JAERI-Research
2002-004

JP0250148

STUDY ON A NEW METEOROLOGICAL SAMPLING SCHEME DEVELOPED FOR THE OSCAAR CODE SYSTEM

March 2002

Xinhe LIU*, Kenichi TOMITA and Toshimitsu HOMMA

日本原子力研究所
Japan Atomic Energy Research Institute

本レポートは、日本原子力研究所が不定期に公刊している研究報告書です。
入手の問合わせは、日本原子力研究所研究情報部研究情報課（〒319-1195　茨城県那珂郡東海村）あて、お申し越し下さい。なお、このほかに財団法人原子力弘済会資料センター（〒319-1195　茨城県那珂郡東海村日本原子力研究所内）で複写による実費頒布を行っております。

This report is issued irregularly.
Inquiries about availability of the reports should be addressed to Research Information Division, Department of Intellectual Resources, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken 〒319-1195, Japan.

編集兼発行　日本原子力研究所

Study on a New Meteorological Sampling Scheme Developed for the OSCAAR Code System

Xinhe LIU*, Kenichi TOMITA and Toshimitsu HOMMA

Department of Reactor Safety Research
Nuclear Safety Research Center
Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

(Received January 31, 2002)

One important step in Level-3 Probabilistic Safety Assessment is meteorological sequence sampling, on which the previous studies were mainly related to code systems using the straight-line plume model and more efforts are needed for those using the trajectory puff model such as the OSCAAR code system. This report describes the development of a new meteorological sampling scheme for the OSCAAR code system that explicitly considers population distribution. A group of principles set for the development of this new sampling scheme includes completeness, appropriate stratification, optimum allocation, practicability and so on. In this report, discussions are made about the procedures of the new sampling scheme and its application. The calculation results illustrate that although it is quite difficult to optimize stratification of meteorological sequences based on a few environmental parameters the new scheme do gather the most inverse conditions in a single subset of meteorological sequences. The size of this subset may be as small as a few dozens, so that the tail of a complementary cumulative distribution function is possible to remain relatively static in different trials of the probabilistic consequence assessment code.

Keywords: Probabilistic Safety Assessment, Accident Consequence Assessment, Meteorological Sampling scheme, Stratified Sampling

---

*LIU Xinhe was a visiting researcher from China Institute of Atomic Energy under the auspices of the Science and Technology Agency Scientist Exchange Program.

OSCAARコードシステム用に開発された新しい気象シーケンスサンプリング法の検討

日本原子力研究所東海研究所安全性試験研究センター原子炉安全工学部
劉　新河*・富田　賢一・本間　俊充

(2002年1月31日受理)

確率論的安全評価のレベル3計算における重要なステップの一つに、気象シーケンスのサンプリングがある。従来、これは大気拡散評価に直線プルームモデルを用いたコードについて検討されており、OSCAARのような流跡線パフモデルのコードではより一層の検討が必要とされていた。本報告書では、OSCAARコードシステム用に人口分布を考慮に入れた新しい気象サンプリング法の開発について記した。新サンプリング法の開発に際しては、網羅していること、適切に層別化されていること、最適に配分されていること、実用的であることを基本原則とした。報告書には、新しいサンプリング手法の手順とその適用について議論がなされている。計算の結果、数少ない環境パラメータで気象シーケンスを最適に層別化することは極めて困難であるが、新手法は最も厳しい結果を生じる気象シーケンスを一つのグループの中に集約することができた。このグループに属するシーケンスの数は高々数十なので、確率論的事故影響評価コードシステムの様々な計算においても、この補累積分布関数の末端部分の計算値が比較的安定した結果となる。

*劉新河は、科学技術庁原子力研究交流制度で来日した中国原子能科学研究院からの客員研究員である。
東海研究所：〒319-1195　茨城県那珂郡東海村白方白根2-4

Contents

目　次

1. INTRODUCTION

Probabilistic Safety Assessment (PSA) has become an effective tool for nuclear safety evaluation (CEC, 1994). One major part of a full PSA is termed as Level 3 PSA, which evaluates the off-site consequences resulting from postulated nuclear accidents. Probabilistic Consequence Assessment (PCA) models developed for off-site consequence assessment predict the transport, dispersion and deposition of the released radioactive materials, describe the food chain transfer of these radionuclides, and estimate the radiation doses, health effects and economical cost. The effects are also accounted for various emergency protective actions such as emergency evacuation, temporary relocation, permanent resettlement and agricultural countermeasures. The objective of PCA is the depiction of the full spectrum of the off-site consequences resulting from the severe accidents that are postulated for a nuclear installation of interest (CEC, 1986; NRPB, 1993), in other words, the endpoints should be the magnitude of consequences and their probability of occurrence.

