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Abstract

SPEEDI, a computer code system for prediction of environmental doses from radioactive materials accidentally released from a nuclear plant has been developed to assist the organizations responsible for an emergency planning. For realistic simulation, have been developed a model which statistically predicts the basic wind data and then calculates the three-dimensional mass consistent wind field by interpolating these predicted data, and a model for calculation of the diffusion of released materials using a combined model of random-walk and PICK methods. Therefore, SPEEDI gives more realistic prediction of radioactivity distribution and doses using the sophisticated models, and makes it possible to consider the effect of complicated topography on the transport and diffusion of effluents. These calculation in the system is carried out in conversational mode with a computer so that we may use the system with ease in an emergency. SPEEDI has also versatile files, which make it easy to control the complicated flows of calculation. In order to attain a short computation time, a large-scale computer with performance of 25 MIPS and a vector processor of maximum 250 MFLOPS are used for calculation of the models so that quick responses have been made. Simplified models are also prepared for calculation in a minicomputer widely used by local governments and research institutes, although the precision of calculation as same with the above models can not be expected to obtain.

The present report outlines the structure and functions of SPEEDI, methods for prediction of the wind field and the models for calculation of the concentration of released materials in air and on the ground, and the doses to the public. Some of the diffusion models have been compared with the field experiments which had been carried out as a part of the SPEEDI development program. The report also discusses the reliability of the diffusion models on the basis of the compared results, and shows that they can reasonably simulate the diffusion in the internal boundary layer which commonly occurs near the coastal region.

Keywords: Computer, Code, Nuclear Plant, Emergency, Accident, Prediction, Release, Diffusion, Plume, Puff, Wind Field, Concentration, Dose, SPEEDI, ARAC, Environment

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SPEEDI：事故放出に伴う公衆被曝線量の
実時間予測計算コードシステム

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要 旨

原子力施設の事故の際は環境中に放出される放射性物質からの被曝線量を予測計算して、緊急時の防災対策に役立てるための情報を提供する計算コードシステム SPEEDI を開発した。SPEEDI では、統計を用いた風の時間的予測を行ない、質量保存則を満たす 3 次元風速場を変分解析により求め、複雑地形上での移流拡散をランダムウォーク法と PICK 法の混合モデルによって計算し、より現実的な被曝線量の推定が行なわれる。またコードシステムとして、従来から使われてきたパフォーマンスおよびガウスブルームモデルの簡易計算コードも参考計算用に組込まれている。本報告では、各計算モデルのほか SPEEDI の構成および機能について述べた。さらに、拡散モデルの野外実験と風洞実験との比較について述べ、計算モデルの性能、その他システムとしての実用性について入力データおよび運用方法などの点から論じた。
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1. Introduction

The importance of emergency preparedness has been well recognized since the beginning of nuclear energy development in Japan. Program of environmental emergency monitoring was prepared to some extent both in national level and local governmental level.

For instance, the prefectural government of Ibaraki-ken where the early reactors were operated, had discussed the environmental emergency planning with the national government and other bodies having nuclear facilities, and the result was tested by an exercise carried out at Tokai-mura in 1971. There were an inactive period of the discussion on emergency preparedness while the discussion was strengthened on follow-up of the requirement for the reduction of release amount of radioactive gaseous waste at the normal operation of light-water-cooled reactors.

The discussion of emergency preparedness started again in Japan but it was not active before Three Mile Island Unit 2 (TMI-2) reactor accident in 1979. After TMI-2 reactor accident, discussions and inspections were made to learn the lessons and were concluded as the recommendations including needs for research and development.

The Japan Nuclear Safety Commission revised the National Research Program of Environmental Radiation Protection in 1980. This five-year program 1981-1985 includes the emergency related researches as “safety assurance at an extraordinary release of radioactive materials”. Then JAERI made the detailed research program and set a committee to check and review the program and the performance.

The development of a computer code system for the real-time prediction of environmental radioactive contamination and radiation dose to the public due to an accidental release from a nuclear site is one of the most important items. JAERI sent a mission to survey the development of such systems in other countries and in 1981 started the development of a code system in cooperation with the Meteorological Research Institute (MRI). In order to support the development and supply data for verification of the effectiveness of computational models and the system, series of atmospheric diffusion experiments and wind tunnel experiments were planned by JAERI and MRI, respectively.

In the United States, Lawrence Livermore National Laboratory is operating ARAC (Atmospheric Release Advisory Capability) project sponsored by the Department of Energy (DOE) and the Department of Defense (DOD). The ARAC project was initiated in 1972 and has evolved from a research and development phase to an operational phase. It has responded to approximately 60 situations, including exercises. Savannah River Laboratory has a similar system named WIND (Weather Information and Display). The computational models in both systems have been verified by field experiments.

The European countries such as Italy and Sweden have their programs to develop real-time prediction systems.

At the start of the development of the computational models of our system, we followed MATHEW for wind field calculation and ADPIC for concentration calculation of ARAC system. This report describes the code system SPEEDI (System for Prediction of Environmental Emergency Dose Information), the results of verification of models and future plans. The fundamental structure of SPEEDI was designed and the first version was completed at the end of FY 1981, i.e. March of 1982, then it was revised into the second version in FY 1982, and the third version which could be used for practical application has been completed.
at the end of FY 1983.

Design concepts are described in Chapter 2. The objective of the development is the practical use of the system. In order to reach the goal fast, the system was designed as a modular system convenient for the development itself. Basic utility softwares such as conversational control, data file handling and graphic display are common in the system. Computational models are incorporated in the system as independent modules and each of them can be operated either as a module in a whole system or as a stand-alone module. Their addition or deletion is also done easily without modification of the whole system.

The models calculating wind field and concentration distribution have been verified with experiments as described in Chapter 3. Necessary environmental data such as terrain height, road and lakes, etc. are provided for eleven areas which include fourteen nuclear power stations. In addition to these data, the system has the nuclear data for the approximation of source term in order to cope with the case where no sufficient data on source terms are available.

The practical realization of the SPEEDI system, including data transmission, terminal minicomputers and local meteorological data acquisition systems is being planned in the Science and Technology Agency (STA) of Japan and will be expected in use within two or three years. Further research items will be incorporated into next revision of the national research program which is to cover the coming five years.

The authors who wrote each section of this paper are shown as follows.

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2. Design and Function of SPEEDI

2.1 Design

2.1.1 Design Concepts

In the period of 1960-1975 the dominant method of systematization of nuclear codes is the sequential connections of already existing nuclear codes by adjusting the contents and formats of their input/output files.

A code system made by this method requires much manpower and computer time in modifications, deletions and additions of codes in the system. The method of recent years adopts a procedure which is commonly used in construction of buildings. According to the procedure, one at first constructs utility softwares such as graphics, file handling programs, data files, user interfaces and a control program which are common to all codes in the system. Then computational codes for physical models are set in the code system as modules. When the code system is designed so that its components, i.e., a code or library are easily changeable, the system and the component are called a modular code system and a module, respectively.

SPEEDI has been constructed by this method. The conversational control program, data files and file handling programs and graphic programs are basic utilities common to all computational codes in SPEEDI. The merits of this method are that firstly using the system the user can use every single code or all relevant codes to some subject, and secondly it is very easy to add, delete or modify codes in the system. The demerit of the method is that it requires much manpower and cost in construction of basic utilities. To avoid the demerit, SPEEDI makes use of existing softwares and data such as DAIAPOOL for file handling, ARGUS for graphics and the numerical mesh data on topography provided by the Land Agency of Japan. In addition to the adoption of the method mentioned above, the following features of the system are pursued in the design and construction of SPEEDI.

(1) Coexistence of research and practice use

When the design and construction of SPEEDI was started, the computational codes for physical models of JAERI to be included in the system were yet in their research and development phase.

Owing to the efforts of researchers of the Geophysical and Environmental Sciences Division at Lawrence Livermore National Laboratory, we can follow physical models and computational codes for three-dimensional wind field and concentration calculations. Even if starting from the same models, however, the codes will differ gradually from original ones in the process of model validation and code verification mainly by adopting the results of experiments.

This shows that although the ultimate goal of the development is to construct a useful code system for practice, we must also maintain the system for research use, and that the codes in the system will be improved frequently. For this reason SPEEDI must allow easy additions, deletions and modifications of codes by researchers. The changes must be done independently of other computational codes or functions of the system. In the practical use of the system, however, codes and functions in the system must be fixed and may not be changed so often. For the coexistence of these two conflicting uses, SPEEDI is designed to be controlled in conversational mode and each computational code is linked up with it very loosely. The method of the linkage is described in Section 2.1.3. The number of parameters
of each conversational command is reduced to a minimum. The system is designed to ask no further questions unless the user requests them.

(2) Realization of modular code system

In a development stage of the system, some computational codes are added and some are deleted from the system because of continuous improvements and assessments. The addition and deletion must not cause modifications of the system scheme, i.e., the system should be a modular code system.

For the modularization, the control method of the conversational control program must be independent of any specific code and the formats of input and/or output files of all codes must be the same. To achieve the modular control method, the input of every computational code should be divided into two parts, i.e., the one which depends on the input through a control table of the conversational control program, and the other which depends on data files of the system or the outputs of other codes. The control method of the former input will be described in Section 2.1.3. As for the latter input, such a file structure as the DATAPOOL must be adopted to unify the format of the observed wind data and results of computational codes.

(3) Partial use of system

In research use, users will calculate only wind field, concentration, or dose according to their interest. In the system every calculation should be done independently of others.

(4) Common data files

It is most important to equip unified data files with SPEEDI because every computation or display is based on common environmental and physical data. SPEEDI has five types of common data files which are automatically invoked before the execution of calculation. More detailed descriptions of the files are given in the Section 2.1.3.

(5) Unification of file format

Every data set which is used in the calculation of wind field, concentration, dose or drawing of maps will also be used in other calculations. For this reason it is best to fix standard formats which are common to all relating calculations.

(6) Easy control of system

It is desirable to operate the system without user’s manuals. For this purpose the system should have instructive functions. SPEEDI has two such functions. One is the HELP command and its text. Using this command the user can learn the syntax of an arbitrary command and physical meanings of its parameters. The other is a method of input and system control by menus. Usually a menu corresponds to a mode or a kind of calculation and it indicates the operand and default values of parameters. By changing the values and assigning next menu the user can input and control the system easily.

(7) Real-time processing

In case of an emergency SPEEDI must reflect on the calculation such real-time data as the release information and observed meteorological data which are varying with time. All computational codes must use the same input data. Any computational code or graphic routine of SPEEDI receives automatically the newest input data from a table of the conversational control program. The observed meteorological data are assumed to be given directly from an online network to the SPEEDI data file, though the user can display or modify the data before their use.

(8) Graphic output

It will be difficult and very time-consuming tasks to interpret the three-dimensional numerical output of wind field, concentration or dose calculation. The code system should provide the user with functions which produce graphic outputs of computational results over
a specified underlying map. The unified file format makes it easy for the graphic routine to draw the output from any computational code in the system.

(9) Automatic provision of initial data
The default data which are necessary for the interpretation of unspecified parameters of commands and the execution of computational codes should be automatically provided by the system to save time and prevent human errors. The longitude, latitude, and height of a stack, for example, should be loaded automatically by only specifying the site and facility names.

(10) Automatic logging
In an emergency the interlaced input information and sequences of computation may sometimes cause confusions in use of results among users. In that case the user of the system will be forced to trace back exactly the interaction between the user and the system. For this purpose the system should retain the records of input commands with their operand parameters, and also the system messages returned to the commands. These records should be displayed at any instance by using a command.

(11) Utilization of existing softwares
It is now a well-known fact that the construction of a code system requires much manpower and that the cost of the construction is mostly consumed in making basic software packages such as graphics, file handling programs, etc. Considering those points, two existing software packages are utilized in construction of SPEEDI. One is a general purpose graphic package ARGUS and the other is a three-structured file handling package DATAPOOL. Both softwares are developed at JAERI and widely used in several application fields.

(12) Systematization for practical application
As is stated in Chapter 1, the SPEEDI system is expected to cover all areas in which Japanese nuclear power plants are located. A network as shown in Fig. 2.1 is an example of operational scheme when the development of SPEEDI has been accomplished. The meteorological data and monitoring data of the areas are gathered by minicomputers of local governments and sent routinely by telephone lines to a small-scale front-end computer of the SPEEDI system.

![Fig. 2.1 Configuration of SPEEDI network.](image)
Fig. 2.2 Two sided design concepts.

### Table 2.1 Code and utility program in the SPEEDI code system

<table>
<thead>
<tr>
<th>Category</th>
<th>Name</th>
<th>Explanation</th>
<th>CPU time (s)</th>
<th>Memory (kB)</th>
<th>I/O times</th>
<th>Source statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Command Control</td>
<td>EMER</td>
<td>Command control and decay calculation</td>
<td>1800</td>
<td>8208</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Datapool</td>
<td>DISDP</td>
<td>Display control information of datapool</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DISPW</td>
<td>Display and update weather datapool</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphics</td>
<td>GWIND</td>
<td>Display weather and wind field data</td>
<td>7</td>
<td>1452</td>
<td>2592</td>
<td>5186</td>
</tr>
<tr>
<td></td>
<td>GCONC</td>
<td>Display concentration data</td>
<td>12</td>
<td>1688</td>
<td>4971</td>
<td>6932</td>
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<tr>
<td></td>
<td>GDOSW</td>
<td>Display dose data</td>
<td>4</td>
<td>1300</td>
<td>1391</td>
<td>5020</td>
</tr>
<tr>
<td></td>
<td>GBACK</td>
<td>Display regional data</td>
<td>2</td>
<td>1140</td>
<td>802</td>
<td>3036</td>
</tr>
<tr>
<td></td>
<td>PLAN</td>
<td>Display areas by countermeasures</td>
<td>4</td>
<td>1210</td>
<td>1613</td>
<td>4020</td>
</tr>
<tr>
<td>Other</td>
<td>SITEMDP</td>
<td>Determine site location automatically</td>
<td></td>
<td></td>
<td></td>
<td>83</td>
</tr>
<tr>
<td>Wind Field</td>
<td>WIND04</td>
<td>3 dim. calc. by variational method</td>
<td>72</td>
<td>3028</td>
<td>4633</td>
<td>1591</td>
</tr>
<tr>
<td>Concentration</td>
<td>PRWDA</td>
<td>Concentration by particle dispersion</td>
<td>151</td>
<td>2636</td>
<td>4542</td>
<td>3660</td>
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<tr>
<td></td>
<td>LSPUFF</td>
<td>Quick calculation by puff model</td>
<td>4</td>
<td>768</td>
<td>777</td>
<td>1923</td>
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<tr>
<td>Dose</td>
<td>CID</td>
<td>Dose calculation by grid-cell model</td>
<td>6</td>
<td>1228</td>
<td>2630</td>
<td>1816</td>
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<tr>
<td></td>
<td>GSDOSW</td>
<td>Quick calc. by Gaussian plume model</td>
<td>7</td>
<td>828</td>
<td>3901</td>
<td>3602</td>
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<tr>
<td>Datapool</td>
<td>RGOND</td>
<td>Construct regional datapool (file)</td>
<td>8</td>
<td>536</td>
<td>7996</td>
<td>6258</td>
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<tr>
<td>Construction</td>
<td>WCREAT</td>
<td>Create weather DP by batch mode</td>
<td>16</td>
<td>1000</td>
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<td></td>
<td>WEADUS</td>
<td>Create weather DP by TSS mode</td>
<td>768</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Datapool Access</td>
<td>DPAC</td>
<td>Interface between physical models and</td>
<td></td>
<td></td>
<td></td>
<td>4662</td>
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<td></td>
<td>datapool files</td>
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<tr>
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<td>ARGUS</td>
<td>General purpose graphic package</td>
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<tr>
<td>Datapool System</td>
<td>DPLIB</td>
<td>Datapool program library</td>
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<td></td>
<td>21419</td>
</tr>
<tr>
<td></td>
<td>DPTSS</td>
<td>Interactive display of datapool</td>
<td>768</td>
<td></td>
<td></td>
<td>15962</td>
</tr>
<tr>
<td></td>
<td>PREPROC</td>
<td>Preprocessor for datapool user program</td>
<td>376</td>
<td></td>
<td></td>
<td>9368</td>
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<tr>
<td>Basic</td>
<td>GGS</td>
<td>Basic graph .sc library</td>
<td>587</td>
<td></td>
<td></td>
<td>10455</td>
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<tr>
<td></td>
<td>PDOS</td>
<td>Library for DSCAN graphic terminal</td>
<td>283</td>
<td></td>
<td></td>
<td>3322</td>
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<tr>
<td>Library</td>
<td>PTS</td>
<td>Library for TEKTRONIX graphic terminal</td>
<td>165</td>
<td></td>
<td></td>
<td>4551</td>
</tr>
<tr>
<td></td>
<td>PNL</td>
<td>Interface for Japanese line printer</td>
<td>65</td>
<td></td>
<td></td>
<td>2700</td>
</tr>
</tbody>
</table>

Note. 1) Memory of EMER contains file handling and graphic routines in execution time
2) CPU time, memory size and I/O times are measured by FACOM M-380 large-scale computer (25 MIPS, or 9 MFLOPS).
Owing to the design concept, the user can use the system for both practice and research. The items relating to the two uses can be categorized as Fig. 2.2.

When an abnormal value is found in the monitoring data, the small computer calls a large-scale computer and asks to predict the situation by sending the meteorological data. The large-scale computer can perform both simple and detailed calculations by using its high speed capability.

It is, however, desirable for the local governments to be able to calculate the same computational codes by using their minicomputers regardless their computation time because it may happen to lose the connection between the computers by some accidents, and because it will improve the robustness of the system by distributing a part of its functions to many computers.

Taking into account the considerations mentioned above, we have taken care that any component of the system does not require redundant memory size and computation time as shown in Table 2.1.

### 2.1.2 Computational Codes in the System

In this section, computational codes in the SPEEDI system are described. The requests for models used in an emergency are firstly that models are practical ones which require the relatively small input and little computation time for the real-time response, and secondly that models have an ability to realistically predict the behavior of radioactive materials released in complex and coastal region.

From a practical point of view, a Gaussian plume model has been currently used because of little computation time and simpleness of the model. The recent advance of computer techniques, however, has made more accurate models applicable to practical predictions. Figure 2.3 shows the computational models which are recently developed to accurately simu-

![Fig. 2.3 The computational models which are recently developed for accurate simulations of the behavior of pollutants.](image-url)
A forecast model of meteorological data (WEADUS2)

A mass-consistent model for 3-D wind field (WIND04)

A random-walk model for atmospheric dispersion (PRWDA)

A cell-integrated model for dose estimation (CIDE)

( ) : Code name

Fig. 2.4 Connection of main codes in SPEEDI.

The behavior of pollutants. In general, it is difficult to improve the accuracy of models with reduction of computation time. Consequently, intermediate models must be selected for relatively accurate and urgent simulations. For the more accurate simulations, the combination of a three-dimensional hydrodynamic model and a Markov-chain model may be the most suitable one. However, it requires much computation time. On the other hand, the Gaussian plume model that is most suitable to the urgent computation has not adequate ability to simulate the airborne concentration in such complex terrains as the surroundings of Japanese nuclear power plants. Therefore, as the main codes in SPEEDI, we selected the combination of a mass-consistent wind field model and a dispersion model which solves a transport-diffusion equation numerically. The first model calculates three-dimensional wind fields and the second calculates the transport and diffusion of pollutants. The connection of main codes in SPEEDI is shown in Fig. 2.4.

