4.0 h	$Q/(6+2n_2)$	$Q/(3+n_2)$		
each puff	4.0–8.0 h	$Q/(48+6n_3)$	$Q/(24+3n_3)$	$Q/(8+n_3)$	
	greater than 8h	$Q/(96+12n_4)$	$Q/(48+6n_4)$	$Q/(16+2n_4)$	$Q/(8+n_4)$

Q is the total amount of released radioactivity, Bq

$$Y^{(i)}_{o,w}=\sum_{k=1}^{w}U_{y,k}(t_k-t_{k-1}),$$

where, $U_{x,k}=V_k\sin\alpha_k U_{y,k}=V_k\cos\alpha_k \alpha_k=180+D_k$(Degree),

D_k, V_k are wind direction and wind speed of ith puff at point of $(X^{(i)}_{o,k}, Y^{(i)}_{o,k}, Z^{(i)}_{o,k})$ in kth time; z is the effective release height of ith puff. The effective release height of ith puff is supposed to be constant during puff moves within calculation domain.

5.1.5 Deviation of plume axis

Simulation experiment in wind tunnel demonstrates that plume axis near source point is subjected to a certain degree of deviation at 4 wind directions (SE, E, ESE, NE) under the condition of neutral stability. It is caused by the obstruction of Qinshan Mountain body (about 1.5 km wide and 2.5 km long) nearby. The deviation DY (m) can be expressed as the function of downwind distance.

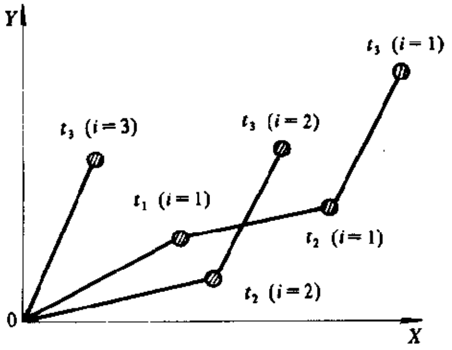

Fig.4 Diagram of puff trajectory

5.1.6 Puff rise

Briggs formula is adopted to calculate the puff rise.

5.1.7 Diffusion parameter

The effective diffusion parameter for ith puff at the end of wth time-step under varying meteorological conditions can be expressed as follows:

$$[\sigma^{(i)}_{j,e,w}]^2=\sum_{k=1}^{w}[\sigma^{(i)}_{j,k}]^2 \quad (j=x,\ y,\ z)\ , \tag{2}$$

where $[\sigma^{(i)}_{j,e,w}]$ is the effective diffusion parameter for *i*th puff at the end of *k*th time-step for *j* direction

$$[\sigma^{(i)}_{j,k}]^2=\sigma^{(i)2}_{j,k}(t_k)-\sigma^{(i)2}_{j,k}\ (t_{k-1})\ , \tag{3}$$

if using the form of power function, then

$$[\sigma^{(i)2}_{j,k}]=P_j^2\{[\sum_{m=1}^{k}(U^{(i)}_m(t_m-t_{m-1})]^{2q_j}+[\sum_{m=1}^{k-1}(U^{(i)}_m(t_m-t_{m-1})]^{2q_j}\}, \tag{4}$$

where supposing

$$\sigma_{x,k}=\sigma_{y,k}\ . \tag{5}$$

In SRDAR-QNPP four sets of diffusion parameters are provided for choice such as observed values (default) of field tracer experiment on site of QNPP which was obtained in a set of SF_6 tracer field atmosphere experiment in 1984–1985, P-G curve, IAEA parameter, Brigg's diffusion parameter suitable for city. Of course the first one is the most suitable to QNPP because it is got with tracer experiment on-site. Other sets of parameter are provided in order to make this code to be widely used for other site than QNPP. In addition, an isotropic diffusion parameter of wind tunnel experiment is also adopted.

5.1.8 Atmosphere stability

Atmosphere stability is determined by an apparatus of stability classifications, which should be input into MV II by pressing terminal key.