Theoretically, the complete spectrum of the consequences might be acquired by performing consequence assessment for every possible meteorological sequence that would be encountered by the released radioactive materials. However, the number of possible, different meteorological sequences is extremely large and some sequences may have similar off-site consequences. It is neither practicable nor necessary to consider each of the sequences. In fact, a set of meteorological sequences with suitable size is sampled from one or more years' worth of meteorological data.

Usually, sampling methods are broadly divided into two categories: stratified sampling and cluster sampling. In stratified sampling, the universal set is classified into a number of subsets or strata in which the members have similar attributes, and then samples are taken from each of the strata. When samples are chosen randomly from each stratum, the term stratified random sampling is used to refer to the overall sampling plan. If there is only one stratum, stratified random sampling turns into "pure" random sampling. While stratified sampling is associated with classification of the members in the set, cluster sampling is related to the clustering of the population (in statistic sense) or the universal set. In clustering sampling, the population is divided into clusters in such a manner that there is little or no variability between clusters (Winkler and Hays, 1975). Cluster sampling, unlike stratified sampling taking samples from each sub-population, randomly selects one or more clusters from the entire set of clusters. Cyclic sampling method selects specimens with a fixed interval defined in such way that the frequency of sampling is not coincident with the harmonic variation of the variable. Based on the definitions of cluster sampling and cyclic sampling, the latter can be considered as a specific case of the former.

A number of sampling methods or procedures have been developed for choosing representative set of meteorological sequences so as to conduct probabilistic consequence assessment (Painz et al. 1989; Jow et al., 1990; Homma et al. 2000). Cyclic, simple random and stratified sampling techniques are widely utilized in the PCA codes. The original emphasis in this area was on stratified sampling (for example, the sampling method incorporated in the MACCS code system) since it was thought to be able to yield better results than cyclic and simple random sampling. Stratified sampling would have better results if the classification of meteorological sequences had met the objectives of the scheme that members in each group should be similar and the groups themselves should be distinctly different from each other. An ideal stratified sampling scheme may identify rare cases that are associated with the most adverse off-site consequences. Cyclic and simple random sampling schemes tend to sample the more common sequences frequently, whilst overlooking the rare cases. They can only be used for predicting the higher percentiles of the distributions of consequences if a large number of sequences is considered for analysis (CEC, 1990). The different sampling schemes were compared in an international comparison of PCA codes. This comparison suggested that the spread of predictions within a single sampling scheme was greater than the spread between the schemes (Van Wonderen, 1994). The experience with the MARC-2A code of National Radiological Protection Board was rather similar to this phenomenon (Jones et al., 1995). Using the PC COSYMA, Telleria (1997) compared results from a stratified sampling scheme with those obtained using cyclic sampling scheme and found that the cyclic sampling scheme performed better than the stratified sampling scheme. The work of Kim (1998) with MACCS reached the same conclusion. These results suggest that further work on meteorological sampling, especially when calculating consequences at a single point with a trajectory model of atmospheric dispersion, would be justified. Two options for improving the existing sampling schemes have been proposed in: (1) selecting more than one sequence from each of the groups included in the current schemes, (2) defining a larger number of groups of conditions and selecting one sequence from each group (Hausmann et al., 1996).