The first step of the prediction is to forecast the meteorological condition automatically whenever the observed data are input. To forecast meteorological data, the WEADUS2 code has been developed. Based on a statistical analysis of observed data, this code forecasts the wind speeds and wind directions at the measuring points. The advantage of the model used in this code is to require considerably less computation time than the three-dimensional hydrodynamic model. The disadvantages are that it cannot predict the variation of turbulence and the rapid change by a front and so on. The method of statistical analysis was developed by the Meteorological Research Institute (MRI), the Meteorological Agency of Japan. The output data file generated by WEADUS2 has both observed data and forecasted data.

For main calculations considering the effect of coastal region and complex terrain, three codes are prepared, i.e., the WIND04 code to calculate wind fields, the PRWDA code to simulate the diffusion of airborne and the CIDE code to evaluate the dose.

The WIND04 code uses a three-dimensional mass-consistent model to calculate wind fields that is influenced by terrain. The approach of this model is a diagnostic wind field analysis and its accuracy depends on the quality and quantity of observed wind data. It cannot estimate the atmospheric turbulent motion.

* The dose is used with the meaning of dose equivalent (rem) or exposure (roentgen) without notice in this paper.
2. Design and Function of SPEEDI

2.1 Summary of the codes in the SPEEDI system

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Code name</th>
<th>Model</th>
<th>Output variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast of meteor. data</td>
<td>WEADUS2</td>
<td>Statistical-analysis model</td>
<td>Forecasted $U$, $V$ at the measuring points</td>
</tr>
<tr>
<td>Wind field</td>
<td>WIND04</td>
<td>3-D mass-consistent model</td>
<td>$U$, $V$ and $W$ in $(x,y,z,t)$</td>
</tr>
<tr>
<td>Concentration</td>
<td>PRWDA</td>
<td>Random-walk model for the gradient-transfer theory</td>
<td>Concentration in $(x,y,z,t)$ and in $(x,y,t)$</td>
</tr>
<tr>
<td>Dose</td>
<td>CIDE</td>
<td>Cell-integrated dose model</td>
<td>External gamma-dose and internal dose in $(x,y,t)$</td>
</tr>
<tr>
<td>Reference calculation</td>
<td>GSDOSE</td>
<td>Gaussian plume model</td>
<td>External gamma-dose and thyroid dose in $(x,y,t)$</td>
</tr>
<tr>
<td></td>
<td>LSPUFF</td>
<td>Puff-plume model</td>
<td>External gamma-dose and thyroid dose in $(x,y,t)$</td>
</tr>
</tbody>
</table>

By using wind fields generated by WIND04, the PRWDA code, which employs a random-walk method to simulate a gradient-transfer process numerically, predicts the spatial and temporal airborne concentration and the surface concentration. The reason why this model is adopted with the SPEEDI system is that finite-difference methods including a PICK method are unsuitable for the estimation of a point release.

The CIDE code has been developed to estimate the external gamma-dose from a radioactive cloud and the internal dose due to inhalation. It is a main characteristic that the CIDE code does not employ a submersion model but a cell-integrated dose model to calculate the external gamma-dose from a randomly distributed radioactive cloud.

Besides these main codes, two codes that employ simple models are prepared for reference calculations of the main codes, i.e., the GSDOSE code using the Gaussian plume model and the LSPUFF code using a puff-plume model.

Although a three-dimensional hydrodynamic model is not available in this stage, the research is being continued by MRI. In future, this model may be included in the SPEEDI system, when it can predict the meteorological condition within a reasonable computation time.

A summary of the codes in the SPEEDI system is shown in Table 2.2, and detail computational procedures and verifications will be described in Chapter 3.

2.1.3 System Control and Utility Programs

(1) Method of system control

The computational flow of our SPEEDI code system is shown in Fig. 2.5.

The software of the system consists of five parts, i.e., i) a control program of conversational mode, ii) datapool for topography, lakes, roads, railroads, and administrative boundaries, iii) datapool for calculated results, iv) a package for graphical output, and v) computational codes for physical models.

The control program for conversational mode is the nucleus of SPEEDI. The control program receives and stores real-time data, executes computations with physical models, displays and outputs the calculated results. The control of SPEEDI is done by inputting commands through a timesharing terminal.

The major commands of SPEEDI are listed in Table 2.3. SITE, TIME and REL commands are used for input of data such as the site location, time of release, rate of release, etc. WIND, CONC and DOSE commands are used to initiate calculation of wind field, concentration and

Fig. 2.5 Computational flow of SPEEDI.
dose, respectively. GWIND, GCONC and GDOSE commands are used for graphic output of the calculated results of the wind field, concentration and dose, respectively. The user can input and display additional information such as the time of display, name of region, underlying map, etc. by specifying additional information in the operand fields of these commands.

The input data in the command operands are retained in a table in the control program and they reflect the most recent values during the execution until other new input data are given to SPEEDI.

Any input sequence of commands to the system is allowed and we can, for example, execute repeatedly only wind field calculations or display contents of some calculated results.

The system is designed to be initiated with a minimum amount of external input data. For this purpose the system contains standard data which are specific to sites or physical models and the data are used automatically unless new values are inputted explicitly. For example we can use SITE command only by specifying site and facility names because such data as the location, stack height, terrain height of the facility are automatically provided in the system. The system has all data of the fourteen sites where nuclear power reactors of Japan are now operating. Every command has those types of default values and this provision makes it easy to use the system in conversational mode.

<table>
<thead>
<tr>
<th>Command Name</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMER</td>
<td>Initiate or restart the code system</td>
</tr>
<tr>
<td>SITE</td>
<td>Set informations of an accident site</td>
</tr>
<tr>
<td>REL</td>
<td>Set informations of radioactive release</td>
</tr>
<tr>
<td>DISPW</td>
<td>Display observed meteorological data of the site</td>
</tr>
<tr>
<td>SETW</td>
<td>Set meteorological data of a meteorological station to fill a lack of data of the station</td>
</tr>
<tr>
<td>WIND</td>
<td>Calculate the wind field of a specified region</td>
</tr>
<tr>
<td>CONC</td>
<td>Calculate the concentration of a specified region The region is included in the one specified by WIND</td>
</tr>
<tr>
<td>DOSE</td>
<td>Calculate the dose of the region specified by CONC</td>
</tr>
<tr>
<td>GWIND, GCONC</td>
<td>Display results over specified maps</td>
</tr>
<tr>
<td>GDOSE</td>
<td></td>
</tr>
<tr>
<td>PLAN</td>
<td>Display dose and conc. isopleths over maps with regulation values for emergency planning</td>
</tr>
<tr>
<td>SUB</td>
<td>Submit a computational module to the computer as a batch processing job</td>
</tr>
<tr>
<td>RUN</td>
<td>Process a computational module as a TSS job</td>
</tr>
<tr>
<td>GO</td>
<td>Same as the above</td>
</tr>
<tr>
<td>DPARAM</td>
<td>Display control parameters of SITE, REL, WIND, CONC, DOSE, GRAPH, PLAN mode, or files</td>
</tr>
<tr>
<td>SET</td>
<td>Set control parameters of modes</td>
</tr>
<tr>
<td>CLOG</td>
<td>Display the past conversational records logged in a logging file</td>
</tr>
<tr>
<td>HELP</td>
<td>Help users by displaying informations on commands</td>
</tr>
<tr>
<td>SAVE</td>
<td>Save the control informations for restart</td>
</tr>
<tr>
<td>END</td>
<td>End the session of the code system</td>
</tr>
</tbody>
</table>

When a 'Q' is added to each command, the system automatically questions the user about input parameters.
(2) Input and system control by menus

Although the method of conversational input to SPEEDI is rather simple as will be shown in Section 2.2.1, a further improvement has been made for a quicker input and easier use of the system. A menu input system by Japanese characters or by English alphabet has been introduced. An example of the menu in Japanese characters is given in Fig. 2.6 and an example of English one is given in Fig. 2.7. The character strings after the colons are default values and when they are changed, the changed values are assumed as inputs. When operating

Fig. 2.6 An example of Japanese menu.

Fig. 2.7 An example of English menu.
the system the user can change the mode of input from this type to the old one described in the Section 2.2.1 and vice versa.

(3) System data files
The invariable data needed to use SPEEDI are locations of power plants, its surrounding topography, isotopic composition of noble gas and iodine in the reactor core and physical constants of anticipated nuclides. These data are stored in the datapool files of SPEEDI and are automatically used by computational models or are displayed by using commands.

1) Regional data
SPEEDI has two types of topographical data files, i.e., one is local, twenty-five kilometer distance from the site and the other is regional, a hundred kilometer distance from the site. The data of the local and the regional files are made for the fourteen operating reactors of nuclear power plants in Japan by using the numerical mesh data of the National Land Agency of Japan. The data consist of terrains, coast lines, administrative boundaries, location names, roads, railroads, and lakes. The terrain of local files is divided into 1 km X 1 km mesh horizontally and 25 m mesh vertically. The terrain of regional files is divided into 4 km X 4 km mesh horizontally and 25 m mesh vertically. The average terrain height in a mesh is assumed as the height in the mesh. These terrain heights are used for detail calculations of wind field and concentration. Although the minimum size of the mesh of the numerical mesh data of the Land Agency of Japan is 250 m X 250 m, we are using the above mentioned wider mesh because of limitations from computer memory and computation time. The other data are used to draw underlying maps when the user wants to make outputs of concentration.

The local or regional data files are provided for every site and by specifying a site name in the SITE command and by specifying the LOCAL or REGIONAL parameter in the WIND, CONC or DOSE command, the corresponding terrain data file are automatically loaded for the execution of computational codes.

SPEEDI has also a utility program which produces the local or regional data file for any location in Japan within ten minutes from the numerical mesh data prepared by the Land Agency of Japan.

2) Site data
The site data file contains longitudes, latitudes, terrain heights, stack heights and types of all power reactors. By specifying a site name and a facility name in the operand of a SITE command, these data are loaded from the file into a table in the conversational control program.

3) Isotopic composition data
The isotopic composition data file contains isotopic fraction of krypton, xenon and iodine in the fuel depending on types of reactors and their burnup. The data are used to anticipate the isotopic composition in the initial stage of an accident.

4) Physical constant data
The physical constant data file contains decay constants, average photon energies, effective photon energies, each photon energy emitted from noble gases, seven isotopes of iodine, thirty-four isotopes of fission nuclides such as cesium and strontium, etc. The data are referred to by dose calculation codes for the estimation of external dose.

(4) Input data to SPEEDI system
There are two kinds of real-time input data to the SPEEDI system. One is the information on release of radioactive materials and the other is the meteorological data.

1) Meteorological data
From a viewpoint of online data acquisition, it is supposed that only data of AMeDAS and/or those supplied by the local governments around the site are available to the system.
Thus the number of observation stations will be limited within ten to twenty in twenty square kilometers around each site. As for the vertical distribution of wind directions and speeds we can only expect data obtained by instruments attached to an observation tower in the site. Considering this situation on meteorological data, the meteorological data file of SPEEDI is designed to record wind directions, speeds, rainfall and atmospheric stabilities with the corresponding locations of measuring stations and heights of instruments. As shown in Fig. 2.8, the meteorological data are stored in a tree-structured file and they are separated in two parts, i.e., one for the invariable and the other for the variable part. The variable part is designed to store and quickly retrieve any time series data of all observation or measuring stations.

2) Information on released radioactive materials

The information on release of radioactive materials is the most important parameter for the calculation of dose. Although it is needed for SPEEDI to know the time-dependent rates of released nuclides, it is difficult to fix the type of input in one way because the real-time information available to the user of the system may be different by accidents.

Thus SPEEDI provides following three types of input by assuming data from the stack monitor.

(a) Release rates of total noble gas and iodine, or the rate of a nuclide of noble gas and the rate of an isotope of iodine.

(b) Value in mR/h measured by an ionization chamber type monitor.

(c) The release rate of another fission nuclide.

When the input of type (a) or (b) is specified, assuming releases of isotopes of krypton, xenon and iodine, using data of measured time of the release, reactor shutdown time and a rate of isotopic composition in the fuel, SPEEDI calculates remaining quantities of the noble gas and iodine at an arbitrary time. The information on the calculated quantities is given to the computational codes of dose calculation through the control table of SPEEDI. The procedure for this calculation is described in (5) in detail. The isotopic composition in the fuel determined by burnup is pre-calculated and tabulated in a data file of SPEEDI.

(5) Linkage of computational codes and system

The computational codes of SPEEDI are loosely coupled with the code system in two ways, i.e., one is through in-core control tables and the other is file handling software.
DATAPool. The feature of the DATAPool is described elsewhere.\(^3\) Input/output statements of every computational code are replaced by statements of subroutine calls which activate the functions of the DATAPool software. The files created by using the DATAPool are called datapool files, or datapools shortly.

In the following we will describe another way of coupling the codes with the system, i.e., the in-core control tables.

SPEEDI has two kinds of in-core control tables. The in-core control table of the first kind ICT1 is loaded on the main memory by inputting EMER command for system initiation. A part of ICT1 is shown in Table 2.4. In Table 2.4 the character string S01C means as follows: S indicates that the site name to be assigned in a SITE command mode, 01 is the identification number of the “site name” among parameters of the SITE command, and C indicates that the value of the parameter must be a character string. Also the character I or R of W03I or W1SR means that the value must be an integer or a real number, respectively. The contents of the ICT1 of SPEEDI is listed in Appendix 3.

The first character R, C, D, G, or P for the parameter specification means that the parameter should be specified in the corresponding command, i.e., in REL for release, CONC for concentration, DOSE for dose, GRAPH for graphic display, or PLAN for emergency planning calculation. A close investigation of the list will reveal the capability of the present SPEEDI code system. The in-core control table ICT1 may be made by using usual text-editing functions of the timesharing system. It is saved as a member in a file of partitioned organization and is loaded in the memory of the system when the user has specified the member and the file name in the operand of an EMER command. Thus the user can change ICT1 easily. The ICT1 shown in Appendix 3 is the default currently used in SPEEDI.

The in-core control table of the second kind ICT2 must be prepared for each computational code in the system. It contains a list of input parameters which is also contained in ICT1. Usually a code needs a key information which controls the calculation. The key information which controls the calculation. The key information is read before the execution by the code using the namelist feature of FORTRAN in the code.

### Table 2.4 A part of ICT1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>J9298.WIND04.LOAD</td>
<td></td>
</tr>
<tr>
<td>J3359.SYNSMV3.DATA(WIND04)</td>
<td></td>
</tr>
<tr>
<td>WIND04</td>
<td></td>
</tr>
<tr>
<td>MAPTPV</td>
<td>W02 C</td>
</tr>
<tr>
<td>IMA</td>
<td>W12 I</td>
</tr>
<tr>
<td>JMA</td>
<td>W13 I</td>
</tr>
<tr>
<td>KMA</td>
<td>W14 I</td>
</tr>
<tr>
<td>DX</td>
<td>W15 R</td>
</tr>
<tr>
<td>DY</td>
<td>W16 R</td>
</tr>
<tr>
<td>DZ</td>
<td>W17 R</td>
</tr>
<tr>
<td>IISTAB</td>
<td>W07 C</td>
</tr>
<tr>
<td>ZO</td>
<td>W11 R</td>
</tr>
<tr>
<td>ISTRDV</td>
<td>W03 I</td>
</tr>
<tr>
<td>ISTRTV</td>
<td>W04 I</td>
</tr>
<tr>
<td>ITINTW</td>
<td>W05 I</td>
</tr>
<tr>
<td>IOPENV</td>
<td>W18 I</td>
</tr>
<tr>
<td>NAMESV</td>
<td>S01 C</td>
</tr>
<tr>
<td>NOSITV</td>
<td>S03 C</td>
</tr>
<tr>
<td>FVMAP</td>
<td>F11 C</td>
</tr>
<tr>
<td>FVWET</td>
<td>F12 C</td>
</tr>
<tr>
<td>FWWIN</td>
<td>F13 C</td>
</tr>
</tbody>
</table>

### Table 2.5 ICT1 for WIND04

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp; PARM</td>
<td>PR=.01, PR2=.001, OM=1.88, LIMIT1=300, IBC=0, A1=0.20, A2=1.00, IMA=51, JMA=51, KMA=21, DX=1000.0, DY=1000.0, DZ=25.0, IISTAB='D', ZO=0.1, NSTMAX=40, REF=25., NMODL='2', IOPENV='0', X00=-30., Y00=-15., IFLGUP=2 &amp; END</td>
</tr>
</tbody>
</table>
If some of the predefined default values in the namelist are different from those of the ICT1, the predefined values must be replaced by values of the ICT1, because ICT1 contains the newest ones. Sensing that new values are inputted, the conversational control program of SPEEDI replaces the values. In this replacement procedure, several routines are invoked for conversions of physical dimensions and units of the values if necessary. ICT2 of the WIND04 code is shown in Table 2.5. This ICT2 has been registered in the system and retained in the conversational control program when the system is in execution.

WIND04 code that is invoked by the command WIND reads its key information in namelist No.1, e.g., a list in Table 2.5. Before the invocation, the conversational control program reads the namelist No.1 and compares the contents with ICT1’s. If values of some parameters in the namelist No.1 are found to be changed, they are renewed using the corresponding values of the ICT1. Then, the new namelist No.1 is written into the input file of WIND04 as namelist No.2.

After the first read of the namelist No.1, WIND04 reads next the namelist No.2 and the renewed values replace the old ones in WIND04. WIND04 also reads the observed meteorological information from the weather datapool file and writes the calculated wind field into a datapool file of wind field via subroutine interfaces.

These ICT2 table and the subroutine interfaces for datapool files are only the link of WIND04 and the code system. Thus a computational code is connected with the system very loosely. Every computational code is not resident in the computer memory when the system is initiated, but the code is loaded and linked dynamically when the code name is specified in the operand of a command. This technique helps the system to save the computer memory needed for codes.

2.2 Procedure of Usage

2.2.1 Computational flow of SPEEDI

The SPEEDI code system is designed to operate in conversational mode. The computational flow of SPEEDI is shown in Fig. 2.5. The user can order sequential calculations of wind field, concentration of radioactive materials and dose by each corresponding command.

At the first onset, after the SPEEDI code system has start, several input parameters such as the location of a nuclear accident site are required. SPEEDI has data on fourteen nuclear reactor sites in Japan, such as longitude, latitude and stack height. These characteristic data on the sites are available by specifying only a nuclear site and facility in the operand of SITE command. After the SITE command, parameters on the time when a reactor shutdown occurs and radioactive materials begin to be released into the atmosphere, etc. are required in the operand of TIME command.

On these bases, sequential calculations of wind field and nuclide concentration are carried out. The topographical data to be used in these calculations are automatically assigned by means of the SITE command which is inputted as mentioned above.

The execution of dose calculation follows the input of source terms; nuclide names and their release rates are expected to be received as usual from a nuclear site in the system. For the cases where availability of the source information is limited, SPEEDI has a program to estimate the isotopic composition of noble gas and iodine as a function of reactor type, i.e., BWR or PWR, and of burnup data depending on the operational history of a reactor. This function is used for giving data required for dose calculation during early periods after an accident occurs. The atmospheric dispersion of nuclides is normally calculated on the assumption of continuous unit release without decay. The result is calibrated by using the
calculated isotopic composition, taking into account the radioactive decay, inside SPEEDI and the available release rate, e.g. total amount of noble gas including $^{133}\text{Xe}$ and $^{85}\text{Kr}$ etc., outside SPEEDI. Photon energy and decay constants of 56 nuclides available for dose calculation are stored in the nuclear data file of SPEEDI. The results of such calculations as wind field, concentration and dose are then stored in datapool files of SPEEDI and displayed on a graphic display terminal together with some map elements, which are contained in the topographical data file. The user can select several kinds of map elements such as administrative boundaries, coastlines, road/railroad, contours of terrain height and locations of towns.

All the data files used in SPEEDI are summarized in Table 2.6.