5.1.9 Puff-concentration formula

Surface concentration at grid point $(x,\ y,\ o)$ for *i*th puff at the end of t_k time-step can be expressed with the following formula which has taken into account the dry and wet deposition depletion, physical decay and the factor of partial plume penetration of an elevated inversion.

$$C^{(i)}_k(x,\ y,\ o)=\frac{2Q^{(i)}F^{(i)}_{d,k}F^{(i)}_{w,k}F^{(i)}_{R,k}}{(2\pi)^{3/2}\sigma^{(i)}_{x,\partial,k}\sigma^{(i)}_{y,\partial,k}\sigma^{(i)}_{x,\partial,k}}\exp[-\frac{(X-X^{(i)}_{o,k})^2}{2\sigma^{(i)2}_{x,\partial,k}}]\exp[-\frac{(Y-Y^{(i)}_{o,k})^2}{2\sigma^{(i)2}_{y,\partial,k}}]$$
$$\{\exp[-\frac{(Z^{(i)}_o)^2}{2\sigma^{(i)2}_{k,\partial,k}}]+F^{(i)}_{p,k}\exp[-\frac{(2L-z^{(i)}_o)^2}{2\sigma^{(i)2}_{z,\partial,k}}]+F^{(i)}_{p,k}\exp[-\frac{(2L+z^{(i)}_o)^2}{2\sigma^{(i)2}_{x,\partial,k}}]\} \tag{6}$$

where $F^{(i)}_{d,k}$, $F^{(i)}_{w,k}$ and $F^{(i)}_{R,k}$ are factor of dry deposition depletion, wet deposition depletion and radioactive decay respectively at t_k time for ith puff; L is height of mixing layer; $F_{p,k}^{(i)}$ is factor of partial plume penetration of an elevated inversion, its definition is given as follows:

$$F_{p,k}^{(i)} = \int_0^L \exp[-\frac{(z-z_o^{(i)})^2}{2\sigma_{x,\partial,k}^{(i)2}}]dz \Big/ \int_0^\infty \exp[-\frac{(z-z_o^{(i)})^2}{2\sigma_{z,\partial,k}^{(i)2}}]dz. \tag{7}$$

5.2 Dose model

5.2.1 External exposure dose from radionuclides in the immersion cloud

Dose D_B (Sv) of plume-immersion exposure at a grid point (x, y, o) in any time interval of accident release is given by following formula:

$$D_B(x, y, o) = S_F \psi(x, y, o) g_B , \tag{8}$$

where $\psi(x, y, o)$ is the time-integrated concentration (Bq. s/m^3) in that release time interval at the point (x, y, o); S_F is the building shielding factor.

5.2.2 Internal exposure dose due to inhalation of radionuclides during the passage of the cloud

Committed-effective dose equivalent D_A^a (Sv) of a-age-group's member produced via inhalation pathway is given by following formula:

$$D_A^a = R_a \psi(x, y, o) g_A^a , \tag{9}$$

where R_a = the air-inhalation rate (m^3/s) of individual for a-age-group; g_A^a = dose transfer factor for a-age-group.

5.2.3 External exposure dose from radionuclides deposited on the ground

The external exposure dose D_B^G (Sv) produced by surface dry, wet deposition of nuclide at t time is given by the following equation:

$$D_B^G(t) = S_F D(t) g_B^G , \tag{10}$$

where $D(t)$ is the surface deposition concentration (Bq/m^2) produced via dry, wet deposition at t time; g_B^G is the dose transfer factor for surface deposition.

5.2.4 External exposure dose from radionuclides in a finite passing puff

The assessment system SRDAAR-QNPP is able to provide not only the model and code of infinite cloud, but also a model and code of finite passing puff to improve the accuracy of dose calculation, especially for area close to source point. The finite puff external dose calculation uses "discrete point approximation" to calculate the dose from a puff. In the discrete point approximation, the puff is assumed to be a cylinder with radius of 2 σ_y and a height of 6 σ_z. This cylindrical puff is then divided, using cylindrical coordinates, into a number of differential puff volumes, for each of which all of the radionuclides in the volume are treated as that they are located at a point in the center of the differential volume.

6 Output of SRDAAR-QNPP

6.1 Output of graphical subsystem

Output of graphical subsystem can be transmitted to three sets of equipment: graphical screen terminal, graph print and plotter. Output of graph contains the following three types:

(1) Plant safety parameter

The latest observed values and historical data of several plant safety parameters for a certain time interval can be displayed and drawn by means of diagram and curve graph .

(2) Gamma exposure rate

The latest measured values and historical data of 4 high pressure ionization chamber at a time range can be displayed and drawn by means of diagram and curve graph.

(3) Contour of concentration and dose

The system can display the contour graph of the following calculation results for any nuclide with a background of site map for three calculation areas (small, intermediate, large): time-integrated concentrations in air, surface deposition amount, external exposure dose from passing plume, external exposure dose from surface deposition, inhalation dose,thyroid dose for iodine, effective dose.