It should be noted that all the current meteorological sampling schemes used for Level-3 PSA are "pure" meteorological, i.e. they focus on meteorological conditions and do not explicitly consider population distribution. An investigation of consequence variability within the groups categorized by one stratified sampling scheme was made recently using the conventional straight-line plume model of MACCS. The results show that the "pure" meteorological scheme is not capable of stratifying the sequences so as to realize the initial intention of the scheme: classifying the sequences having similar consequences into one group (Liu and Homma, 2001). The variability within a single group is greater than that between the groups (see Figures 1 and 2). Therefore, there must be other environmental conditions that should be embraced by the sequence sampling schemes. The purpose of this study is to design an appropriate meteorological sampling scheme that explicitly considers population distribution for use with the puff trajectory dispersion model used in an accident consequence assessment code, called OSCAAR developed by Japan Atomic Energy Research Institute.

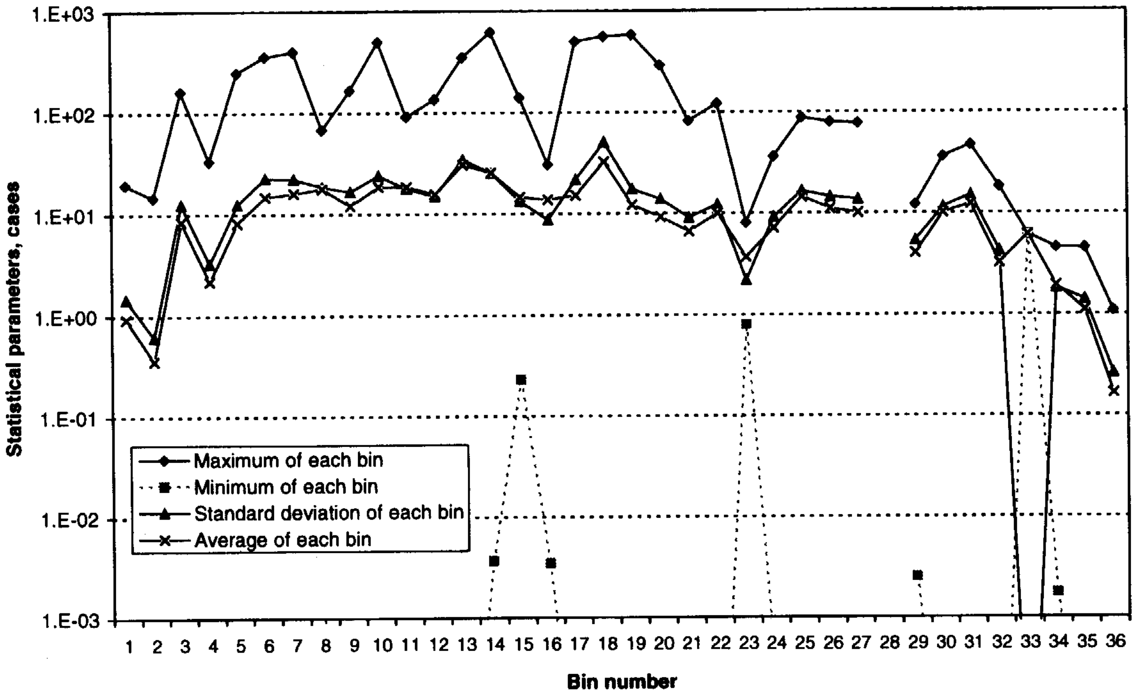

Figure 1. Variation of early fatality estimation results

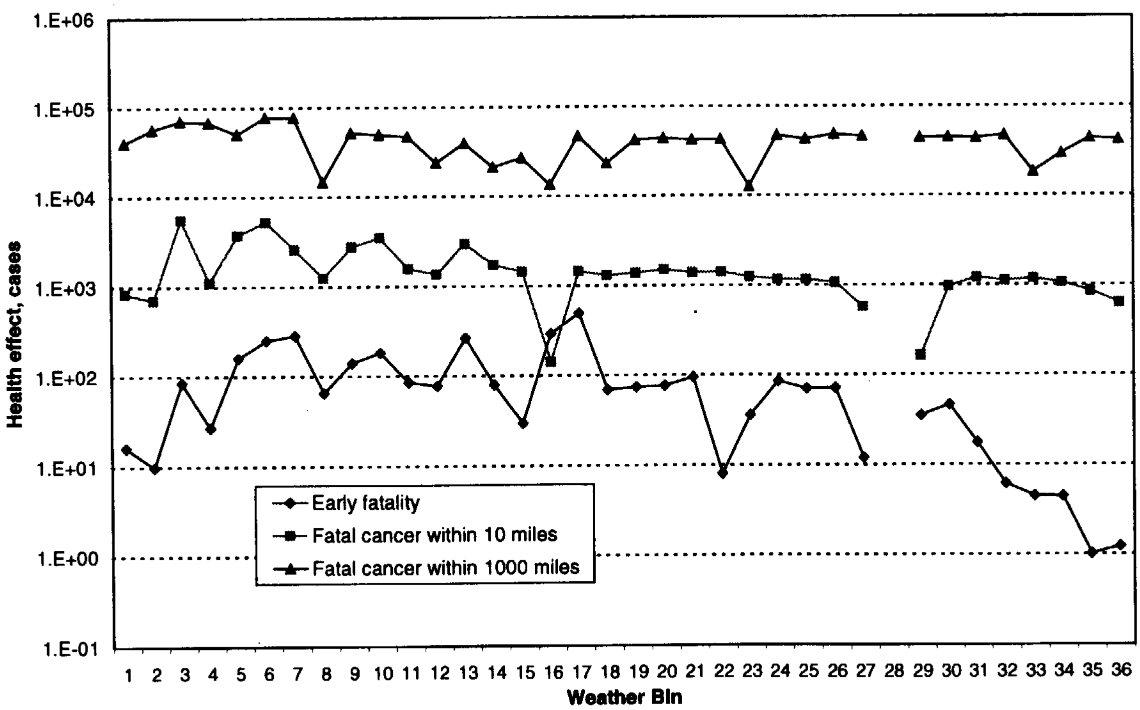

Figure 2. The 99 percentile of health effect estimation for each bin

2. GENERAL CONSIDERATIONS

In developing the new scheme of meteorological sequences for the OSCAAR code, the following issues were contemplated.

A. COMPLETENESS: Because the objective of Level-3 PSA is to describe the complete distribution of off-site consequences due to postulated nuclear accidents, the sampled meteorological sequences should cover the rare cases that lead to the most severe consequences. Hence, the sequences chosen should represent the complete range of all possible sequences and yield the full spectrum of the consequences related to the postulated accident under investigation.

B. CONSISTENCY: The parameters selected for classification of meteorological sequences and the sampling scheme itself should be seamlessly associated with the models, parameters and methods used in the code system. In the OSCAAR code system, trajectory puff model is utilized to predict the transport and dispersion of released radioactive materials, so travelling information of a puff has to be accounted for. This is expected to ensure meteorological sequences be specially chosen for the dispersion model used in the code system.