### 2.2.2 Weather Data Acquisition

The function of collecting and editing meteorological data is necessary in the use of the SPEEDI system. During the development stage of SPEEDI, two computer softwares are made and used for creating and editing the weather datapool. The first one is called WCREAT, which creates the weather datapool using the AMeDAS data and the observation by local government stored in the magnetic tape. The weather datapools created by WCREAT have been used for the system check and the verification studies of the wind field and diffusion models. WCREAT has only the function of creating a new weather datapool. The other one is called WEADUS (Weather Datapool Update System), which creates a new datapool and updates the existing datapool. By the use of WEADUS, an operator can input the temporal weather data into the existing weather datapool. The revised version of WEADUS, WEADUS2, has functions of data check and predicting the wind field up to 6 hours ahead. WEADUS and WEADUS2 are described in Appendix 1. The statistical method for the data check and the wind prediction are explained in Section 3.1. In the operational stage of SPEEDI, the meteorological data should be collected and edited automatically. The outline of automated system for the data acquisition is being designed now.

The above system of weather data acquisition exists independently of the following command system. Though the weather data acquisition including prediction is considered to be a subsystem at present, therefore, the user will not need to operate this subsystem when the meteorological data are collected and edited automatically.

### 2.2.3 Commands and their Usage

Through the above calculational flow, the usage of the commands of SPEEDI will be explained briefly in an orderly manner. The following assumption of an accidental release from a nuclear plant is made as an exemplification. At 12:00 am. on August 20th in 1981, a shutdown of JPDR (Japan Power Demonstrating Reactor) in JAERI could occur and three hours immediately after the shutdown noble and iodine nuclides, consisting of 15 and 7

---

**Table 2.6 Summary of data files in SPEEDI**

<table>
<thead>
<tr>
<th>Computed data files*</th>
<th>System data files**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind field data</td>
<td>Nuclear site characteristic data</td>
</tr>
<tr>
<td></td>
<td>Meteorological observation data</td>
</tr>
<tr>
<td>Concentration data</td>
<td>Topographical data</td>
</tr>
<tr>
<td>Dose data</td>
<td>Isotopic composition data</td>
</tr>
<tr>
<td></td>
<td>Nuclide physical data</td>
</tr>
</tbody>
</table>

* Files for calculated results.
** Files prepared in advance by SPEEDI.
nuclides, would be released at the rate of 1000 Ci/hour* and 1 Ci/hour, respectively. The plume would be released at the height of 10 m and the burnup would be assumed to be 10000 MWd/t.

i) Through the SITE command the accident site and facility etc. are specified in the operand in the following format.

```
SITE[Q]  \{ site name, facility name, \{ * \} release height
\{, longitude, latitude, terrain height, release height
[, burnup]
```

It should be noted that the user must choose one item of the two in the brace. When items in the bracket is not specified, a default value is automatically used by SPEEDI. By means of the addition of Q just after the command, SPEEDI issues prompt messages to the user so that he can operate SPEEDI without taking care of the input format. In the case of the accident assumed here, the following input should be made.

```
SITE TOKAI, JPDR, 10., 10000.
```

ii) By using the TIME command, shutdown and release starting time, etc. are inputted.

```
TIME[Q]  \{ release starting time ( YYMMDD )
   \, release starting time ( HHMMSS )
   \, shutdown time ( YYMMDD )
   \, shutdown time ( HHMMSS )
   \, prediction starting time ( YYMMDD )
   \, prediction starting time ( HHMMSS )
   \, predicted period ( HHMMSS )
   \, damping interval ( HHMMSS )
```

The input for the accident is shown as follows.

```
TIME  810820, 150000, 810820, 150000, +
     810820, 150000, 20000, 10000
```

iii) On the basis of above condition, wind field calculation among sequential ones leading to doses starts through the WIND command. Atmospheric stability, computational codes and domain which can be selected between the two, local scale in 50 km x 50 km or regional scale in 200 km x 200 km, etc. are required to calculate the wind field.

* As the units of activity, dose equivalent and exposure we use not the SI unit but Curie (Ci), rem. and roentgen (R) which are in common use from the viewpoint of practice.

1 Ci = 3.7 x 10^10 Bq, 1 rem = 10 mSv, 1 R = 2.58 x 10^-4 C/kg.
After the WIND command, the execution command SUB is used for starting computation. When the SUB command is specified, SPEEDI issues values of its table of the conversational control program, so that the user can confirm the values of parameters to be used in the corresponding calculation. By checking the display the user can correct erroneous input before the calculation. The input of the accident is shown as follows.

\[
\text{WIND} \quad \text{WIND04, LOCAL, STAB = D}
\]

On the basis of these data, using the observed wind data as shown in Fig. 2.9, the calculation is carried out and the results of the wind field is shown in Figs. 2.10 and 2.11. Figure 2.10 represents a horizontal section at the height of 100 m above sea level.

iv) The CONC command for calculating nuclide concentration is used in the following input format.

\[
\text{CONC} \quad \text{model name}
\]
\[
\{ \text{LOCAL} \}
\]
\[
\{ \text{REGIONAL} \}
\]
\[
[ , \text{prediction starting time (YYMMDD)}
\]
\[
[ , \text{prediction starting time (HHMMSS)}
\]
\[
[ , \text{predicted period (HHMMSS)}
\]
\[
[ , \text{damping interval (HHMMSS)} \}
\]
\[
[ , \text{WEF = meteorological data file name ]}
\]
\[
[ , \text{WIF = wind field data file name ]}
\]
\[
[ , \text{STAB = [A B C D E F G ]}
\]
\[
, \text{STAB = [A B C D E F G ]}
\]
\[
, \text{STAB = [A B C D E F G ]}
\]
The input for the assumed accident is

```
CONC   PRWDA,  LOCAL
```

With respect to this calculation the concentration is calculated on the assumption of continuous unit release without decay of radioactivity. If a more detailed information on source terms such as the temporal variation of the release were available, e.g., at several hours after the accident, the concentration would be calculated in a refined way by means of inputs of accurate information on duration of the release, etc.

The calculated results of the concentration are exemplified in Figs. 2.12 and 2.13, which represent hourly average concentration of noble gas near the ground and surface concentration of $^{131}$I, respectively.

v) As a next command, release information for source terms, such as time at which release rate is measured or estimated, etc. is employed in the following format.

```
REL[Q] |
| , mode number of release information |
| , determined time of release rate ( YYMMDD ) |
| , determined time of release rate ( HHMMSS ) |
| [ , nuclide name 1 |
| , release rate 1 |
| [ , nuclide name 2 |
| , release rate 2 |
| [ , nuclide name 3 |
| , release rate 3 ] ] ]
```

Mode number of release information indicates an available type of that, e.g., either total release rate of noble gas or release rate of a particular nuclide, which will be described in detail in Chapter 4. The input of the assumed accident is

```
REL  1, 810820, 150000, NOBLE, 1000., IODINE, 1.
```

vi) As a final sequential calculation through the DOSE command dose calculation is performed using the concentration data file created by the preceding calculational flow.

```
DOSE[Q] |
| model name |
| { LOCAL |
| { REGIONAL |
| [ , prediction starting time ( YYMMDD ) |
| , prediction starting time ( HHMMSS ) |
| [ , predicted period |
| [ , damping interval ] ] ] |
| [ , INCF = instant concentration file name ] |
| [ , GMF = exposure rate data file name ] |
| [ , CUMF = external dose data file name ] |
| [ , THYF = thyroid dose data file name ] |
| [ , INHF = internal dose data fiel name ] |
```
The input of the assumed accident is

\[
\text{DOSE CIDE, LOCAL, PRWDA}
\]

Figure 2.14 and 2.15 show the examples of display obtained in this dose calculation; the former indicates the distribution of external gamma-dose from the radioactive cloud and the latter the thyroidal dose distribution.

The several displays of the results in the preceding calculations are obtained through the graph commands made by adding G in front of the corresponding commands, e.g., GWIND, GCONC, or GDOSE. The input format of GDOSE command is shown as an example of the graph commands in the following.

\[
\text{GDOSE}[] \quad \text{figure name, model name, associated parameters}
\]

In Table 2.7, printing and graphic outputs of SPEEDI are summarized.

### 2.3 Computer System Used for Calculation

#### 2.3.1 Computer System and SPEEDI

The SPEEDI code system has been developed by using the computer system installed at JAERI Computing Center. The hardware configuration of our computer system is shown in Fig. 2.16. Three large-scale computers are being operated on loosely-coupled-multi-processor (LCMP) mode.

The global processor, i.e., system B is dedicated for timesharing use and accepts the commands from a timesharing terminal for SPEEDI.

The computational codes for simple and quick calculation can be executed on the system B in timesharing mode. The user can obtain the calculated results in thirty seconds. The codes for complex and detail calculation are executed on the system A or C. In operation of scalar mode on the system A or C, the user can obtain the calculated results of the wind field, concentration or dose in three minutes. In vector mode operation on the system A, the time is reduced within one minute.

<table>
<thead>
<tr>
<th>Table 2.7 Printing and graphic outputs of SPEEDI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calculation (unit)</strong></td>
</tr>
<tr>
<td>___________________</td>
</tr>
<tr>
<td>Wind data</td>
</tr>
<tr>
<td>Wind field</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Concentration</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Dose</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
WIND OBSERVATION

SITE = TOUKAI
DATE = 01/08/20
TIME = 15:00

Fig. 2.9 Graphic output of observed wind data.
(original hard copy of the color graphics of SPEEDI)
REGIONAL WIND FIELD
HORIZONTAL VIEW (HEIGHT = 100 m)
MODEL = WIND04
DATE = 01/05/20
TIME = 15:00

Fig. 2.10 Graphic output of calculated wind field, horizontal view.
(original hard copy of the color graphics of SPEEDI)

TOPOGRAPHIC DATA
1. 100.0 (m)
2. 200.0
3. 300.0
4. 400.0
5. 500.0

IVI = 0.89E+01
HMAX = 5.0
REGIONAL WIND FIELD
CROSS SECTION ( Y = 0.0 km )

MODEL = WIN004
DATE = 01/08/20
TIME = 15:00
Z-RANGE = 50

Fig. 2.11 Graphic output of calculated wind field, cross sectional view.
(original hard copy of the color graphics of SPEEDI)

$|V| = 0.36 \times 10^2$
$HMAX = 5.0$
INSTANT CONCENTRATION ISOPLETH
(Ci/m$^3$)

MODEL = PRFDA
NUCLIDE = IODINE
DATE = 81/09/20
TIME = 16:00
VERT. LEVEL (0) 0.0 - 25.0 m

CONTOUR VALUES $10^{-12}$
1 1000.0
2 100.0
3 70.0
4 30.0
5 10.0

MAXIMUM POINT
(-0.1, -0.1) km

8.784E-09 Ci/m$^3$3

Fig. 2.12 Graphic output of concentration distribution at the ground level.
(original hard copy of the color graphics of SPEEDI)
Fig. 2.13 Graphic output of distribution of iodine deposited on the ground.
(original hard copy of the color graphics of SPEEDI)
EXTERNAL GAMMA DOSE EQUIVALENT (mrem)

MODEL = CODE
DATE = 01/09/20
TIME = 16:00

CONTOUR VALUES 10mm-4
1 1000.0
2 700.0
3 300.0
4 100.0
5 10.0

= MAXIMUM POINT
(-0.4, -0.1) km
7.563E-01 (mrem)

Fig. 2.14 Graphic output of external gamma-dose-equivalent distribution. (original hard copy of the color graphics of SPEEDI)
Fig. 2.15 Graphic output of thyroid dose-equivalent distribution. (original hard copy of the color graphics of SPEEDI)
As for the timesharing terminal for SPEEDI, we are using a Japan-made raster-scan type color graphics terminal with 4000 × 4000 resolution. It is connected with the system B, i.e., the computer dedicated for timesharing use, using a 9600 bits/second communication line.

2.3.2 High Speed Computation by Vector Processor

In the present SPEEDI code system, codes for detailed calculation such as WIND04 and PRWDA require rather lengthy computation time. For example WIND04 and PRWDA require two and three minutes of execution time respectively on FACOM M-380 computer with performance of 25 MIPS (Million Instructions Per Second) or 9 MFLOPS (Million Floating Operations Per Second). It is desirable to reduce the computation times for quick responses in case of an emergency. Thus the codes WIND04 for wind field, PRWDA for concentration and CIDE for dose calculation have been rewritten in the forms suitable to vector processing and tested on a vector processor. The results are shown in Table 2.8. As is shown in the Table, the codes attained good performances and the performances will be more improved by refine-

<table>
<thead>
<tr>
<th>Code</th>
<th>Speed ratio</th>
<th>Computer</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIND04</td>
<td>9</td>
<td>FACOM VP-100</td>
</tr>
<tr>
<td>PRWDA</td>
<td>4</td>
<td>FACOM VP-100</td>
</tr>
<tr>
<td>CIDE</td>
<td>6</td>
<td>FACOM VP-100</td>
</tr>
</tbody>
</table>
ments of vectorization in the near future.

2.3.3 Portability of SPEEDI with Minicomputers

In addition to the implementation of SPEEDI on the large-scale computers, it was one of our development goals to construct a portable code system with minicomputers. As is shown in Section 2.1, the system is rather complex one, so that it will be difficult to implement it on a minicomputer of small memory size and different architecture from our large-scale computers. For this reason, we have selected a minicomputer (FACOM S-3300) which has the same architecture, very similar functions as our large-scale computers. In the process of implementation, slight modifications on the softwares of the SPEEDI system were done to adjust it to the minicomputer. The modifications are as follows:

1. Datapool files of direct access method (DAM) organization have been changed to ones of virtual storage access method (VSAM) organization.
2. Name strings of files of maximum forty-four characters have been truncated to twenty-six characters.
3. Timesharing commands in catalogued procedures and the conversational control program have been converted to those of the minicomputer.
4. Job control procedures written in the job control languages of our large-scale computers have been converted to those of the minicomputer.

After these modifications the code system SPEEDI has been successfully implemented on the minicomputer and it has produced the same calculated results.
3 Physical Models

3.1 Main Models

3.1.1 Statistical Prediction Model

The methods for weather prediction are categorized into the dynamical methods and the statistical ones. The dynamical methods are widely used in the short term weather prediction of synoptic and global scale, and they achieve considerable success. However, it is not easy to apply the dynamical methods to the weather prediction of local scale. The main difficulty arises from the shortage of the data for the initial and the boundary conditions. The local wind circulation is complicated and dependent on the places, so that it requires dense observation of meteorological data to define the initial state and the boundary conditions. Though several researchers have proposed the dynamical models for the local-scale weather prediction, they are still in research level and they cannot be used routinely.

The statistical prediction method is commonly used in the long term weather prediction. The method is modified and applied to the regional wind flow by Sakagami as described below. The method consists of two stages, the first stage is a pre-analysis of the wind by the statistical factor analysis and the second is the prediction in the routine operation. In the pre-analysis, eigenvectors which describe the statistical features of the temporal variation of wind vectors are composed using the wind data for a long term, usually one year or two. By the use of these eigenvectors, a set of observed wind data at time \( t \), expressed by a vector form, \( \mathbf{W}(t) \), is expanded as

\[
\mathbf{W}(t) = \sum_{k=1}^{2N} A_k \mathbf{P}_k, \tag{3.1.1-1}
\]

where \( \mathbf{P}_k \) is the \( k \)-th eigenfunction, \( A_k \) is its amplitude and \( N \) is the number of meteorological stations. The reason why the dimensions of \( \mathbf{W} \) and \( \mathbf{P} \) are \( 2N \) is that a wind vector at each station is a two dimensional vector. \( A_k \) is obtained by

\[
A_k(t) = \mathbf{W}(t) \cdot \mathbf{P}_k, \tag{3.1.1-2}
\]

because \( \mathbf{P}_k \)'s are orthogonal with each other. If the summation of Eq. 3.1.1 is done for all eigenfunctions \( (k = 1, 2N) \), Eq. 3.1.1 is exactly valid. However the summation is sometimes done for the components of major contribution. The advantage of the transformation of Eq. 3.1.1-1 into Eq. 3.1.1-2 is that one may follow the temporal variation of each \( A_k \) instead of that of \( \mathbf{W} \). The temporal variation of \( A_k \) is more systematic than that of each component of \( \mathbf{W} \), because each eigenfunction \( \mathbf{P}_k \) expresses a statistical feature common to many stations. Although \( A_k \) shows systematic variation with time, the change is still large so that the temporal extrapolation is difficult. In order to get the time series which changes moderately, a further transformation is carried out. The time series of \( A_k \) is rearranged to vectors as

\[
A_k(t) = \begin{pmatrix} A(t) & A(t+1) & A(t+2) & A(t+3) & A(t+4) & A(t+5) \end{pmatrix}
\]

\[
A_k(t+1) = \begin{pmatrix} A(t+6) & A(t+1) & A(t+2) & A(t+3) & A(t+4) & A(t+5) \end{pmatrix}
\]

\[
A_k(t+2) = \begin{pmatrix} A(t+6) & A(t+7) & A(t+2) & A(t+3) & A(t+4) & A(t+5) \end{pmatrix}
\]

\[
A_k(t+3) = \begin{pmatrix} A(t+6) & A(t+7) & A(t+8) & A(t+3) & A(t+4) & A(t+5) \end{pmatrix}
\]

\[
A_k(t+4) = \begin{pmatrix} A(t+6) & A(t+7) & A(t+8) & A(t+3) & A(t+4) & A(t+5) \end{pmatrix}
\]
The eigenfunctions for the variation of $A$ are also obtained in the pre-analysis and a set of $A$ is expanded as

$$A(t) = \sum_i B_i(t) \cdot H_i$$  \hspace{1cm} (3.1.1-3)$$

where $H_i$ is the eigenfunction, and the subscript $k$ is omitted. The coefficient $B_i$ is obtained by

$$B_i(t) = A_i \cdot H_i$$  \hspace{1cm} (3.1.1-4)$$

The $B_i$ changes so moderately with time that the extrapolation is not difficult. The future values of $B_i$ are predicted by the extrapolation and the $A$ is obtained by Eq. 3.1.1-3. The predicted values of wind are also computed by Eq. 3.1.1-1. The general flow of a routine prediction is summarized in Fig. 3.1. The arrows show the data flow.

In the SPEEDI system, the statistical wind prediction model mentioned above is combined with WEADUS2, Weather Data Update System. Then the predicted values of wind can be used in the same manner as observed ones for the computation of wind field.

![Fig. 3.1 Overview of the statistical prediction method. The arrows show the data flow.](image-url)
3.1.2 Wind Field Model

(1) Description of the model

WIND04\(^{(10)}\) is a computer code that calculates three-dimensional mass-consistent wind field using data of wind and atmospheric stability. It is important that the wind field in which materials are transported should satisfy the mass conservation law, because the erroneous convergence or divergence in the wind field may result in the convergence or divergence of the materials which causes unrealistically high or low concentrations. If the divergence of the wind field is \(2.78 \times 10^{-6} \text{ (s}^{-1}\text{)}\), the total mass in a unit cell changes by 1% during an hour's integration. When a regional wind field is interpolated by weighting observed data with inverse square of the distances, its evaluated divergence included is nearly \(10^{-4} \text{ (s}^{-1}\text{)}\). Suppose that the difference of the interpolated wind is 1 m/s between the neighboring grid points and the mesh width is 1 km, the magnitude of divergence is \(10^{-3}\). Then the error of divergence must be reduced by the order of three.

As the consequence of the imposition of mass conservation, WIND04 reflects the effect of topography on the wind field. Over the complex terrain the structure of the wind field is rather complicated even in the neutrally stratified condition. A part of the airflow goes over the mountain and the other part goes around it. When the atmosphere is stably stratified, the major flow goes around the mountain. On the other hand, when the atmosphere is unstable the major flow may go over it. A valley may cause a channeling effect for the wind. It is difficult to monitor such various kind of airflow by a network of anemometers. Furthermore, the vertical component of the wind, which is essentially important in the flow over complex terrain, is not directly measured by an ordinary observation. Then a certain model is needed to deduce the three-dimensional wind field from limited number of wind data. The computer code, WIND04, computes the airflow around topographic obstacles by the iterative computation for reduction of the divergence and convergence at the surface of topography.