As an example, Fig.5 gives the contour graph of time-integrated concentration in air for I-131; Fig.6 gives the contour graph of effective dose produced by all nuclides for an assumed accident.

6.2 Output of table displaying subsystem

Cooperating with the graph-displaying subsystem, the table-displaying subsystem can display and print the basic data and results for the SRDAAR-QNPP in the form of the table on computer screen or print paper. The subsystem provides working way of multistage menu prompting in Chinese and man-computer talking.

7 Validation of dose prediction

In order to validate dose prediction given by this code, a comparison example between manual and code calculation is given as follows:

Input data about source term of an accident: release height: 25 m; thermal release rate: 1400 kcal/s; nuclides: I-131, Kr-85; release amount: 7.46E17 Bq for I-131,

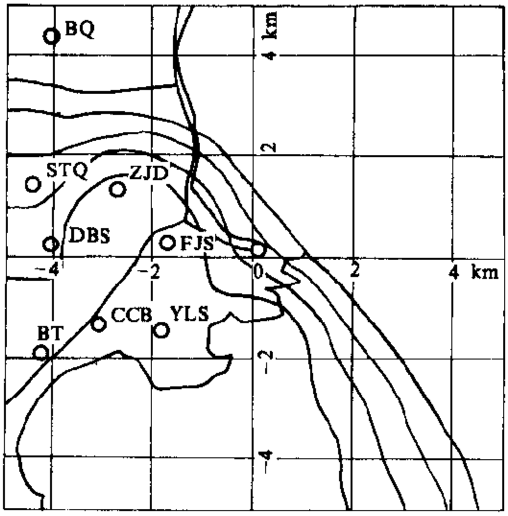

Fig.5 Contour graph of time-integrated concentration Current time: 91-07-03 14:00 Wind SPD: 12.0 m/s Wind DIR: 12.0 deg. Stability: D Rainfall 13.0 mm/h ACC. Type: PWR11 Duration 8.0 h Start time: 91-07-03 10:00 Release height: 50.0 m Item: integral concentration Nuclide: I-131 Unit: Biq s/m^3 #1: 0.10E-10 #2: 0.10E-05 #3: 0.10E+00 #4: 0.20E-15

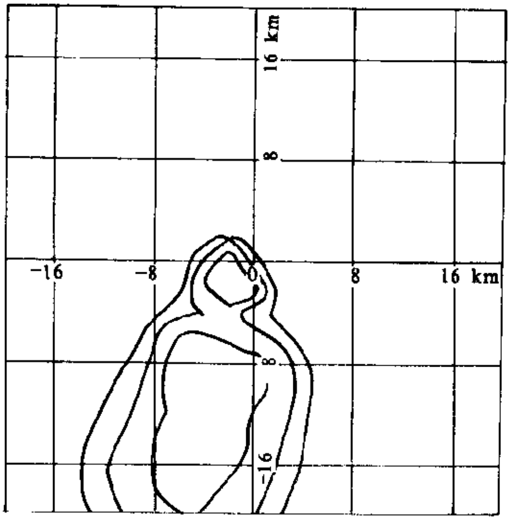

Fig.6 Contour graph of effective dose Current time: 91-07-03 12:30 Wind SPD: 5.0 m/s Wind DIR: 5.0 deg. Stability: C Rainfall 5.0 mm/h ACC. Type: PWR11 duration 8.0 h Start time: 91-07-03 10:00 Release height: 50.0 m Item Effect-Dos-for-Adult Nuclide: all nuc. Unit: Sv #1: 0.10E-21 #2: 0.10E-15 #3: 0.10E+09

1.04E16 Bq for Kr-85; release time: 0.5 h; meteorological condition for release time is given in Table 2.

Table 2 Meteorological data for release time

Time	0-10 min	10-20 min	20-30 min
Wind direction	S (180°)	SSE (157.5°)	SSW (202.5°)
Wind speed, m/s	1.0	2.0	3.0
Stability	D	D	D

Table 3 shows that the calculation results by manual and by the code system. In the calculation 3 puffs are supposed to be released. The duration of each puff is 10 minutes. In Table 3, P_1 and P_2 represent the points to the concerned. Their coordinates are as follows: P_1 (−2000 m, 8000 m, 0 m), P_2 (−500 m, 1000 m, 0 m).

t_1, t_2 and t_3 means 10, 20 and 30 minutes after release. Table 3 shows that the dose prediction given by this code system is valid.