C. OPTIMUM STRATIFICATION The sampling scheme could divide the entire set of meteorological sequences in such a manner that the members in each single stratum or group would be very similar and the strata be quite dissimilar. This is the guarantee of reasonable results from a stratified sampling scheme.

D. PRACTICABILITY: An execution of OSCAAR for one meteorological sequence takes about 10 seconds to 10 minutes on Pentium II machine. A full scale of Level-3 PSA consists of assessment of a series of postulated nuclear accidents and the corresponding uncertainty and sensitivity analyses. The computation time consumption will definitely be intolerable if the number of samples is too large. A practicable number of samples should be predetermined according the models used in the consequence assessment code system.

E. OPTICAL ALLOCATION: In some of the existing sampling schemes, sample number for each group is equal or proportional to the size of each group. These procedures may obtain a satisfactory solution when the sizes are equal for all the groups or all the groups are equally important for prediction of the consequences. A fixed number of samples need to be optically allocated among the groups in order to "maximize" the precision of consequence assessment. Therefore, more sequences should be sampled from a particular group if (1) the group size is larger, (2) the variance of consequences is larger, or (3) the members are of higher interest. Additionally, a lower number of sequences to be sampled from each group should be determined in such a way that the consequence variability within a single group can be reflected.

Obviously, the detailed criteria or quantitative description of these principles depend on the model used in the Level-3 PSA code system, the computer performance and the purposes of the assessment undertaken. For example, if the rare cases of catastrophic health effects are to be emphasized, more samples should be allocated in the group that may likely lead the highest health consequences. The number of samples should be decided on a case-by-case basis.