This type of the computer code is originally developed by Sherman\(^6\) and is used in the

![Fig. 3.2 Overall concept of the method for the calculation of three-dimensional mass-consistent wind field.](image-url)
ARAC system. The general concept of the calculational flow is expressed in the Fig. 3.2. In the first step of the calculation, an initial guess of the wind vector at each grid is computed using the observed or predicted wind data produced by WEADUS2. The surface wind is interpolated by

\[(u,v)_{i,j} = \frac{\sum_{n=1}^{N} (u,v)_n/r_{n,i,j}^2}{\sum_{n=1}^{N} (1/r_{n,i,j}^2)} \]  

(3.1.2-1)

where \((u,v)_{i,j}\) is the horizontal components of the wind at the \((i,j)\)-th grid, \((u,v)_n\) is the observed wind components at the \(n\)-th meteorological station, and \(r_{n,i,j}\) is the distance between the \(n\)-th station and the \((i,j)\)-th grid. The wind vectors in the upper layers are interpolated and/or extrapolated as follows. The interpolated surface wind \((u,v)_{i,j}\) is extrapolated up to 200 m above the ground by the power law expressed as

\[u(z) = u_{obs}(\frac{z}{z_{obs}})^p.\]  

(3.1.2-2)

Above this layer, the observed upper wind data is used. If the upper wind data \((u_2,v_2)\) is obtained at the height of \(z_1\) and \(z_2\), the wind data between these two levels is interpolated by

\[u = a \log z + b,\]  

(3.1.2-3)

\[v = c \log z + d.\]  

(3.1.2-4)

The coefficients \(a, b, c\) and \(d\) are determined so that the interpolated values coincide with the observed values at \(z_1\) and \(z_2\). Above the highest level of wind observation, the wind is assumed to be constant. When upper wind data are not available, the power law, Eq. 3.1.2-2 is extended to higher levels.

In the second step, the initial guess is adjusted so that the wind field satisfied the equation of mass conservation,

\[\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0,\]  

(3.1.2-5)

with possibly small adjustment. The wind field \((u, v, w)\) should satisfy Eq. 3.1.2-5 and the total of the adjustment,

\[\int V [a_1^2 (u-u^0)^2 + a_2^2 (v-v^0)^2 + a_3^2 (w-w^0)^2] dV \]  

(3.1.2-6)

should be kept as small as possible. According to the variational method, such wind field is obtained as a set of functions which minimizes a functional

\[E = \int V [a_1^2 (u-u^0)^2 + a_2^2 (v-v^0)^2 + a_3^2 (w-w^0)^2 + \lambda (\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z})] dV,\]  

(3.1.2-7)

where \(u^0, v^0, w^0\) are the interpolated wind components, \(a_1\) and \(a_2\) are weighting coefficients which prescribe the ratio of horizontal adjustment to vertical adjustment and \(\lambda\) is a Lagrangian multiplier. In this case, this Lagrangian multiplier plays the role of velocity potential of the adjustment. The condition giving a stationary value of \(E\) yields four Eular-Lagrange equations,

\[u - u^0 + \frac{1}{2a_1^2} \frac{\partial \lambda}{\partial x} \]  

(3.1.2-8)

\[v - v^0 + \frac{1}{2a_2^2} \frac{\partial \lambda}{\partial y} \]  

(3.1.2-9)

\[w - w^0 + \frac{1}{2a_3^2} \frac{\partial \lambda}{\partial z} \]  

(3.1.2-10)
and
\[ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0. \tag{3.1.2-11} \]

with three boundary conditions,
\[ \lambda \delta(u) \cdot n_x = 0, \quad \lambda \delta(v) \cdot n_y = 0, \quad \lambda \delta(w) \cdot n_z = 0, \tag{3.1.2-12} \]

where \( \delta(u), \delta(v) \) and \( \delta(v) \) are the first variations of variables, and \( n_x, n_y, n_z \) are direction cosines of a unit vector vertical to the boundary surface for computation area.

Rearranging the Eqs. 3.1.2-8 to 3.1.2-11, a Poisson’s equation for \( X \),
\[ \frac{\partial^2 \lambda}{\partial x^2} + \frac{\partial^2 \lambda}{\partial y^2} + \frac{\partial^2 \lambda}{\partial z^2} + 2 \alpha^2 \left[ \frac{\partial u^0}{\partial x} + \frac{\partial v^0}{\partial y} + \frac{\partial w^0}{\partial z} \right] \tag{3.1.2-13} \]
is derived. The right-hand side expresses the divergence of the interpolated wind field. The problem is reduced to solve Eq. 3.1.2-13 with the boundary conditions 3.1.2-12. Once \( \lambda \) is obtained, the adjusted wind components are computed by Eqs. 3.1.2-8 to 3.1.2-10.

For the numerical computation, Eqs. 3.1.2-8 to 3.1.2-13 are transformed to finite difference equations. The staggered scheme is employed in order to avoid the computational error and to increase the resolution of the topography. Eq. 3.1.2-13 is solved iteratively by SOR (successive over-relaxation) method.

(2) Efficiency of variational adjustment

The divergence involved in the adjusted wind field is computed at each grid point for various stages of iterative calculation. The result is listed in Table 3.1. In the left-hand column the degree of the precision of the solution is described by the relative change of \( \lambda \). The values written in the top line express the order of magnitude of the divergence, and the figures in the Table are numbers of cells which contain the divergence listed at the top line. It is clearly seen that the erroneous divergence contained in the interpolated wind field is reduced by the order of four, even if a rather rough convergence criterion is adopted for \( \lambda \).

(3) Discussions

WIND04 is not a hydrodynamic model that is currently under study. It is basically a code that uses one of the interpolation methods, so that the quality and the quantity of input data directly affect results. So long as the each wind observation represents the wind of the wide region around the station well, the results of WIND04 are of much confidence.

| Order of magnitude of divergence calculated at each cell |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( 10^{-2} \) | \( 71 \) | \( 2599 \) | \( 891 \) | \( 47 \) | \( 2 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-3} \) | \( 29 \) | \( 2587 \) | \( 929 \) | \( 61 \) | \( 3 \) | \( 1 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-4} \) | \( 0 \) | \( 1740 \) | \( 1681 \) | \( 182 \) | \( 7 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-5} \) | \( 0 \) | \( 1729 \) | \( 1679 \) | \( 184 \) | \( 16 \) | \( 2 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-6} \) | \( 0 \) | \( 1737 \) | \( 1723 \) | \( 143 \) | \( 7 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-7} \) | \( 0 \) | \( 0 \) | \( 326 \) | \( 1999 \) | \( 1189 \) | \( 86 \) | \( 10 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-8} \) | \( 0 \) | \( 0 \) | \( 1464 \) | \( 1875 \) | \( 270 \) | \( 1 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-9} \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 418 \) | \( 2027 \) | \( 1143 \) | \( 22 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-10} \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 428 \) | \( 517 \) | \( 1998 \) | \( 662 \) | \( 5 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-12} \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 428 \) | \( 518 \) | \( 63 \) | \( 251 \) | \( 2216 \) | \( 134 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-14} \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 1234 \) | \( 1336 \) | \( 31 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 0 \) |
| \( 10^{-16} \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 428 \) | \( 518 \) | \( 63 \) | \( 0 \) | \( 0 \) | \( 0 \) | \( 979 \) | \( 1355 \) | \( 251 \) | \( 11 \) | \( 3 \) | \( 2 \) | \( * \) | \( * \) | \( * \) | \( * \) | \( * \) | \( * \) |

* Calculated in double precision
Under some conditions, however, the distribution of the wind is so complicated that the network of wind observation is insufficient to describe it. Such a condition may occur, for instance, in winter midnight when the ground surface is cooled and the local drainage flow dominates. In such a case, the results of WIND04 may contain a large error. The function of WIND04 is only to adjust the interpolated wind field, so that it cannot predict the dynamical effects such as the wakes at the lee side of a mountain if they are not included in the observation.

The appropriate values of the parameter $\alpha_1$ and $\alpha_2$ are somewhat uncertain. As mentioned before, the ratio $\alpha_1/\alpha_2$ prescribes the fraction of the horizontal and vertical adjustment. When the ratio is low, the horizontal adjustment dominates and the airflow goes around the topographical obstacles, while the ratio is high, it goes over the obstacles. The atmospheric stability may concern with the value of the ratio. When the stability is unstable, the vertical component of the wind is fairly large and the ratio should be high. On the other hand, when the atmosphere is stably stratified, the horizontal adjustment is relatively large and the value of the ratio should become lower. The value may also be affected by the complexity of the terrain. The ratio has not yet been determined in high confidence. An appropriate value between 0.01 and 0.2 are temporally used at present, which seems to assure the reasonable results. Determination of the value is now planned by the use of results of wind tunnel experiments and those of wind observation over the complex terrain. Hydrodynamic models will offer many suggestions for the values of $\alpha_1$ and $\alpha_2$.

A typical computation time for the running of WIND04 was 90 seconds for the calculation of $51 \times 51 \times 21$ meshes on FACOM M-380 computer. The vectorized version of WIND04 has completed the same calculation in less than ten seconds by a vector computer FACOM VP-100.

### 3.1.3 Transport and Diffusion Model

#### (1) Random-walk method to solve a transport-diffusion equation

Numerical solutions of the transport-diffusion equation based on the assumption of gradient-transfer theory (K-theory) and the continuity equation have long been used to simulate the spatial and temporal concentration in complex terrain. The ADPIC code in ARAC, which employs a PICK method to solve the equation, is a famous one as the code successfully applied to accidental releases.

Although finite-difference methods and the PICK method are currently used to solve the equation, these methods are mainly applicable to the volume source whose spatial scale is at least two times the grid interval used in the model. Due to this major limitation in predicting the concentration from a point source such as a release from a stack, the PRWDA code employs the random-walk method of particles based on K-theory. The advantages are firstly that, the enough large scale of cloud to determine the concentration gradient, which the PICK method also needs, is not necessary because the random-walk method moves each particle independently. Secondly, the procedure is simple, and thirdly, the fictitious Eulerian numerical diffusion from which simple finite-difference methods suffer is eliminated by using Lagrangian marker particles.

Several random-walk methods have been proposed and are categorized into two types; (a) those, using a simple random-walk displacement based on K-theory, and (b) those, which use Markov process taking into account the turbulence spectrum.

Although the simulations of the atmospheric diffusion with a combination of turbulent closure theory and Markov process theory have been performed recently for the research purpose, these models require a considerable amount of computation time. Therefore,
the method of type (a) is used in the PRWDA code. The defect of the simple random-walk methods is that the unrealistic flux is generated which is not proportional to the concentration gradient but to the concentration when the methods fail to account for the inhomogeneous turbulence varying with height. To avoid this problem, PRWDA employs the PICK method for vertical diffusion after the evolution of cloud exceeds two times as wide as the vertical grid cell.

In order to simulate motions of a particle, a sequence of turbulent fluctuation steps, $\delta x_i$, $\delta y_i$, and $\delta z_i$ at time intervals of $\Delta t$, will be necessary. The particle location at the sequential time step is determined from

$$x_{i+1} = x_i + u_i \Delta t + \delta x_i, \quad y_{i+1} = y_i + v_i \Delta t + \delta y_i, \quad z_{i+1} = z_i + w_i \Delta t + \delta z_i,$$

(3.1.3-1)

where $u_i$, $v_i$, and $w_i$ are components of mean velocity which are calculated by the interpolation of three-dimensional wind field generated by WIND04. The turbulent fluctuation steps for the (x)- and (y)- components by the random-walk method are represented by random numbers which are generated following a probability density function. This function's standard deviation $\sigma_f((f= x, y, z))$ is expressed by

$$\sigma_f = \sqrt{2 K_i \Delta t},$$

(3.1.3-2)

where $K_i$ is an eddy diffusivity coefficient. For the convenience, the PRWDA code uses an uniform probability function, so the generation of $\delta x_i$, for example, can be expressed by

$$\delta x_i = \delta x_i,$$

(3.1.3-3)

where $\{R \}_{i}^{l}$ indicates a random number distributed uniformly in the range from $(-l)$ to $(+l)$. The variable $l$ is selected so that Eq. 3.1.3-2 should be satisfied

$$l = \sqrt{6 K_i \Delta t}.$$  

(3.1.3-4)

In the PICK method applied to the (z)-direction diffusion, $\delta z_i$ is expressed by

$$\delta z_i = w_i' \Delta t,$$

(3.1.3-5)

where $w_i'$ is the turbulent velocity defined by

$$w_i' = (K_i/x) (\partial x / \partial z),$$

(3.1.3-6)

and $x$ means the concentration.

By using these equations, we rewrite Eq. 3.1.3-1 as follows;

$$x_{i+1} = x_i + u_i \Delta t + \delta x_i,$$

$$y_{i+1} = y_i + v_i \Delta t + \delta y_i,$$

$$z_{i+1} = z_i + w_i \Delta t + \delta z_i.$$  

(3.1.3-7)

However, the random-walk method is also used in the (z)-direction before the cloud expands.

Variables of $K_i$ and $\Delta t$ are selected as follows. From a practical point of view, $K_i$ is calculated from the atmospheric stability category which is routinely observed in a nuclear power plant. The eddy diffusivity coefficient $K_i$ is defined by

$$K_i = \frac{1}{2} \frac{d \sigma_f^2}{dt},$$

(3.1.3-8)

where $\sigma_f$ is a standard deviation of plume. From a practical point of view, $\sigma_f$ is given as functions of the downwind distance and the stability category which is obtained in routine
observation. The formulae of $\sigma_y (= \sigma_z)$ and $\sigma_z$ in this code are derived from Pasquill-Gifford (P-G) chart\(^{17}\), so Eq. 3.1.3-8 is rewritten as follows:

$$K_t = \frac{1}{2} \frac{dr}{dt} \frac{d\sigma_y}{dr} = u \sigma_z \frac{d\sigma_z}{dr} \quad (3.1.3-9)$$

Although the surface roughness and the sampling time vary according to the accidents, no correction to the formulae of P-G chart is given. The P-G $\sigma_z$ is derived from the experiments using a ground source. Consequently, it is a problem to apply it to the elevated source in case that the turbulent condition at the release height is different from the observed stability category. In this code, three horizontal layers that piled vertically can be modeled. These are, for example, equivalent to the fully mixed layer, the neutral layer and the stable layer above mixed layer in the daytime. Upper two layer's turbulent conditions are assigned from the observation of temperature lapse rate or fluctuation of wind direction. In the later discussions, we call this assumption a multi-layer model. When efficient vertical data about the turbulence cannot be obtained, the neutral condition is assumed for the second layer. Although the main aim of this model is the simulation of the dispersion in the existence of capping inversion and so on, this is also effective for the simulation of fumigation by an

![Graph](image-url)  

**Fig. 3.3** Comparison of downwind concentration at the ground level between a Gaussian plume model and PRWDA. The calculational conditions are that atmospheric stability is D, wind speed is 1 m/s and release height H is variable.
Another variable, $\Delta t_e$, is restricted so that no particle moves more than one cell within one time step.

The verification of model in homogeneous airflow is performed. Figure 3.3 shows the comparison of downwind concentration at the ground level between the Gaussian plume model and the present model. The calculational conditions are that atmospheric stability is $D$, wind speed is 1 m/s and release height $H$ is variable. The good agreement of the results between models shows that the PRWDA code can simulate the gradient-transfer process correctly in the simple airflow.

The outputs of the PRWDA code are the airborne concentration ($\text{Ci/m}^3$) and the surface concentration ($\text{Ci/m}^2$) which are averaged in the predicted time. As shown in Fig. 3.4, the concentration presented as a cell average is calculated by the volume (or area) apportionment of a particle's activity between cells. In the figure, the overlap of a shaded area with the Eulerian grid cell determines the activity apportionment. This shaded area shows the cell in which the activity of a particle is spread uniformly. The volume (or area) averaging procedure is an effective way to reduce the statistical fluctuation caused by the sparse distribution of particles. The Eulerian cell size for recording the concentration distribution is defined automatically according to the grid cell size of topographic data. In addition, the user can change the size, if necessary.

Besides these outputs, data of particle positions are outputted when the prediction is ended. Those are utilized as the initial condition of airborne effluent at the start of the next sequential prediction, when the simulation are carried out intermittently in a real-time response.

(2) Short discussion

The PRWDA code still has several problems, though the first stage of code development has finished. The P-G standard deviation for calculation of the eddy diffusivity coefficient $K_e$ is originally obtained under the condition in a rather smooth surface and a sampling time

![Fig. 3.4 Area weighting interpolation for calculating cell concentration.](image-url)
of three to ten minutes. However in the PRWDA code, we apply $K$, derived from P-G $\sigma$, to the calculation for different conditions, because diffusivities computed by this method can be obtained easily from the routine measurements of meteorological conditions. In future, $K$, will be derived from a numerical simulation such as a second-order closure model or from the precise observation of turbulence.

For the realistic estimation of deposition, a surface depletion model is employed to the dry deposition. However the washout coefficient and the deposition velocity of nuclides have big uncertainty according to the ground condition and the chemical form of nuclides, etc. Therefore, the reliability of the results of deposition may be valid only in the relative distribution pattern.

The method to present the concentration by averaged value in the cell always has more or less the defect of underestimation of the concentration near the release point. The degree of underestimation depends on the volume of grid cell, the turbulent condition and the down-wind distance.

### 3.1.4 Dose Model

(1) Cell-integrated dose model

A computer code using a cell-integrated dose model has been developed mainly for calculation of the external dose from an arbitrarily distributed radioactive cloud. We refer to this code as CIDE (Cell Integral Dose Evaluation)\(^{19}\), which includes calculation of the internal dose due to inhalation. The available codes at present for dose evaluation only deal with the exposure to a Gaussian plume in which the concentration can be described in an analytical expression.\(^{19,20}\) Therefore, the dose calculation from an arbitrarily distributed plume is needed for estimation of the radiological consequence due to the dispersion corresponding to wind field in complex terrain.

In the cell-integrated dose model, nuclides in a cell, into which a calculation space is divided, are assumed to be uniformly distributed in every part of the cell by the mean concentration. The three-dimensional integration over the cell is carried out as a constant concentration by a point kernel method. Therefore, doses attributable to each cell having unit concentration of nuclides can be evaluated independently of concentration distribution of a radioactive cloud, and those are tabulated in order to reduce running time of computation. This is the characteristics of the cell-integrated dose model developed for SPEEDI.

The dose evaluated by the cell-integrated dose model is obtained by summing the attributable cell doses, that is:

$$D_i(x,y,0) = \sum_{i,j} \sum_{m,n} \chi(i,m,n) \cdot AD(i,j,m,n)$$

where

- $D_i(x,y,0)$ = exposure rate at the point $(x,y,0)$ of the cell $(i,j,1)$,
- $\chi(i,m,n)$ = nuclide concentration of the $(i,m,n)$,
- $AD(i,j,m,n)$ = attributable dose to the point $(x,y,0)$ from the cell $(i,m,n)$ having unit concentration,
- $L$, $M$, and $N$ = numbers of each cell of $x$, $y$ and $z$-coordinates.