Table 3 A comparison between manual and code calculation

(a) Concentration for different time, Bq/m^3

Nuclides	Concerned point	t_1		t_2		t_3	
		Manual	Code	Manual	Code	Manual	Code
I-131(infant)	P_1	0.0	0.0	0.0	0.0	2.15E-36	2.08E − 36
	P_2	1.52E-1	1.54E-1	7.18E + 9	7.18E + 9	3.35E + 1	3.33E + 1
I-313(child)	P_1	0.0	0.0	0.0	0.0	2.76E-38	2.78E − 36
	P_2	2.01E-3	2.05E-3	9.56E + 7	9.58E + 7	4.46E − 1	4.45E − 1

(b) Immersion dose, *Sv*

Nuclides	Concerned point	t_1		t_2		t_3	
		Manual	Code	Manual	Code	Manual	Code
I − 131	P_1	0.0	0.0	0.0	0.0	2.98E-47	0.0
	P_2	2.10E-12	2.12E-12	9.97E-2	9.91E-2	9.97E-2	9.91E-2
Kr-85	P_1	0.0	0.0	0.0	0.0	2.46E-51	0.0
	P_2	1.73E-16	1.72E-16	8.23E-6	8.04E-6	8.23E-6	8.04E-6

(c) Inhalation dose, *Sv*

Nuclides	Concerned point	t_1		t_2		t_3	
		Manual	Code	Manual	Code	Manual	Code
I-131(infant)	P_1	0.0	0.0	0.0	0.0	5.79E-45	0.0
	P_2	4.08E-10	4.17E-10	1.94E + 1	1.95E + 1	1.94E + 1	1.94E + 1
I-313(child)	P_1	0.0	0.0	0.0	0.0	7.34E-45	0.0
	P_2	5.17E-10	5.29E-10	2.46E + 1	2.47E + 1	2.46E + 1	2.47E + 1

8 Comparison of main performance among the computer code system for QNPP real-time dose assessment and other country

Table 4 gives the comparison of main performance among the SRDAAR-QNPP, US ARAC and Japan SPEED on local site.

Table 4 Comparison of main performance among the SRDAAR-QNPP, US ARAC and Japan SPEEDI on local site

Item	US ARAC system local site computer	Japan SPEEDI system local site computer	SRDAAR-QNPP
Type of computer	Main computer: VAX-II/782 local site computer: PC-350	Main computer: vector processor VP-110 Local site computer: minicomputer	VAX-II
Model of wind field	MATHEW Mass-consistent model for 3-D wind field	WIND04 Mass-consistent model for 3-D wind field	WINDF Mass-consistent model for 3-D wind field in which the coordinate is changed with topography
Concentration model	Main system: ADPIC Particle dispersion model of 3-d. Local site: Gaussion plume model	Main system: PRWDA Random-walk model for atmospheric dispersion and transport Local site: LSSPUFF Puff Model	Main system: QSPAMR Lagrangian puff model under changing meteorological condition
Dose model		Main system: CIDE dose model of grid-cell Local site: GSDOSE quick calc. by Gasussion plume model	"Concentration factor method" for infinite cloud, inhalation and ingestion. "discrete point approximation" for finite cloud
Calculation time	Less than 15 min	Several minutes	About 10 minutes after input data
Calculation scale	About 5 km around source point	<25 km, <100 km	0-5, 5-20, 20-80 km (radius form source point)
Output	Concentration dose field in the 5 km of radius from source point	Graph: display data of weather and wind field, concentration data dose data, site data.	Graph: latest, historical data of plant safety parameter, contour of concentration,dose,Table:meteorological data, environmental monitoring data, data of concentration and dose

References

Dickerson MH. Summary of MATHEW/ADPIC Model Evaluation Studies, UCRL-92319, 1985

Desiato F, Guidoni A. Sequential puff for atmospheric dispersion evaluation, DISP/ARA/MUT, Italy, 1980: 53

IAEA, Techniques and decision making in the assessment of off-site consequences of an accident in a nuclear facility, Safety Series, 1985; (86): 185

Imal K, Chino M, Ishikawa H, Kai M, Asai K, Homma T, Hidaka A, Nakamura Y, Iijima T, Morivchi SPEEDI: A computer code system for the real-time prediction of radiation dose to the public due to an accidental release, JAERI-1297, 1985: 89

Lowellen WS. Comparison of the 1981 INEL dispersion data with results from a number of different models, NUREG/CR-4159, 1985

UIF Tveten, Environmental consequences of release from nuclear accident. Norway: Nordic liaison committee for atomic energy, 1990: 261

(Received by April 21, 1993)