3. RADIOLOGICAL CONSEQUENCES AND RELATED ENVIRONMENTAL PARAMETERS

3.1 Calculation conditions

The OSCAAR code system was used to calculate radiological consequences for one year's worth of hourly meteorological data for Tokai site. This enables a view of the "true" spectrum of radiological consequences due to a postulated nuclear accident. Applying trajectory multi-puff dispersion model, this code system developed for level-3 PSA is capable of simulating circle-around phenomenon of the released radioactive materials in the assessment domain. This feature is perhaps essential for application in complex region such as coastal areas. Basic environmental parameters were calculated with some modules of the code system, and two important input files were obtained. One file consists of integrals of meteorological parameters along the passage of a puff. The other is the compilation of information about the puff, for instance, travel time to a specific segment in the area of interest, average stability class and total precipitation amount during the time when the puff strolling in the segment, stopover time and population in the segment.

Three FORTRAN programs were prepared to perform FFT(Fast Fourier Transform) analysis, association level evaluation, and classification test of meteorological sequences.

For the purpose of this study, it is assumed that a reactor is located at a coastal site facing the Pacific Ocean. Diurnal variation of wind direction prevails because transition of the ground surface from sea to land. Population is not homogeneously distributed at all, large water surfaces of no population accompanying areas of high population density on the land.

The ST2 source term provided in an international comparison of PCA codes (NEA/CEC, 1994) was adopted in the calculations of this work. The features of this source term are summarized in Table 1.

3.2 Periodic variation of consequences

In the light of some previous studies on meteorological sampling scheme comparisons, cyclic sampling can yield probabilistic consequence results better than those using more sophisticated sampling schemes, for example, stratified sampling. Provided a specific accidental radioactive release, the OSCAAR code system was executed for a whole year round of hourly meteorological data. As a result, a time series of four important radiological effects (early fatality, early morbidity, latent fatal cancer, and hereditary effects) was achieved for different starting time of the release.

Table 1. Characteristics of the source term adopted in this study

Item				Value			
Time before release				2.0 h			
Duration of release				1.0 h			
Warning time				1.0 h			
Release height				10 m			
Energy content of release				0 MW			
Reference Inventory				1250 MW(e)			
Group	Xe-Kr	Organic I	I	Cs-Rb	Te-Sb	Ba-Sr,Ru	La
Release fraction*	1.0	0.001	0.1	0.1	0.1	0.01	0.001

*The release fraction is applied to the inventory of radionuclides in a reactor.

Radiological consequences of a postulated nuclear accident are influenced by a number of processes and conditions such as amount and nuclide composition of the releases, release mode, population distribution around the facility, meteorological conditions encountered by the dispersing radioactive materials, agricultural activities, and emergency protection actions. Cyclic changes of meteorological conditions can be observed with spectral analysis techniques. As a result of these cyclic changes, the consequences of a postulated accident have also cyclic characteristics to some extent, as is shown is Figures 3 through 6.

The relative contribution of different frequency fluctuations to early fatality is given in Figure 3. From this figure, it can be seen that the most outstanding cycle is diurnal fluctuation, which is perhaps the reflection of the diurnal changes of atmospheric stability, wind direction and wind speed at the site being studied. The cycle of 4-day is not so significant as expected (USNRC, 1975). The relative contribution of it is much smaller than that of the cycles of 2-day or 3-day. Seasonal variation of early fatality is not remarkable.

In Figure 4, relative contribution of different frequency fluctuations to latent fatal cancer is illustrated. Both diurnal and seasonal variations are remarkable, whilst the relative contributions of cycles of 6.3-day and 3.5-day are also not negligible. The diurnal variation of weather conditions is probably the reason for diurnal fluctuation of latent fatal cancer from a postulated nuclear accident. The seasonal change of latent fatal cancer needs further investigation.

The relative contributions of various frequencies to early morbidity are shown in Figure 5. The diurnal fluctuation is apparently a larger contributor among the others. Compared with the fluctuation of early fatality and fatal cancer, early morbidity has some special periodic changes, cycles of 4 to 5 days, 12 days, and 20 days. Seasonal change is not so remarkable as that of fatal cancer.