The attributable cell dose is:

$$AD(i,j,m,n) = \int_{(x-i-1/2)dx}^{(x-i+1/2)dx} \int_{(y-j-1/2)dy}^{(y-j+1/2)dy} \int_{(z-n-1/2)dz}^{(z-n+1/2)dz} \frac{K \cdot n_{en} \cdot E \cdot \exp\left(-\frac{\mu r}{4 \pi r^2}\right) \cdot B(E,r) dx dy dz}{4 \pi r^2}$$

where
$DX$, $DY$ and $DZ$ = cell sizes of $x$, $y$ and $z$-coordinates,

$K$ = conversion factor into exposure rate,

$\mu_{en}$ = linear energy absorption coefficient in air,

$\mu$ = linear attenuation coefficient in air,

$E$ = initial energy of photon,

$r$ = distance from an infinitesimal element in the radioactive cloud to the point $(x, y, 0)$,

$B(E, r)$ = dose buildup factor.

When the concentration of plume is a Gaussian distribution, the results of CIDE code are compared with those of GAMPUL which is a code developed for the accurate calculation of dose from the Gaussian distribution by numerical integration in three dimensions. Figures 3.5 and 3.6 show the result of comparison of distribution to the downwind axis and that of distribution to the crosswind axis, respectively. The results of CIDE code may become accurate with decreasing cell size. It appears that the cell size of $x$ and $y$-coordinates less than 250 m would permit us to practically use CIDE code. The cell size of 1000 m could, however, be selected for the purpose of calculating the doses at the points of 10 km apart from a release point. The results of further comparisons have been obtained in the reference (18) using different conditions of atmospheric stabilities and release heights.

(2) Thyroid dose from iodine

It is important to estimate thyroid doses due to inhalation of iodine that concentrates in thyroids weighing 20 g in adults. For deciding whether any remedy actions should be taken into account, therefore, we must estimate the doses to thyroids as accurate as possible considering age-dependence.

The thyroid dose is obtained by the equation:

$$D (Sv) = 51.2 \times \frac{g \cdot f \cdot T_{exit}}{0.639} \times \frac{g}{m} \times \frac{1}{3.7 \times 10^6}, \quad (3.1.4-3)$$
where

\[ q \] = intake of radioiodine (Bq),

\[ f_t \] = thyroid uptake factor,

\[ T_{\text{eff}} \] = effective half-life of iodine (day),

\[ \epsilon \] = effective absorbed energy of radioiodine (MeV),

\[ m \] = thyroid mass (g).

Recent internal dosimetric models require the summation of attributable doses from source organs giving energy of penetrating radiation to an estimated target organ, that is.

\[ H_T = 1.6 \times 10^{-10} \sum T_{\text{eff}} \cdot \sum SEE(T \rightarrow S), \]

(3.1.4-4)

where

\[ H_T \] = committed dose equivalent to a organ T (Sv),

\[ U_s \] = number of nuclear transformations over 50 years in a source organ S,

\[ SEE(T \rightarrow S), \] = specific effective energy of radiation \( i \) given from a source organ S to a target organ T (MeV g\(^{-1}\)/dis).

### Table 3.2 Values of parameters used for calculating thyroid doses

<table>
<thead>
<tr>
<th>Age group</th>
<th>( f_t )</th>
<th>( T_{\text{eff}} ) (day)</th>
<th>SEE (MeV/g·dis.)</th>
<th>Respiration (m(^3)/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant (aged 1)</td>
<td>0.2</td>
<td>40</td>
<td>3.4 \times 10^{-2}</td>
<td>6</td>
</tr>
<tr>
<td>I-129</td>
<td></td>
<td>6.7</td>
<td>1.0 \times 10^{-1}</td>
<td></td>
</tr>
<tr>
<td>I-131</td>
<td></td>
<td>0.095</td>
<td>2.8 \times 10^{-1}</td>
<td></td>
</tr>
<tr>
<td>I-132</td>
<td></td>
<td>0.83</td>
<td>2.2 \times 10^{-1}</td>
<td></td>
</tr>
<tr>
<td>I-133</td>
<td></td>
<td>0.37</td>
<td>3.5 \times 10^{-1}</td>
<td></td>
</tr>
<tr>
<td>I-134</td>
<td></td>
<td>0.28</td>
<td>2.1 \times 10^{-1}</td>
<td></td>
</tr>
<tr>
<td>I-135</td>
<td></td>
<td>9.6 \times 10^{-4}</td>
<td>1.0 \times 10^{0}</td>
<td></td>
</tr>
<tr>
<td>I-136</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Child (aged 4)</td>
<td>0.2</td>
<td>40</td>
<td>1.7 \times 10^{-2}</td>
<td>14</td>
</tr>
<tr>
<td>I-129</td>
<td></td>
<td>6.7</td>
<td>5.0 \times 10^{-2}</td>
<td></td>
</tr>
<tr>
<td>I-131</td>
<td></td>
<td>0.095</td>
<td>1.4 \times 10^{-1}</td>
<td></td>
</tr>
<tr>
<td>I-132</td>
<td></td>
<td>0.83</td>
<td>1.1 \times 10^{-1}</td>
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<td>0.37</td>
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</tr>
<tr>
<td>I-134</td>
<td></td>
<td>0.28</td>
<td>1.1 \times 10^{-1}</td>
<td></td>
</tr>
<tr>
<td>I-135</td>
<td></td>
<td>9.6 \times 10^{-4}</td>
<td>5.0 \times 10^{-1}</td>
<td></td>
</tr>
<tr>
<td>I-136</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult (aged 20)</td>
<td>0.2</td>
<td>40</td>
<td>3.4 \times 10^{-3}</td>
<td>29</td>
</tr>
<tr>
<td>I-129</td>
<td></td>
<td>6.7</td>
<td>1.0 \times 10^{-2}</td>
<td></td>
</tr>
<tr>
<td>I-131</td>
<td></td>
<td>0.095</td>
<td>2.8 \times 10^{-2}</td>
<td></td>
</tr>
<tr>
<td>I-132</td>
<td></td>
<td>0.83</td>
<td>2.2 \times 10^{-2}</td>
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<tr>
<td>I-133</td>
<td></td>
<td>0.37</td>
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<td>I-135</td>
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<tr>
<td>I-136</td>
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</tr>
</tbody>
</table>

* \( f_t \) : thyroid uptake factor

\( T_{\text{eff}} \) : effective half-life from thyroid

SEE : specific effective energy
According to ICRP publication 30\cite{22}, the metabolism of iodine is to recycle by making the thyroidal hormone inorganic, it represents three compartment model composed of an inorganic iodine compartment of total body, an organic one of total body and a thyroid one.

However, the dose to thyroid is almost composed of the contribution of radioiodine existing in itself, and the energy imparted from other organs is negligible. If the effective half-life of iodine in thyroids\cite{23} is used as values considering iodine recycling, the simple Eq. 3.1.4-3 can be useful in estimating the thyroid dose instead of the new dosimetric model using three compartments. The values of parameters used in the Eq. 3.1.4-3 are shown in Table 3.2, including data of respiratory rate\cite{24,25}.

### 3.2 Experimental Validation of Main Models

#### 3.2.1 Simulations of the Fumigation in Coastal Region

**(1) Outline of experiments**

All of Japanese nuclear power plants are located in the coastal regions that differ from the inland with regard to the effect on the atmospheric diffusion. This difference is caused by the occurrence of sea breezes and a coastal internal boundary layer (IBL). The IBL is caused by the difference in surface temperature and surface roughness between sea and land. In the case of onshore flow, the atmospheric stability is gradually modified from stable to unstable from the coastline. Consequently, the IBL increases in depth with downwind distance. The airborne effluent released in the stable onshore flow above IBL may result in the fumigation after entering into the IBL. Experimental studies\cite{26} show the importance of fumigation and trapping in the coastal site and the necessity of the modeling of these phenomena.

Field experiments started in 1980 at Tokai, Japan have been carried out to provide the data of transport and diffusion in coastal region. The focus of measurements for the first four years was on the fumigation in coastal region and that of the last two years is on the effect of the terrain. In Table 3.3, it is listed the outlines of series of experiments in the coastal region during 1980, 1981, 1982 and 1983. In this section, simulated results of experiments in first three years are described.

The experimental site is a mainly plain area bordering on the Pacific in the 120 km northern part of Tokyo. The deployments of equipments are shown in Fig. 3.7.

<table>
<thead>
<tr>
<th>Table 3.3 Outline of series of experiments in coastal region</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Release type</strong></td>
</tr>
<tr>
<td>Continuous line source of SF$_6$</td>
</tr>
<tr>
<td>Release height : 150 m</td>
</tr>
<tr>
<td><strong>Objective of experiment</strong></td>
</tr>
<tr>
<td><strong>The number of runs</strong></td>
</tr>
</tbody>
</table>
In the experiments in 1980 and 1981, the tracer gas, SF$_6$, was released by a helicopter for 1.5 hour along the seashore at 150 m and 120 m height above the ground level, respectively. The aim of the experiment with a line source was to research the vertical dispersion by the compensation of horizontal dispersion. The measurements of vertical profiles of wind speeds, wind directions and temperatures at the tethering points of balloons were performed during the experiment in addition to the routine measurements, at 20 points, of wind speeds, wind directions near the ground level. Sampling-units for measuring vertical distribution were attached to the tethered balloons up to a height of 300 m every 50 m interval. About 30 points of tracer sampling-units at the ground level were arrayed uniformly within 10 km downwinds from the source line. The measurements of concentrations were performed once
during 30 minutes after 1 hour since the start of release. Tracer samples were analyzed by the use of gas chromatography.

In the experiments in 1982, the tracer gas was released from the fixed point 120 m above the ground level using the tethered balloon at the seashore. The measurements of vertical wind speed, direction and temperature profiles at the five points, i.e., the sea, the release point and inland points, were performed during the experiment in addition to the routine measurement near the ground level at 30 points.

The ground level tracer sampling-units were arrayed on the arcs with radii of 0.6, 1.0, 2.0, 3.0, 4.0, 5.0, 10.0 and 15.0 km every angular interval of 5 degrees. In the experiments, the periods of release were 3 hours and samplings were performed twice during 30 minutes after 1 hour and 2.5 hours since the start of release. In the rest experiments, these were once after 1 hour since the start of release. The releases were continued for 1.5 hour.

(2) Simulations and comparisons

The calculations were made by using the WIND04 code and the PRWDA code for complex simulations. The effort for simulation of the IBL was performed using a multi-layer model to the IBL. Three different layers were specified by a layer completely adjusted to the ground roughness, a transition layer whose turbulence was intermediate and a stable layer above the IBL. The \( K_i \) was calculated by using Eq. 3.1.3-9 and the atmospheric stability category was classified by the reference of temperature lapse rate specified in U.S.NRC Regulatory Guide 1.23\(^27\). Figure 3.8 shows the general concept of a simulation model for the IBL.

As is shown in the Figure, this model cannot take into account the increase of the IBL near the coastline, because the simulation taking into account the three-dimensional increase of the IBL near the coastline is impractical and difficult due to the complex shoreline and the scarcity of meteorological data. Many experiments at JAERI show that turbulent conditions were divided into three groups; the superadiabatic layer adjusted completely by the land, the neutral layer which is intermediate between unstable and stable layers and the stable layer of shoreflow. And the increases of adjusted layers were limited within 2 km downwind, though the transition layer increases extremely in about 5 km inland in some cases\(^28,29\). For these reasons, the multi-layer model may be reasonable for the simulation of the IBL in spite of a great simplification.

The comparisons of simulated results with observed ones were performed on the vertical

![Fig. 3.8 Modeling for an internal boundary layer (IBL).](image)
Fig. 3.9 Comparison of vertical concentration distribution at the tethered points of balloons between observed data and calculated ones by PRWDA. D.D. shows downwind distance.
distribution in 1980 and 1981 and on the horizontal distribution at the ground level in 1982. The fumigation appeared in seven runs in 1980 and 1981. Figure 3.9 shows the comparisons of vertical concentration distributions. In each figure, solid lines show calculated results and dotted lines show experimental ones. Figure 3.10 shows the comparisons of the downwind concentration distributions at the ground level. The results of the Gaussian plume model in the Figures are calculated by using the atmospheric stability category determined from the surface wind speed and the insolation. As shown in these Figures, the multi-layer model can simulate the complex vertical dispersion by considering the flow in the stable layer at the upper region.
The comparisons of horizontal distributions in 1982 experiments are shown in Fig. 3.11. In each figure, solid lines are calculated results and dotted lines are the experimental ones. Values of isopleths are 3000 ppt (part per trillion \( \times 10^{-12} \)) at the inside and 300 ppt at the outside. On Run 1, the IBL and the wind direction changed with time. The mean airflow changed gradually from ESE to ENE with time, which results in the horizontal spread wider than other runs. In this simulation, meteorological data were inputted at the intervals of every one hour, so the plume center line by calculation was clearer to WSW than the observed one.

On Run 2, the samplings were carried out twice after 1 hour and 2.5 hours from the start of release. In the first sampled results, the two peaks of concentration appeared at 0.6 km and at 3.0 km (less than 3000 ppt). The turbulent condition estimated from the temperature lapse rate showed that the neutral condition was dominant near the height of release. The cause of peak at 0.6 km could not be made clear from the observed meteorological data and the calculated peak position agreed with the second peak. On Run 4, the samplings were also carried out twice. During the first sampling, a clear leakage from SF\(_6\) cylinders appeared and the effect of leakage could not be ignored against the observed results within several kilometers. The wind direction changed between the first and the second sampling period. On Run 5 and Run 6, the sampling-units seemed to catch the plume center line. On Run 7, on the other hand, the plume center line seemed to flow between the sampling-units. In most experiments, the horizontal concentration distributions agreed well with the observed results except the neighborhood of the release point. The overestimation of calculated results in the region close to the release point is to be considered by the ignorance of the IBL slope in the model. In the case that the plume is released in the stable onshore flow, the spread of the plume in the crosswind direction tends to become narrower than the P-G \( \alpha_y \) determined from the surface wind speed and the insolation. The calculated results by the present model also showed these phenomena by considering the upper stable or neutral layer.

(3) Short discussion

According to the comparisons, it became clear that the multi-layer model would be effective for simulation of the fumigation in the existence of the IBL despite the great sim-

---

**Fig. 3.10** Comparison of downwind concentration distribution at the ground level between observed data and calculated ones by PRWDA.
Fig. 3.11  Comparison of horizontal distribution pattern at the ground level in 1982 experiment between observed data and calculated ones by PRWDA.
plification. Although the ignorance of the increasing depth of the IBL close to the shoreline did not result in the big error against the experiments, the magnitude of error may be different depending on the relative position between the source height and modeled IBL. The error due to the assumption of the constant-height multi-layers could not be examined at the inland where the IBL became obscure. In the inland, the turbulence of airflow above IBL is expected to become the neutral condition from the stable one. This may cause the error in some degrees. Another problem is how to simulate the IBL made by the onshore flow in complex terrain, but the experimental studies about this problem are not enough.

The atmospheric stability categories of multi-layers are determined from the temperature lapse rate or the standard deviation of horizontal wind-direction fluctuation. But the routine measurement at the two level of tower in the site cannot supply enough data identify even the existence of the IBL. Therefore, the special measurement by a radiosonde or alternative instruments in an emergency or a routine observation of an acoustic sounder would be effective to resolve these difficulties.

### 3.2.2 Simulations in Complex Terrain

In this section two verification studies in complex terrain are introduced. As for the wind field and the dispersion over complex terrain, there are no field data which can be used as references for verification, because the field experiment in the complex terrain contains many difficulties. One of the verification studies is the simulation of the trajectories obtained by the flight of constant level balloons. The trajectory of the balloons are simulated by the use of the three dimensional wind field computed by WIND04. The horizontal scale of the simulation is within 100 km. The other study is a simulation of wind tunnel experiment by WIND04/PRWDA. A wind tunnel experiment itself is one of the simulation techniques, and the result should be verified by the comparison with the field experiments. However the wind tunnel experiments are carried out on the basis of similarity law of the fluid dynamics, so that we can expect considerable confidence of the results. Furthermore, the comparison between

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Release time</th>
<th>Tracking duration</th>
<th>Recovery site</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/6 15:39</td>
<td>*****</td>
<td>Yamagata-cho, Ibaraki</td>
</tr>
<tr>
<td>2</td>
<td>10/7 12:18</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>3</td>
<td>10/7 15:02</td>
<td>*****</td>
<td>Nasu-cho, Tochigi</td>
</tr>
<tr>
<td>4</td>
<td>10/12 11:45</td>
<td>*****</td>
<td>Simotsuma city, Ibaraki</td>
</tr>
<tr>
<td>5</td>
<td>10/13 11:30</td>
<td>12:51 - 13:27</td>
<td>Katsura-mura, Ibaraki</td>
</tr>
<tr>
<td>6</td>
<td>10/13 13:08</td>
<td>14:28 - 15:38</td>
<td>Bato-cho, Tochigi</td>
</tr>
<tr>
<td>7</td>
<td>10/13 16:33</td>
<td>16:34 - 17:38</td>
<td>*****</td>
</tr>
<tr>
<td>8</td>
<td>10/14 12:50</td>
<td>13:10 - 14:25</td>
<td>Yachiyo city, Chiba</td>
</tr>
<tr>
<td>9</td>
<td>10/14 15:10</td>
<td>15:05 - 17:25</td>
<td>*****</td>
</tr>
<tr>
<td>10</td>
<td>10/15 10:45</td>
<td>10:45 - 12:01</td>
<td>Kuroiso city, Tochigi</td>
</tr>
<tr>
<td>12</td>
<td>10/16 12:00</td>
<td>12:01 - 14:31</td>
<td>*****</td>
</tr>
<tr>
<td>13</td>
<td>10/16 14:56</td>
<td>14:57 - 26:41</td>
<td>*****</td>
</tr>
<tr>
<td>14</td>
<td>10/20 10:10</td>
<td>10:11 - 12:58</td>
<td>*****</td>
</tr>
<tr>
<td>16</td>
<td>10/20 15:28</td>
<td>15:41 - 16:24</td>
<td>Tochigi city, Tochigi</td>
</tr>
</tbody>
</table>
different simulation techniques is important, because it clears the advantage and the defect of each technique.

(1) Simulation of trajectory

The balloon flights used in this study were conducted in October, 1981. Balloons equipped with rawin-sonde were released and tracked by two rawin-sonde tracking stations. The horizontal position of the balloon was calculated from the azimuthal angles observed by tracking stations. The altitude of the balloon was ballasted for 300 m, and the variation of the altitude was obtained from the pressure signals transmitted from the rawin sonde. Among 18 balloon flights, 14 flights were tracked by this method to the downwind distance of 20 km from the release point. The balloons were recovered in 11 flights at the distance ranging from several kilometers to a hundred kilometer. These balloon flights are summarized in Table 3.4.

The area of interest, which locates in the middle of Japan, and the distribution of meteorological stations are depicted in Fig. 3.12. The southern part of this area is a large plain, but the northern and the north-western areas are mountainous districts. The eastern edge is open to the Pacific Ocean. The location of Tokai, where the balloons were released, is shown in the Figure. All of meteorological stations are surface stations, and their heights above sea

![Fig. 3.12 Computational area and the wind observation included in it. The arrows show the examples of observed surface wind. Closed circles represent the meteorological stations whose data are available but are not included in this study.](image-url)
level are ranging from zero meter to several hundreds of meters, among them the 11-th station locates on the top of a solitary mountain, Mt. Tsukuba, whose height is 876 m. In the numerical calculation, the whole area is divided into 50 × 50 × 20 cells. The size of a cell is 4000 m × 4000 m × 40 m. Then the whole of the computational volume is 200 km × 200 km × 800 m.

The wind vector at each grid point is calculated by WIND04 using the surface wind data shown in Fig. 3.12. In order to judge the efficiency of mass-conservation technique, three kind of wind fields are calculated. In the first and the simplest case, WFD1, we only interpolate the data of surface wind over the three dimensional grid point by Eq. 3.1.2-1. The observed data at the 11-th station is not used in this interpolation, because of its singularity mentioned above. The vertical profile of the wind is roughly accounted for by the use of the power law. The terrain height is not included. The variational technique is not applied in this calculation. In the second case, WFD2, the interpolation is accomplished by the same method used in the first case, but the terrain height is included. Furthermore, the variational adjustment technique is applied so as to ensure the conservation of the mass. In the last case, WFD3, we use the wind observation as the 11-th station as the upper wind observation, Mt. Tsukuba. The topography is included and the variational adjustment is applied. The differences of three cases of wind field calculation are summarized in Table 3.5.

A trajectory of a balloon is computed by following a marker particle released into the wind field. The position of the marker particle at time \( t \), \( X_t \), is computed by

\[
X_t = X_{t-\Delta t} + v_{t-\Delta t} \cdot \Delta t,
\]

(3.2.2-1) where \( \Delta t \) is the time increment, which value is 1 min., and \( v_{t-\Delta t} \) is the wind vector at the position of the marker particle.

A trajectory is calculated for each wind field, WFD1, WFD2 and WFD3, and is referred to as TRA1, TRA2 and TRA3, respectively.

The TRA3s of Run 15, 17, 18 are depicted in Fig. 3.13. Closed circles represent calculated trajectories. Open circles are the observed trajectories and the double circles are the points of balloon recovery. Closed circles and open circles are the positions of the balloon for every ten minutes after the release of the balloon.

The difference among the three methods is shown in Fig. 3.14 as for the RUN10. Triangles, open circles and closed circles represent TRA1, TRA2 and TRA3, respectively. The altitude of the marker particle at every one hour after release is also shown in the figure. The altitude of TRA1 is held constant, 300 m, because no vertical wind component is specified in the WFD1.

TRA1 and TRA2 are not much different each other, whereas the TRA3 is different. The observed trajectory is between TRA2 and TRA3, but the point of recovery is only simu-

<table>
<thead>
<tr>
<th>Table 3.5</th>
<th>List of the condition of wind field calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal interpolation</td>
</tr>
<tr>
<td>Case 1 (WFD 1)</td>
<td>Weighted by the reverse square of distance</td>
</tr>
<tr>
<td>Case 2 (WFD 2)</td>
<td>same as Case 1</td>
</tr>
<tr>
<td>Case 3 (WFD 3)</td>
<td>same as Case 1</td>
</tr>
</tbody>
</table>
lated by TRA3. The difference of TRA3 from other trajectories are due to the use of the data of upper wind. This result implies the importance of the upper wind data. TRA1 and TRA2 differ slightly. This difference is due to the variational adjustment. It can be seen that the TRA2 goes around the hill as in the Figure, whereas the TRA1 go across it. It is because that the interpolated wind is adjusted so as to flow around the hill in the result of variational adjustment. In this case the trajectory is not much modified by the imposition of mass conservation. However in some other cases, TRA1 goes straight into the mountainous region, whereas the TRA2 is greatly modified so that it goes around the topographic obstacles.

(2) Simulation of wind tunnel experiment

Wind tunnel experiments are often used for the purpose of estimating the effect of complex topography and of the buildings on the dispersion of materials. As a part of research cooperation programs, a series of wind tunnel experiments has been performed by the Meteorological Research Institute of Japan. In these experiments the precise measurements of wind and concentration were carried out. In this subsection, the results of the calculations executed by WIND04 and PRWDA in the SPEEDI system are compared with the results of
wind tunnel experiments.

Prior to the description of comparison, the equipments of the wind tunnel and the characteristic features of the wind tunnel experiments should be referred to. The wind tunnel experiments are performed in regard of neutrally stratified atmosphere. The wind speed is measured by a hot-wire anemometer. Propane gas is used as a tracer of the diffusion experiment. The gas is sampled by tubes, and the concentration is measured by a hydrocarbon-analysyr. The reducing ratio of the topographic model is 1/2000.

The order of the Reynolds number of the flow of real atmosphere is about \(10^8\). If the wind speed in the wind tunnel is same to the real atmosphere, the order of the Reynolds number of the flow in the wind tunnel is still \(10^4\). There is no need to keep the Reynolds number of both flow exactly same, because both Reynolds numbers are sufficiently large. Fluid motion is not sensitive to the difference of Reynolds number in the high Reynolds number condition. The wind speed in the wind tunnel is set in 3 (m/s), and the vertical profile of the wind is created. The turbulent surface layer is exerted by the use of roughness panel and blocks, which are shown in the Fig. 3.15.

The results of experiments and those of calculation should be compared carefully considering the difference of the scale. In order to cancel the difference of the scale,
\[ \chi = \frac{C \cdot U}{Q} = \frac{C_w \cdot U_w}{Q_w} \cdot S_i^2 \]  
(3.2.2-2)

is used, where \( C \) (Unit/m^3) is the concentration, \( U \) (m/s) is the wind speed at release point and \( Q \) is the release rate (Unit/s). Subscript \( w \) implies that the value is the result of the wind tunnel experiment. \( S_i \) is the reducing ratio of the model (= 1/2000).

The similarity of both values is judged by the following quantities,

**Bias**:
\[ \bar{D} = A - B, \]  
(3.2.2-3)

**Variance**:
\[ S_i^2 = \frac{1}{N-1} \sum_{n=1}^{N} (A_n - B_n - \bar{D})^2, \]  
(3.2.2-4)

**Root Mean Square Error**:
\[ \text{RMSE} = \sqrt{\frac{1}{N} \sum_{n=1}^{N} (A_n - B_n - \bar{D})^2}, \]  
(3.2.2-5)

**Correlation**:
\[ R = \frac{\sum_{n=1}^{N} (A_n - \bar{A}) \cdot (B_n - \bar{B})}{\sqrt{\sum_{n=1}^{N} (A_n - \bar{A})^2 \cdot \sum_{n=1}^{N} (B_n - \bar{B})^2}}, \]  
(3.2.2-6)

where \( A \) and \( B \) are experimental and computed values, respectively, and the bar implies the mean value over the set. The number of the evaluation points is 577 for all the region. The statistical quantities mentioned above are computed for all of the points and for some subset of the points (surface points, points at some fixed downwind distances).

The features of dispersion simulated in the wind tunnel are checked by the comparison of dispersion experiments over a flat plate with the Gaussian plume model (Fig. 3.16). The horizontal diffusion parameter \( \sigma_x \) and the vertical dispersion parameter \( \sigma_z \) are compared.

![Fig. 3.15 Arrangement in the wind tunnel.](image)
It is noted that the $\sigma_z$ in the experiments is close to that of Pasquill's stability class $D$ (neutral) or $E$ (slightly stable), and the $\sigma_z$ is close to $C$ (slightly unstable). The concentrations of the dispersion experiments over a flat plate are compared with the Gaussian plume model for various atmospheric stabilities in Fig. 3.17. In each sub-figure, the abscissa is the concentration of the wind tunnel experiment and the ordinate is the concentration computed by the Gaussian plume model. It can be seen that the results of the wind tunnel experiments are between stability class $C$ and $D$, and the overall distribution is close to stability class $C$. Then, the following computation by SPEEDI is performed for stability $C$.

The region of concern is depicted in Fig. 3.18. It is the site of a nuclear power plant facing on the Sea of Japan. The area enclosed by dashed line is the scope of the experiment in the wind tunnel, and the solid lines show the boundary of the computational domain.

In the wind tunnel experiment, two opposing boundaries are walls of wind tunnel, so that the boundary condition of computation is slightly modified at the corresponding boundaries. An example of the comparisons is shown in Figs. 3.19, 3.20 and 3.21. The pattern of the surface concentration is shown in Fig. 3.19. In Fig. 3.20 is shown the distribution of materials in several vertical cross sections between 0.7 to 2.5 km down from the source. The center of the plume shifts eastward with the downwind distance, and the shift is large near the surface and is relatively small in the upper layer. The reason is that the wind near the ground is affected by the topography. In this present case, airflow, which goes around a big hill at the southwest part of the region, shifts the plume eastward. The result of computation retains this effects well. Figure 3.21 shows the correlation of the values for total points. The experiment and computed values show good agreement. The correlation factor is 0.89. The statistical quantities are listed in Table 3.6. These statistical quantities are also computed for the surface concentration and for the concentration in the vertical cross section at some appointed downwind distances. Those values are also shown in Table 3.6.
It must be mentioned that the one of the governing parameters for the computation is the ratio of weighting coefficients of $\alpha_1/\alpha_2$ in the wind field calculation. In order to obtain the ratio which gives the best simulation of the wind tunnel experiments, the simulation is carried out for several values of $\alpha_1/\alpha_2 = 0.02, 0.04, 0.08, 0.16$ and $0.20$. The correlation coefficients of the concentration for various values of $\alpha_1/\alpha_2$ are listed in Table 3.7. The ratio between 0.16 and 0.20 is suitable from the viewpoint of correlation.

Fig. 3.17 Correlation between the diffusion experiment of neutral stability on the flat plate and the Gaussian plume model of various stability classes.
**Fig. 3.18** Area of interest. The region of the wind tunnel experiment is enclosed by dashed lines. Solid lines show the boundaries of the computational domain. A circle with dot denotes the source point. The tracer gas is released 100 m, in real scale, above this point.

**Table 3.6** Statistical comparison of computed concentration and wind tunnel experiment

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean</th>
<th>Bias</th>
<th>Variance</th>
<th>RMSE</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>3.56E-6</td>
<td>7.55E-6</td>
<td>4.53E-11</td>
<td>7.79E-6</td>
<td>0.892</td>
</tr>
<tr>
<td>Surface</td>
<td>7.58E-6</td>
<td>4.95E-6</td>
<td>1.29E-10</td>
<td>1.23E-5</td>
<td>0.663</td>
</tr>
<tr>
<td>700 m</td>
<td>7.31E-6</td>
<td>1.25E-5</td>
<td>3.66E-10</td>
<td>2.26E-5</td>
<td>0.841</td>
</tr>
<tr>
<td>1000 m</td>
<td>6.05E-6</td>
<td>1.02E-0</td>
<td>1.02E-10</td>
<td>1.26E-5</td>
<td>0.886</td>
</tr>
<tr>
<td>1500 m</td>
<td>4.29E-6</td>
<td>1.83E-1</td>
<td>1.83E-11</td>
<td>5.96E-6</td>
<td>0.936</td>
</tr>
<tr>
<td>2000 m</td>
<td>2.98E-6</td>
<td>2.93E-6</td>
<td>4.57E-12</td>
<td>3.62E-6</td>
<td>0.943</td>
</tr>
<tr>
<td>2500 m</td>
<td>2.35E-6</td>
<td>2.47E-6</td>
<td>2.47E-12</td>
<td>2.35E-6</td>
<td>0.941</td>
</tr>
<tr>
<td>3000 m</td>
<td>1.98E-6</td>
<td>1.42E-6</td>
<td>1.42E-12</td>
<td>1.78E-6</td>
<td>0.920</td>
</tr>
</tbody>
</table>

*) The figures of the first column show downwind distance.
**Fig. 3.19** Distribution of the surface concentration. The dashed lines show the result of experiment. Computational result is shown by solid lines.

**Table 3.7** Correlation of the wind tunnel experiment and the computed concentration for various values of $\alpha_1/\alpha_2$

<table>
<thead>
<tr>
<th>$\alpha_1/\alpha_2$</th>
<th>Total</th>
<th>Surface</th>
<th>700 m</th>
<th>1000 m</th>
<th>1500 m</th>
<th>2000 m</th>
<th>2500 m</th>
<th>3000 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>0.480</td>
<td>0.693</td>
<td>0.306</td>
<td>0.571</td>
<td>0.253</td>
<td>0.228</td>
<td>0.350</td>
<td>0.460</td>
</tr>
<tr>
<td>0.04</td>
<td>0.693</td>
<td>0.719</td>
<td>0.522</td>
<td>0.827</td>
<td>0.618</td>
<td>0.522</td>
<td>0.745</td>
<td>0.783</td>
</tr>
<tr>
<td>0.08</td>
<td>0.811</td>
<td>0.679</td>
<td>0.980</td>
<td>0.890</td>
<td>0.828</td>
<td>0.714</td>
<td>0.821</td>
<td>0.846</td>
</tr>
<tr>
<td>0.16</td>
<td>0.892</td>
<td>0.663</td>
<td>0.841</td>
<td>0.886</td>
<td>0.936</td>
<td>0.943</td>
<td>0.941</td>
<td>0.913</td>
</tr>
<tr>
<td>0.20</td>
<td>0.896</td>
<td>0.639</td>
<td>0.841</td>
<td>0.879</td>
<td>0.911</td>
<td>0.921</td>
<td>0.929</td>
<td>0.876</td>
</tr>
</tbody>
</table>
Fig. 3.20 Vertical cross section at various downwind distances. Lines are same as Fig. 3.19. The topography is described by solid curves with oblique lines, and the topographic model used in calculation is plotted by thick lines with dots.
3.3 Simple Models for Reference Calculation

3.3.1 Plume Model

In an emergency planning, it is necessary at the early stage of emergency to estimate roughly but quickly the external gamma-dose from radioactive noble gases, the thyroid dose following inhalation of radioactive iodine and the surface concentration of the depositing iodine for provision of countermeasures such as evacuation or of the environmental surveillance.

For this purpose, we have developed a computer code GS DoSE which calculates the external gamma-dose, the thyroid dose and the surface concentration quickly on the basis of the Gaussian plume model.

(1) Calculation of the external dose due to radioactive noble gases

The GS DoSE calculates the external gamma-dose from plumes by means of interpolation or extrapolation of the normalized doses which have been prepared in advance. The normalized dose is defined later in this section.

1) Calculation of release rates, effective energy and average energy

It is in general considered that the release information is limited at the early stage. Therefore the GS DoSE at first calculates the release rate \( \bar{q} \), the effective energy \( E^* \) and the average energy \( \bar{E} \) or mixed noble gases at time \( t_i \) during the release on the assumption that the release rate is constant between \( t_{i-1} \) and \( t_i \).

The release rate of nuclide \( i \) is calculated as follows.
where

\( q_{0i} \): release rate of nuclide \( i \) at the shutdown time.

\( \lambda_i \): decay constant of nuclide \( i \).

\( t_j \): a time during the release and

\( t_s \): shutdown time.

\( q_{0i} \) is initially calculated by the SPEEDI system.

The release rate and effective energy of mixed noble gases at \( t_j \) are then calculated from Eq. 3.3.1-2 and Eq. 3.3.1-3, respectively.

\[
\bar{\gamma}(t_j) = \sum_i \gamma_i(t_j),
\]

(3.3.1-2)

\[
E^*(t_j) = \frac{1}{\bar{\gamma}(t_j)} \sum_i \gamma_i(t_j) E_i^* \times \left( E_i^* \cdot \sum_k N_i E_{rk} \cdot f_{rk} \right),
\]

(3.3.1-3)

where

\( E_i^* \): effective energy of nuclide \( i \).

\( E_{rk} \): energy of \( k \)-th gamma ray of a nuclide \( i \) (MeV/photon),

\( f_{rk} \): intensity of \( k \)-th gamma ray per disintegration of a nuclide \( i \) (photon/dis) and

\( N_i \): number of gamma rays per disintegration of a nuclide \( i \),

which are provided from the nuclide data file in this system.

The average energy of mixed noble gases, which is used for interpolating or extrapolating the normalized doses with respect to the energy, is calculated as follows.

\[
\bar{E}(t_j) = \frac{\bar{\gamma}(t_j) E^*(t_j)}{\sum_i \gamma_i(t_j) \sum_k N_i E_{rk}},
\]

(3.3.1-4)

2) Calculation of external gamma-dose

The normalized dose is defined as the dose on the ground when a gamma-emitting nuclide is released at the rate of 1 Ci/h, the effective energy of the nuclide is 1 MeV and the wind speed is 1 m/s. Therefore the external dose due to the mixed noble gases from the beginning of release to the end is calculated as follows.

\[
D(x, y, t_s, t_E) = \sum_f \bar{\gamma}(t_j) E^*(t_j) \frac{D_0}{u(t_j)} \times (t_j - t_{j-1}),
\]

(3.3.1-5)

where

\( t_s \): time when the release begins,

\( t_E \): time when the release ends,

\( D_0 \): normalized dose (rem \cdot (m/s) \cdot MeV^{-1} \cdot Ci^{-1}) and

\( u(t_j) \): wind speed at \( t_j \) (m/s).

3) Interpolation or extrapolation method of the normalized doses

The normalized dose is the function of five elements, that is, exposure points \((x, y)\) which are prepared on the Cartesian coordinates, atmospheric stabilities, release heights \( (H) \) and average energies \( (E) \). The normalized doses of 120960 kinds are prepared for all the combinations of these five elements which are given in Table 3.8.

The normalized doses are interpolated or extrapolated assuming a quadratic relationship between the dose and the elements, that is,

\[
\log D_0 = \alpha \xi^2 + \beta \xi + c.
\]

(3.3.1-6)

For the interpolation or extrapolation with respect to \( x \) or \( E \), logarithmic values of these elements are substituted in \( \xi \), while for \( y \) or \( H \) are used the values themselves of
Table 3.8 Values of elements for which the normalized doses are provided

<table>
<thead>
<tr>
<th>Gamma energy (MeV)</th>
<th>0.05, 0.08, 0.1, 0.15, 0.2, 0.5, 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release height (m)</td>
<td>0, 10, 20, 40, 70, 100, 150, 200, 300, 500</td>
</tr>
<tr>
<td>Stability</td>
<td>A, B, C, D, E, F</td>
</tr>
<tr>
<td>Downwind distance (km)</td>
<td>-0.5 0.3 2.0 20.0 100.0</td>
</tr>
<tr>
<td></td>
<td>-0.2 0.4 3.0 50.0 200.0</td>
</tr>
<tr>
<td></td>
<td>-0.1 0.5 5.0</td>
</tr>
<tr>
<td></td>
<td>0.01 0.6 10.0</td>
</tr>
<tr>
<td></td>
<td>0.02 0.7</td>
</tr>
<tr>
<td></td>
<td>0.05 0.8</td>
</tr>
<tr>
<td></td>
<td>0.1 0.9</td>
</tr>
<tr>
<td></td>
<td>0.2 1.0</td>
</tr>
<tr>
<td>Crosswind distance (km)</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td></td>
<td>0.01 0.02 0.2 1.0</td>
</tr>
<tr>
<td></td>
<td>0.02 0.05 0.5 2.0</td>
</tr>
<tr>
<td></td>
<td>0.04 0.1 1.0 4.0</td>
</tr>
<tr>
<td></td>
<td>0.07 0.2 1.5 7.0</td>
</tr>
<tr>
<td></td>
<td>0.1 0.3 2.0 10.0</td>
</tr>
<tr>
<td></td>
<td>0.15 0.45 2.5 15.0</td>
</tr>
<tr>
<td></td>
<td>0.2 0.7 3.5 20.0</td>
</tr>
<tr>
<td></td>
<td>0.3 1.0 5.0 25.0</td>
</tr>
<tr>
<td></td>
<td>0.45 1.5 7.0 35.0</td>
</tr>
<tr>
<td></td>
<td>0.7 2.0 10.0 50.0</td>
</tr>
<tr>
<td></td>
<td>1.0 4.0 20.0 100.0</td>
</tr>
</tbody>
</table>

these elements. The coefficients $a$, $b$ and $c$ are determined by the Gauss-Jordan method with a set of three equations for the nearest three points to a point for which the dose is to be calculated.

The interpolation of the normalized dose would not cause errors larger than 1% for most of the cases. The details of the interpolation or extrapolation method and precision are described in the reference (30).

(2) Calculation of thyroid dose due to inhalation of radioactive iodine

The ground level airborne concentration $\chi(x, y, t_j)$ of radioactive iodine $\iota$ is calculated from the following equation:

$$\chi(x, y, t_j) = \frac{\tilde{q}_i(t_j)Rd(x, t_j)}{3600\pi \sigma_y \sigma_z u(t_j)} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left(-\frac{H^2}{2\sigma_z^2}\right),$$  \hspace{1cm} (3.3.1-7)

where $\sigma_y$ and $\sigma_z$ are crosswind and vertical dispersion parameter (m), respectively.

$\tilde{q}_i(t_j)$ is given by Eq. 3.3.1-1. The depletion factor $Rd(x, t_j)$ is given in GSDOSE as follows.

$$Rd(x, t_j) = \exp\left[-\frac{1}{u(t_j)}\left\{A x + \sqrt{2/\pi} \cdot V_d \int_0^\infty \frac{1}{\sigma_z} \exp\left(-\frac{H^2}{2\sigma_z^2}\right) dX\right\}\right],$$  \hspace{1cm} (3.3.1-8)

where

$A$ : washout coefficient (l/s) and
$V_d$ : deposition velocity (m/s).

The time integrated concentration of radioactive iodine $\iota$ from the beginning of release
to the end is calculated from

$$x_i(x, y, t_s, t_t) = \sum_j x_j(x, y, t_j) \times (t_j - t_{j-1})$$

(3.3.1-9)

and then the thyroid dose is calculated as follows.

$$D_t(x, y, t_s, t_t) = Y_i B \sum_j x_j(x, y, t_j) (DF)_i$$

(3.3.1-10)

where

- $D_t$: thyroid dose equivalent of age group $i$ (rem),
- $Y_i$: coefficient which produces $D_t$ from the thyroid dose for the adult group, 
  (1 for adults, 2 for children and 1.5 for infants),
- $B$: the breathing rate for adults ($m^3/h$),
- $(DF)_i$: committed dose equivalent of the thyroid for adults who inhaled 1 Ci of the nuclide $i$.

(3) Calculation of surface concentration

The deposition rate due to dry deposition at $t_i$ is calculated as follows.

$$S_{di}(x, y, t_i) = V_{di} x_i(x, y, t_i) \times 3600$$

(3.3.1-11)

The deposition rate due to washout by rain at $t_i$ is calculated as follows.

$$S_{wi}(x, y, t_i) = A x_i^{*}(x, y, t_i) \times 3600$$

(3.3.1-12)

where $x_i^{*}(x, y, t_i)$, vertically integrated concentration, is calculated from

$$x_i^{*}(x, y, t_i) = \frac{\bar{q}_i(t_i) R d(x, t_i)}{3600(2\pi)^{1/2} \sigma_y \sigma_x} \exp\left(-\frac{y^2}{2\sigma_y^2}\right).$$

(3.3.1-13)

Therefore the surface concentration at $t_i$ of each radioactive iodine is calculated as follows.

$$C_i(x, y, t_i) = \sum_j [(S_{di}(x, y, t_i) + S_{wi}(x, y, t_i)) \exp(-\lambda_i(t_i - t_j) \times (t_j - t_{j-1})].$$

(3.3.1-14)

3.3.2 Puff Model

To effectively give the real-time dose predictions within about 10-kilometer radius of a site, we use a puff dispersion model which can account for the spatial and temporal variations in meteorological conditions as well as time dependence of release rate of effluent. The development of this model is undertaken to integrate three capabilities for wind field, atmospheric dispersion, and dose calculations as shown in Fig. 3.22 to minimize the amount and frequency of data transfer. Whenever meteorological data is acquired from the site and its surrounding stations, the wind fields for the area of interest are calculated to determine the advection of the puffs generated from the source location. Once the advection and size of all puffs have been calculated, updated ground level airborne concentrations, surface concentrations and external gamma-doses are simultaneously obtained at each grid point by summing up all the contributions from the puffs in the grid area. The ground level airborne concentrations are used to obtain the thyroid doses due to inhalation at each grid point with breathing rate and dose conversion factor.

(1) Wind field calculation

In determining the trajectories of each released puff, the wind fields must be specified as a function of location and time over the entire area. The wind field should be obtained by an objective analysis procedure based on a network of wind measurements at meteorological stations. Although thermal, topographic and frictional effects on atmospheric boundary layer flow may be significant for the microscale and mesoscale wind field, we only take
topographic effects into account because the analysis should be simply and economically appropriate for real emergency applications. The analysis presented here was developed in original form by Endlich\(^{31}\) and applied by Liu and Goodin\(^{32}\) for use in mesoscale wind field. It is a point-iterative method to reduce the two-dimensional divergence in a wind field.

We consider the vertically integrated continuity equation and specified the divergence \(D(i, j)\) at each grid point as

\[
\frac{\partial(hu)}{\partial t} + \frac{\partial(hv)}{\partial t} = D(i, j)
\]

where the time variation of the inversion base above topography, \(\frac{\partial h}{\partial t}\) is small in comparison with other spatial variations. Here \(u\) and \(v\) are the \(x\) and \(y\) mean wind velocity component within the mixed layer below the inversion base. As a starting point, a first guess of the surface wind field is interpolated from the measured data using inverse distance-squared weighting.

The initial mean wind velocity within the mixed layer is computed from the interpolated surface wind field using the profile by the power law. The final step is to adjust the flux field of Eq. 3.3.2-1 with the objective of reducing \(D(i, j)\). To remove the divergence at a grid point, alterations are made to the \(u\) components at the neighboring points of \(x\) direction and to the \(v\) components at the neighboring points of \(y\) direction. These alterations are made equal and of opposite sign. Thus, the entire grid must be scanned iteratively in order to uniformly reduce the divergence and this procedure proceeds until all values of \(D(i, j)\) are less than some small value \(\epsilon\).

(2) Atmospheric dispersion and deposition

This model uses a puff dispersion model to predict the advection and diffusion of airborne releases. The puff model can simulate the instantaneous plume picture by a proper distribution of puffs of different sizes. Within an individual puff, the distribution of material is hypothesized to follow the Gaussian form:

---

![Fig. 3.22 Schematic of the LSPUFF model capabilities and their interrelationships.](image-url)
\[ \chi(x, y, z, t) = \frac{Q(t)}{(2\pi)^{3/2} \sigma_x(t) \sigma_y(t) \sigma_z(t)} \exp \left\{ \frac{-(x-x_0(t))^2}{2\sigma_x^2(t)} + \frac{(y-y_0(t))^2}{2\sigma_y^2(t)} + \frac{(z-z_0(t))^2}{2\sigma_z^2(t)} \right\} \times \left[ \exp \left\{ \frac{(z-z_0(t))^2}{2\sigma_z^2(t)} \right\} + \exp \left\{ \frac{(z+z_0(t))^2}{2\sigma_z^2(t)} \right\} \right] \] (3.3.2-2)

in which \( \chi(x, y, z, t) \) is the concentration at the point \((x, y, z)\); \( Q(t) \) is the total material in the puff; \( \sigma_x(t), \sigma_y(t), \sigma_z(t) \) are standard deviations of the Gaussian distributions in the horizontal and vertical directions, respectively; \( x_0(t), y_0(t), z_0(t) \) are coordinates of the center of the puff. Eq. 3.3.2-2 includes total reflection at the ground surface and assumes that alongwind and crosswind diffusion of the puff are equal. The horizontal locations \((x_0(t), y_0(t))\) of each puff center are determined by computing their advection for a finite time step using interpolated winds. These winds are computed by spatial interpolation between the puff center and the surrounding grid points and temporal interpolation between winds at the last and next observation times. The vertical location \( z_0(t) \) is the release height above the ground. The presence of high terrain can result in a high dose due to the receptor on terrain being closer to the puff. To account for such situation the height correction for \( z_0(t) \) is assumed by the method suggested by Egan.\(^{33}\)

The terms, \( \sigma_x \) and \( \sigma_z \), which define the growth of the puff depend on the intensity and scale of the turbulence. In this model we apply the theory of relative diffusion given by Smith and Hay\(^{34}\) to calculate the growth rate of the puff. They proposed

\[ \frac{d\sigma}{dx}_{\text{max}} = \frac{2}{3} \beta \rho^2 \] (3.3.2-3)

which is representative of the maximum growth rate, where \( \rho \) is the intensity of turbulence; \( \beta \) is the ratio of Lagrangian to Eulerian scales of turbulence and \( x \) is the downwind distance. Eq. 3.3.2-3 becomes \( \sigma = 0.22 \rho x \) with the relation by Wandel and Kofoed-Hansen.\(^{35}\) To a close approximation the values of the standard deviation of wind direction represent the intensity of turbulence \( \rho \). These standard deviations can be obtained from the sensitive vane.

Concentration distributions from a given source can be evaluated in this model by the convolution of the piecewise constant emissions, \( Q_{m-n+1} \), with integration of a Gaussian kernel Eq. (3.3.2-2) evaluated over periods of release duration \( dt \):

\[ C(x, y, z, t) = \sum_{n=1}^{\infty} Q_{m-n+1} \int_{m-1}^{m} \int_{t'} \chi(x, y, z, t-t') dt' \] (3.3.2-4)

The methods used in this model to predict dry deposition from the atmosphere are based on the concept of deposition velocity and the source depletion model.\(^{36}\) The limitations of the source depletion model have been discussed by various authors,\(^{37}\) but it normally remains valid for the spatial area of interest in this model. The removal of material by wet deposition is evaluated using the washout coefficient defined as a function of precipitation rate.

(3) Dose calculation

The estimates of external gamma-dose from a passing plume require the spatial integration over complex plume geometries when the plume dimensions are of the order of the mean free path of gamma radiation or smaller. Therefore the method of plume-shine calculation must coincide with the spatial model of atmospheric dispersion. It is recognized, however, that the numerical integration of radionuclide concentration requires extensive computation time. This model adopts the isotropic cloud approximation based on the unpublished work by Gamertsfelder\(^{38}\) and provides simplified solutions of dose equations instead of integrals in graphical form in Meteorology and Atomic Energy\(^{39}\) to reduce the running time.
The external gamma-dose rate to the receptor \((x, y, z)\) from the cloud is given by

\[
D_r(x, y, z, t) = K\mu \varepsilon E_r \int_0^\infty \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} B(\mu r) e^{-\mu r} \frac{1}{4\pi r^2} x(x', y', z', t) dx' dy' dz' \quad (3.3.2-5)
\]

in which \(K\) is the dose conversion factor; \(E_r\) is the photon energy; \(B(\mu r)\) is the dose buildup factor; \(\mu\) is the energy absorption coefficient in air; \(\mu\) is the linear attenuation coefficient in air; \(x\) is the concentration at the source \((x', y', z')\); \(r\) is the distance from the source to the receptor, \(r^2 = (x-x')^2 + (y-y')^2 + (z-z')^2\). A single puff formula, Eq. 3.3.2-2 is used as \(x\) to integrate Eq. 3.3.2-5. With the assumption of a power function representation of the dose buildup factor, \(B(\mu r) = 1 + \sum_{n=1}^\infty \kappa_n (\mu r)^n\), Eq. 3.3.2-5 for an isotropic cloud \((\sigma_n = \sigma = \sigma)\) can be written as:

\[
D_r = \frac{K\mu \varepsilon E_r Q}{2(2\pi)^{3/2}} (I_0 + \sum_{n=1}^\infty k_n I_n) \quad (3.3.2-6)
\]

where

\[
I_n = \frac{\mu^{n-1}}{\sigma} \int_0^\infty \frac{r^{n-1} e^{-\mu r}}{m} \left[ \exp \left( -\frac{(m-r)^2}{2\sigma^2} \right) - \exp \left( -\frac{(m+r)^2}{2\sigma^2} \right) \right] dr \quad (3.3.2-7)
\]

and \(m\) is the distance from the center of the puff to the receptor. While value of \(I_0\) can be

![Comparison of the LSPUFF model solutions with the Strenge's numerical solutions.](image)

**Fig. 3.23** Comparison of the LSPUFF model solutions with the Strenge's numerical solutions.
determined by numerical integration technique such as the formula by Takahashi and Mori\textsuperscript{40),}
the solution of $I_n(n>0)$ is straightforward in terms of the error function. Since the error
function is available in computer software, the solution of these integrals allow rapid estima-
tion of external gamma-dose rate.

The preceding equations are applied to an isotropic cloud ($\sigma_x = \sigma_y = \sigma$). Since the real
diffusion of material results in a nonisotropic formulation, we adopt the method of correction
for a nonisotropic cloud which is to use an average value of $\sigma$ given by $\sigma = (\sigma_x \sigma_y)^{1/2}$. This
puff model which incorporates the isotropic cloud approximation has been successfully
tested against the finite cloud dose rate factors for the Gaussian plume model given by Strenge
et al.\textsuperscript{41) Figure 3.23} shows a comparison of Strenge's numerical solutions for centerline plume
dose rate factors with those from the puff model for three Pasquill stability classes, B, D and
F. The agreement is good for each stability class.

(4) Limitations and extensions

The method presented here has some limitations. The important problem is how the
wind vectors used to determine the advection of the center of a puff should be estimated
in complex conditions, including nonuniform topographical features and sea breeze circula-
tion. Although this model adopts the mean wind vector within the mixing layer, the advection
of the center of a puff should be calculated by the mass-weighted mean wind vector. As
suggested by Sheih\textsuperscript{42), the wind shear is an important factor in determining concentration
distributions and should not be neglected. However, we need some more information on
vertical meteorological conditions to simulate the above effect.

Finally, for the unlikely and rapid release of all or a large fraction of volatile fission
products, the plume rise can result in significantly lower predicted values of downwind radiation
exposures. The estimates of plume rise will be incorporated in the present puff model.
4. System Capability of Emergent Response

4.1 Availability of Input Data

4.1.1 Meteorological Data

The reliability of the results of SPEEDI depends greatly on the quality and the quantity of the meteorological data used in the calculation. The requirement for the quantity of meteorological data are different among the physical models. The simplest model requires only the single wind data and the atmospheric stability at the site. The three dimensional models or the long range transport models require greater amount of meteorological data in order to make use of their full capability, though they are programmed so that they can fulfill their calculation with only a set of site data.

The sources of meteorological data available to SPEEDI are as follows,

1) site observation,
2) AMeDAS (Automated Meteorological Data Acquisition System),
3) local meteorological network operated by local governments,
and
4) other data sources.

Every nuclear plant observes various meteorological elements such as the wind speed and direction at the top of the stack, temperature and its lapse rate, insolation and net radiation. The meteorological data at the site are especially important, because they determine the distribution of radioactive materials in the vicinity of the site, where the maxima of concentration and surface dose take place. The meteorological data of site are usually collected by a minicomputer in the plant, together with the monitoring data for environmental radiation. They could be used in SPEEDI, if a link is established between the minicomputer and the SPEEDI host-computer with an agreement of the nuclear power plant.

AMeDAS has a dense network of the automated meteorological stations all over Japan. The average spacing between the stations is about 20 km. Wind speed and direction, temperature, insolation and precipitation are measured hourly, and the data are assembled to the AMeDAS center in Tokyo through telephone lines. These data are open to the public, and they can be obtained within the thirty minutes after each observation, if a link is established between the user's computer and the minicomputer of Japan Weather Association, which is in charge of distribution of the data. Several tens of the AMeDAS stations exist in the regional scale (200 km X 200 km) computation of SPEEDI, and they supply a sufficient amount of surface wind data to the regional transport model. As for the local scale (50 km X 50 km) computation, five or six AMeDAS stations are usually available.

Many local governments maintain their automated local meteorological and air quality monitoring stations. Some of the meteorological stations are set up as a part of monitoring for environmental radiation and the others are set up for air quality monitoring. Surface wind is observed at the most of the stations, and the data are assembled to the monitoring center hourly. Insolation and precipitation are also observed at some of the stations. The spatial density of the stations has variety among the networks of different local governments, and the distribution of the stations are not uniform. However they are valuable for the calculation over the local scale, because they fill up the sparse area between the AMeDAS stations. These data can also be used in SPEEDI, if a link is established between the monitoring center of each
local government and the SPEEDI host-computer. In the last group are included the observations conducted by the Ministry of Construction, fire office and/or other organization. Some of them are located in the sparse area of the present meteorological network. At these stations, data are not monitored either continuously or periodically. For this reason, it is not easy to use these data. However, if we construct a certain special network, these data will be available within a short time.

Most of the present meteorological data mentioned above are those of surface observation. In order to use the three-dimensional models in SPEEDI effectively, observations in upper layers (up to several hundreds of meters) are desirable. The upper wind data and the data of the atmospheric stability in upper layers are especially important, which largely affect the surface concentration and the dose. Additional surface stations are also required in some regions where the topography is complex, where an observed wind is only the representative of small area. Furthermore, intensity of the atmospheric turbulence, which directly affects the atmospheric diffusivity, is not monitored in the present status. The verification study of three-dimensional models (Section 3.2.2) implies that the inclusion of these data improves the precision of the results quite well. In order to obtain these data, special meteorological stations should be built around the nuclear sites. An example of the distribution of the meteorological stations around TOKAI site in Ibaraki-ken, where JAERI and other nuclear facilities locate, is shown in Fig. 4.1. Distribution of the AMeDAS stations are also shown in Fig. 3.12.

4.1.2 Source Term

(1) Outline of methods for release estimation

Data as source terms are critical in estimating the concentration and the dose from its radioactive cloud, and linearly affect the results of these in general. In the SPEEDI code system, every radioactive nuclide name and its release rate as source terms are expected to be received from a nuclear accident site. Such a detailed information as source terms, however, could not be obtained during early periods after the accident should occur. In such case, if a total amount of release rate of noble gas is only known as source terms, it is impossible to determine photon energy and decay constant for dose calculation. For this reason, the SPEEDI system has a program to estimate the isotopic composition of noble gas and iodine as a function of reactor type, i.e., BWR or PWR, and burnup data depending on the operational history of a reactor.

The following input types of release data as source terms are considered by SPEEDI.

Mode 1: Either the total amount of release rates in noble gas or iodine (unit: Ci/hour) is inputted, or release rate of a dominant nuclide. This mode is utilized in the case where each isotopic fraction of noble gas or iodine is unavailable.

Mode 2: As to noble gas, the readings of an ionizing chamber as a stack monitor that is modified by geometrical efficiency is inputted, and about iodine the total release rate of $^{131}$I that may be dominant among its isotopes is put in.

Mode 3: Each release rate of all the isotopes in noble gas or iodine is inputted in order of mass number.

Mode 4: The release rate of a nuclide is inputted, which can be selected among 56 nuclides including such fission products as $^{137}$Cs and $^{90}$Sr. etc. This mode is also utilized for calculating a single nuclide of noble gas or iodine.

In mode 1 and 2, the estimating routine of isotopic composition of noble gas or iodine is used. In SPEEDI, the isotopic composition of release rate of noble gas or iodine is estimated based on the following assumptions.

i) The same isotopic composition as a reactor inventory at shutdown time might be released
into the atmosphere. Separation of a particular isotope from other ones could not be performed by the isotope effect such as physisorption or chemisorption, which is caused by the difference among energy states of nuclei.

ii) The values of isotopic composition at shutdown time are based on burnup calculation considering reactor type of BWR and LWR.

(2) Estimation methods of release rates

The release rate of each nuclide in noble gas or iodine adjusted to reactor shutdown time, considering isotopic composition and radioactive decay, is estimated by the following equations.

Mode 1: In case of total amount of release rates,

\[ Q_i = \frac{Q}{\sum f_i \cdot \exp(-\lambda_i \tau)} \cdot f_i \]  (4.1.2-1)

where

- \( Q \) = total amount of release rate,
- \( f_i \) = isotopic fraction at reactor shutdown,
- \( \lambda_i \) = decay constant of a nuclide \( i \),
- \( \tau \) = duration between shutdown and measurement of a crude release rate,
- \( Q_i \) = adjusted release rate of a nuclide \( i \).

In case of a dominant nuclide \( k \),

\[ Q_i = \left( Q_k / \exp(-\lambda_k \tau) \right) \cdot (f_i / f_k) \]  (4.1.2-2)

where

- \( Q_k \) = release rate of a dominant nuclide \( k \).

Mode 2: The exposure rate (mR/hr) measured with an ionizing chamber as a stack monitor is proportional to absorbed energy in air. Let \( K_o \) (mR/hr)/(Ci/m³) denote the measured value of a specified noble gas having unit concentration. \( K_o \) usually shows the characteristics of an ionizing chamber. The following relation is derived from the proportionality of absorbed energy in air measured with the same monitor.

\[ R / K_o = \left[ \sum p_i \cdot q_i \cdot \exp(-\lambda_i (t - t_0)) \cdot E_{f_i} \cdot \mu_{en}(E_{ao}) / \rho \right] / \left( E_{f0} \cdot \mu_{en}(E_{ao}) / \rho \right) \]  (4.1.2-3)

\[ q_i = p_i \cdot q_r \]  (4.1.2-4)

where

- \( R \) = exposure rate,
- \( p_i \) = isotopic fraction of a nuclide \( i \) at shutdown,
- \( q_i \) = concentration of a nuclide \( i \) at shutdown,
- \( q_r \) = total concentration of noble nuclides at shutdown,
- \( t \) = time when exposure rate is measured,
- \( t_0 \) = shutdown time,
- \( E_{f_i} \) = effective photon energy (MeV/dis),
- \( E_{ao} \) = average photon energy (MeV/photon),
- \( E_{f0} \) = effective photon energy of a specified nuclide,
- \( E_{ao0} \) = average photon energy of a specified nuclide,
- \( \mu_{en} / \rho \) = mass energy absorption coefficient.

The effective photon energy and average photon energy of a nuclide \( i \) are expressed, respectively, as

\[ E_{f_i} = \sum_j (f_{ij} \cdot E_{ij}) \]  (4.1.2-5)
where

\[ E_{ij} = j \text{ photon energy emitted by a nuclide } i, \]
\[ f_{ij} = \text{intensity of a photon } j \text{ per disintegration of a nuclide } i. \]

By combination of the equations from Eq. 4.1.2-3 to Eq. 4.1.2-6, \( Q_i \) is obtained, by which the release rate needed in dose calculation of SPEEDI is given as

\[ Q_i = (p_i \cdot q_i) \cdot w \]

\[ \cdot \left( \frac{R}{K_0} \right) \cdot \frac{\mu_{en}(E_{g0})/\rho}{\left( \sum \rho_i \cdot \exp\left( \lambda_i(t-t_0) \right) \cdot E_{f1} \cdot \mu_{en}(E_{21})/\rho \right) \cdot w}, \]

where

\[ w = \text{exhaust volume in hour of stack (m}^3/\text{hr).} \]

(3) Isotopic composition

1) Effects of variation in reactor output

In the SPEEDI system, the isotopic composition of noble gas or iodine is employed to evaluate the release rate of each nuclide as source terms using a total amount of these nuclides or measured valued with stack monitors etc. The isotopic composition is obtained based on the assumption that a reactor shutdown should occur immediately after the rated output had gone on with average burnup of the reactor core. It is, however, likely that the output of a reactor may change to some extent by the event that might be related with the accident. The inventory of noble gas or iodine markedly depends on the operational history of a reactor shortly before its shutdown, since the half-lives of many nuclides among noble gases or iodines are less than a few days. The effects of variation in reactor output shortly before shutdown on the evolution of isotopic composition following it had been analyzed by the NICCA code for calculating the activity of fission nuclides normally accumulated in fuel rods.\(^{43}\) When the calculation is carried out based on the assumption that the shutdown should occur immediately after the continuation of rated output, the isotopic fraction of nuclides with longer half-lives was largely underestimated and that with shorter ones was overestimated in comparison with the results obtained considering the variation in reactor output shortly before the shutdown. From the standpoints of dose evaluation, it was found that the external exposure to total noble isotopes was estimated to be at most approximately 20% higher 10 hour immediately after the shutdown, but the thyroid dose to total iodine isotopes was underestimated to be 30% at maximum.

Generally speaking, it became obvious that the external dose from total nuclides was overestimated with no consideration for the variation of reactor output shortly before the shutdown, and that the error of the dose evaluation increased with reduction of reactor output and decreased with both its duration and time after the shutdown. On the other hand, the thyroid dose from total isotopes of iodine was more largely underestimated by increasing reduction rate of reactor output and its duration, and in the same way as noble nuclides decreased with time after the shutdown, since the fraction of \( ^{131}I \) among iodine exerted a large influence on the dose evaluation.

2) Effects of buildup of nuclides after shutdown

In the methods described in the subsection (2), we do not consider the buildup of the isotopes that are produced by the decay chains of other fission products. Particularly, concerning the isotope of iodine, \( ^{132}I \), produced by the \( \beta \) decay of a fission nuclide \( ^{132}Te \), its isotopic fraction among iodine is much different from that in the case of no consideration for the buildup from its parent nuclide. The contribution of \( ^{131}I \) among iodine for thyroid doses
due to the inhalation of unit activity, however, occupies 83% but that of $^{132}$I dose only 0.49%. For this reason, the effect of the buildup of $^{132}$I from its parent nuclide may be small from the viewpoint of dose evaluation. However, whether to consider the buildup of the isotopes that are produced by decay chains may be attributed to the behavior of fission products in a reactor until atmospheric release.

4.2 Operational Tests

4.2.1 Expected Response

The primary data essential in the calculation of SPEEDI are the meteorological, release and geographical data. In general, the efforts will be made for the acquisitions of these data in the first stage. The geographical data of all sites in Japan are already stored in the system, and even when an unexpected area experiences an accident, a new topographical datapool can be built in about thirty minutes by the extraction from the master data base which has been developed by the Land Agency of Japan. Meteorological data are obtained through the AMeDAS system and the observation systems of local governments. Because these data are observed in routine work, the locations of measuring points can be stored in the SPEEDI system beforehand. In the case that several observed data, upper air observation data, etc., are supplied in the emergency, the addition of locations will be performed within five minutes. The temporal data are the observed meteorological data and the source information. The SPEEDI system has no data transmission media in the present stage and the data must be manually entered into computer files. The time lag concerning this work will become an obstacle against the quick response. In the practical stage, the data transmission media connected with the meteorological data observation systems such as the AMeDAS and the observation systems of local governments will be established by telephone lines, radio and microwave and so on. Even when the transmission system are settled, the time lag from the observation at each point to the acquisition will remain in about twenty minutes for AMeDAS and ten minutes for each local government. About the source information, the possibility to obtain the data in real-time depends on the nature of an accident. Almost all stack monitors currently used are only effective to the noble gas, so the release rate of iodine may not be immediately available.

For these circumstances, if the data can be obtained through the computer link and SPEEDI can monopolize a processor of the host computer system, the effort to make the geographical and meteorological data available to SPEEDI will become very small. Even when the accident occurs at an unexpected area, the preparation of SPEEDI's response will be established within one hour. It may take much time to get the effective meteorological data obtained from extra observations.

After the preparation, the types of the operation will be categorized into two. The first case is that the emission of radioactive materials into the environment is anticipated, where the SPEEDI's staffs have a plenty of time to prepare for the response before the accidental release. From the initial stage, the SPEEDI system will be able to perform the real-time and forecasting simulations according to normal procedure. The exercise of operation with the field experiment, which will be mentioned in the next sub-section, is one of the examples in this case.

The second case is that several hours elapsed between the beginning of release and the activation of SPEEDI. The SPEEDI system will respond with the calculation of the dose distribution since the start of the release, and after that it comes up to real-time and forecast simulations as soon as possible. And it will take one or two hours for the calculations to
overtake real time. The estimation of the time does not, of course, involve the delay time caused by human failures which may occur in the chaotic condition in emergency facilities. After these works, calculations will be made for the simulation including the forecast of dose distribution two or three hours hence. In any way, it is desirable for the staffs to experience many types of exercises.

4.2.2 Exercise with the Field Experiment

The exercises of real-time response were carried out in the series of field experiments in 1983. The method of experiment was almost the same as that of experiment in 1982 mentioned in subsection 3.2.1.

Geographical data of Tokai site are already stored in the system as one of the service sites. The meteorological data were obtained by telephone from the air-pollution-control center of Ibaraki-ken and by the acoustic sounder deployed in JAERI site. Figure 4.2 shows the locations of meteorological measuring system. The system of local government measured the wind direction and speed at the height 10 m and the acoustic sounder measured the vertical profile of wind speed, wind direction and the standard deviation of wind direction. These data were acquired at intervals of one hour to the SPEEDI system. The time lag of data acquisition to the SPEEDI system was about fifteen minutes after the real-time observation. After the acquisition, meteorological data, including the location of meteorological measuring system, were stored in the data file within three minutes. Data concerning the nature of release were obtained by telephone from an experiment control center. Therefore the total time lag between the start of real-time prediction and the meteorological observation was about twenty minutes.

In this section, the exercise on Run 5 is described as an example. The progress with time of real-time response on Run 5 is shown in Table 4.1. The release started at 1000 JST (Japanese Standard Time) on 4th August and continued three hours. The operation of the SPEEDI system started at 0950 JST. In the first ten minutes till the release started, the initial conditions were set by the SITE, TIME and REL commands. After making the meteorological datapool of 1000 JST, the prediction of the average concentration for one hour from 1000 to 1100 JST was performed by the WIND04 code and the PRWDA code. Till the next meteorological data were inputted, the rest time was utilized to the graphic output. These procedures were repeated three times till 1300 JST. Temporal data essential to the calculation were inputted as the operands of the SITE, TIME, REL, WIND and CONC commands. The input variables supplied to the SET command were only the cell size, in this case 500 m X 500 m X 25 m was applied, and the IBL data to the PRWDA code was obtained from the standard deviation of wind direction.

These exercises were performed in the time sharing system of JAERI computing center, so the SPEEDI system did not monopolize the processor. For this reason, the computation time to obtain the results depended on the congestion of jobs in the computer system and the average for one response-operation was about forty-five minutes. If the SPEEDI system has the highest priority for use of the vector processor in JAERI, the output can be obtained within three minutes.

The graphic outputs of the SPEEDI system were handed to the researcher who was engaged in experiments and were utilized for the planning of next sampling. The typical outputs of wind field and concentration distribution are shown in Figs. 4.3 and 4.4. The overlay map of Fig. 4.4 shows the shoreline and roads. Although the outlook of Figures are the same as the examples of the system output in sub-section 2.2.3, the unit of concentration contours is not (Ci/m^3) but (ppt).
Fig. 4.1 Distribution of the various kind of meteorological stations around Tokai nuclear site. Solid squares are site observations, dots are AMeDAS stations and the triangles are local network operated by the local government.

Fig. 4.2 Location of meteorological measuring system which supplied data to SPEEDI in real time.
Fig. 4.3 Typical output of wind field at 125 m from the sea level in real-time response tests.

Fig. 4.4 Typical output of concentration distribution on the ground level in real-time response tests.
### Table 4.1 Progress with time of real-time response

<table>
<thead>
<tr>
<th>Time</th>
<th>Experiment</th>
<th>Acquisition of meteorological data</th>
<th>Output of SPEED1</th>
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<td>(10:19)</td>
<td>Start (9:50)</td>
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<tr>
<td>11:00</td>
<td>Sampling</td>
<td>(11:17)</td>
<td>Initial data set</td>
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<td></td>
<td>(11:30)</td>
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<td>Observed wind data (10:30)</td>
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<td>3-D wind field (10:45)</td>
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<td></td>
<td></td>
<td>Concentration (10:59)</td>
</tr>
<tr>
<td>12:00</td>
<td>Sampling</td>
<td>(12:15)</td>
<td>3-D wind field (11:35)</td>
</tr>
<tr>
<td></td>
<td>(12:30)</td>
<td></td>
<td>Concentration (11:52)</td>
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<tr>
<td></td>
<td>The end of release</td>
<td></td>
<td>Observed wind data (12:20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Concentration (12:41)</td>
</tr>
</tbody>
</table>
5. Conclusion

The ultimate goal of the development of SPEEDI is to complete a practical computer code system for rapid calculation of the various information on radiation levels and radioactive concentration under the situation of accidental release from nuclear facilities. From this point of view, the design and development of SPEEDI have been carried out, and the final version has completed, which satisfies the practical needs for the application to the national service network system for real-time estimation and prediction in an emergency situation.

At a starting point of the design of this code system the next three basic requirements were taken into accounts. These are: (1) to have modular code structure, (2) to have versatile datapool system and (3) to have functions for colour graphics and hard copy for easy understanding of output. In the present version of SPEEDI these all requirements have been realized successfully.

The first aim of development of SPEEDI is at the preparation for the countermeasures against accidental release especially in the early phase of release. Therefore, SPEEDI should perform the real-time analysis and prediction calculation in a reasonably short time and has to provide information with adequate reliability.

In the case of our large-scale computer FACOM M-380 the results of doses can be obtained within less than 10 minutes in sequential calculations, and by the use of a new vector processor VP-100, which has been recently introduced to JAERI, the computation time has been further reduced within a few minutes. Furthermore, SPEEDI has two calculational modes of local scale of within 25 km and regional scale of up to 100 km from a facility, and the evaluated domain can be selected depending on the magnitude of the consequences of the accident.

The necessity of capability of the long term evaluation is often discussed to obtain the information for making a decision of evacuation from and re-entry to the contaminated area after an accidental release and also, the propriety of the range of evaluation area is frequently discussed relating to the emergency planning zone (EPZ) which may be set in a range of 8-10 km from a nuclear plant in Japan. But in case of SPEEDI we have basically designed the system to cover the time range till an accidental release of radioactive materials become substantially controlled, and to select the evaluation area flexibly taking into account the scale of accident and meteorological condition regardless EPZ.

The verification of various physical models used in SPEEDI has been continued by comparison studies using actual concentration and meteorological observation data obtained from SF6 gas tracer field experiments. The comparisons showed that the coastal typical diffusion phenomena under the presence of an internal boundary layer could be well simulated by using calculation models provided in SPEEDI. On the other hand, in order to clarify the feasibility of the wind field model to the site in the complex terrain the field experiments have been carried out around the isolated mountain mass since 1983 and the comparison of experiment and calculation has been continued using actual data on wind flow, concentration distribution and trajectory of non-lift balloon. On the basis of these comparisons we can conclude that SPEEDI gives an effective information on environmental radiation in the vicinity of the plant, though these models are being verified for application to the diffusion in regional scale with complex terrain beyond the range of 10-15 km from a release point.

There are many problems to be solved and clarified hereafter; they are, for example,
(1) verification of the wind field model on the site of wide and complex terrain mentioned above, (2) the sensitivity study using field experimental data for optimum deployment of meteorological observatory network and (3) survey of site specific conditions of each nuclear plant and evaluation of feasibility of models to their sites.

SPEEDI should essentially be given the effluent rate and amount of radioactive materials from the plant. However, considering the case that the source information cannot be offered rapidly both from monitoring and accidental analysis especially in early stage of accident, SPEEDI has a simple program for estimation of the relative nuclear fraction of effluent radioactive materials.

One of the most important problems for the practical use of SPEEDI is how to obtain and evaluate the input source data for quantifying the calculated results. Hereafter, we consider that we should develop a method for estimation of source terms as input data to SPEEDI by calculation and by emergency survey for measurement of environmental distribution of gamma exposure and radioactive concentration. Furthermore, we think that it is also very important to develop a practical method for comparison and adjustment of calculated results with measurements. By the establishment of cooperation between environmental monitoring and predicted calculation, SPEEDI will function as a versatile system for emergency environmental countermeasures.

Now the development of SPEEDI has arrived at the final stage and a new plan is arranged for practical application to the emergency preparedness, that is establishment of central computing facilities and automated data acquisition network system which collects radiological monitoring and meteorological observation data around 14 nuclear plant sites in Japan. For the establishment of emergency advisory system in Japan this new program starts from FY 1985 and is expected to be completed in a few years.
Acknowledgements

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Members of JAERI Computing Center who programmed some software utilities of SPEEDI.
Publication List on SPEEDI

References


Appendix

Appendix 1: WEADUS, WEADUS2

a. WEADUS

In the present status, SPEEDI has no software such as an automated data acquisition and update of weather datapool. WEADUS, i.e. Weather Data Update System., is a computer program which creates and updates the weather datapool by manual input of meteorological data from a character display terminal. WEADUS has following functions,

1) creation of weather datapool,
2) registration of additional stations,
3) input and rearrangement of the meteorological data,
4) supplement of the meteorological data,
5) display of site data,
6) display of data of each station, and
7) display of meteorological data at each time.

When meteorological data is given in form of a sheet, they can be inputted by the function 3. If the meteorological data are not obtained at some stations, we may input -999 instead of the observed data and may make input the appropriate values lately by the function 4. When some stations are additionally set up during an accident, those stations are registered in the weather datapool by the function 2. The stored data can be checked by the function 5 to 7.

b. WEADUS2

In addition to the functions of WEADUS, WEADUS2 has a function of forecasting the wind vector up to six hours ahead at each meteorological station. When a set of wind data is made input, WEADUS2 checks these data in the statistical way at first. If the abnormal data are found, they are replaced by -999, which implies no data. Then WEADUS2 predicts the hourly wind vector at each station up to six hours ahead by a statistical prediction method.

Appendix 2: RGONDP

RGONDP is a software that creates the regional datapool at any site in Japan. The SPEEDI system already has complete regional datapool for every nuclear site in Japan. However a nuclear accident may take place at an unexpected site. A typical accident of this class is the one during the transportation of radioactive material. In such a case, regional datapool around the place of accident must be created immediately.

(1) Master data

The master data have been offered by the Land Agency of Japan. These data contain the data of the terrain height, coastlines, lakes, administrative boundaries, roads, railroads and the land uses. The terrain height data are obtained at every 250 m X 250 m grid point. The whole data are arranged according to the three different scales of mesh. The first mesh covers the area, which longitudinal width is one degree and the latitudinal width is forty minutes. The second mesh divides the first mesh into 8 X 8 area. The third mesh divides the second mesh into 10 X 10 area.
(2) Site specification
The range of the region that the regional datapool covers is specified by the following parameters,
   a) latitude and longitude of virtual origin of the map,
   b) the position of southwest corner of the region,
   c) south-north and west-east lengths of the region and
   d) mesh number of the south-north and west-east direction.
The relation of these data are illustrated in the Fig. A.1.

(3) Data conversion
The master data are arranged in the latitude and longitude, whereas the regional datapool is referred to the local cartesian coordinates. The master data should be converted into the local cartesian coordinates. Among many conversion methods, RGONDP prepares the rectangular projection method, the conical projection method and the stereographic projection method. The line data such as the coastlines and the administrative boundaries are simply computed by the conversion of the coordinates of the points. However the spatially averaged data such as the mean height of a unit mesh of terrain should be converted with the consideration of the difference of the mesh size. In general, the mesh of regional datapool does not coincide with the mesh of master data. The basic concept of the data transformation is described by Tabei et al. (1981)*. A typical example is illustrated in Fig. A.2. Not only the mesh size but also the direction of coordinates differ, because of the effect of spherical surface of the earth. The mean height of unit mesh of regional datapool is computed with the weight of the area of the associated master mesh.

(4) Data processing
The general flow of the data processing is shown in Fig. A.3. At first, the first mesh numbers of the master data which contains the data of the interested area are selected, and

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* Tabei et al. (1981)
the necessary data are copied on the magnetic disk from master magnetic tapes. Then, the data are rearranged into the local cartesian coordinates and are stored in the regional datapool. A new datapool is created within thirty minutes in the normal operation of JAERI computing center.

Fig. A.2 Mesh data transformation using the concept 'Shared Area' (after Tabei et al.).

Fig. A.3 Data processing flow.
The contents of the ICT1 of SPEEDI is listed in Table A.1.

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