In Figure 6, Diurnal and seasonal variations of later somatic effects is clearly demonstrated. A cycle of 6.3 days is also quite marked and so is another of 3.5 days. The overall shape of later somatic effects is rather similar to that of latent fatal cancer.

From the figures mentioned above, it can be concluded that the health effects due to releases at different starting times indicate the existence of periodic variations, so cyclic sampling may produce reasonable assessment results. It is also evident that the time series of health effects are not composed of a small number of "ideally" harmonic waves. Consequently, cyclic sampling is destined to have uncertainty. However, a suitable selection of time interval for cyclic sampling may reduce the uncertainty. The four kinds of health effects do not always fluctuate synchronously. The sole common periodic variation of them is the cycle of 24-hour, which may be the reflection of the typical meteorological cycle in the coastal region. Hence, when a time interval other than 24-hour plus an increment is selected for meteorological sequence sampling, minimum uncertainty for all kinds of consequences will not be realized simultaneously. If the analysis is oriented to minimize the uncertainty in one health effect, the uncertainty in the other health effects will be escalated. Therefore, the time interval should be chosen according the objectives of assessment.

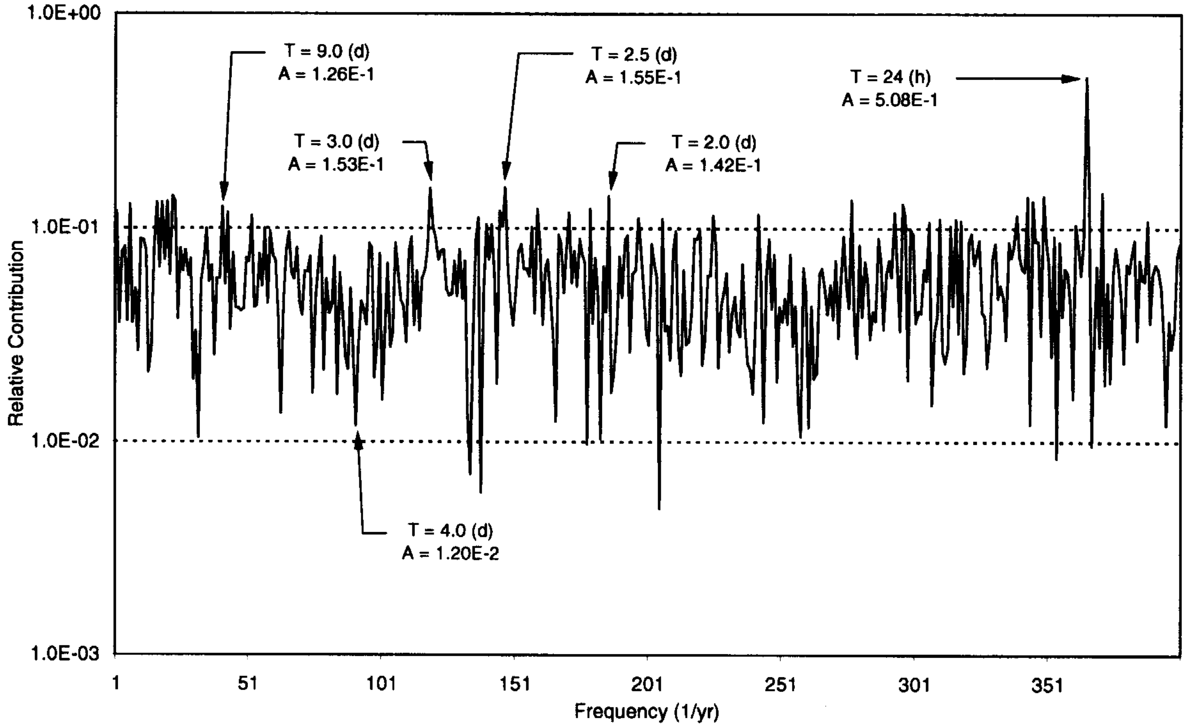

Figure 3. Relative contribution to early fatality from frequencies < 400 (1/yr)

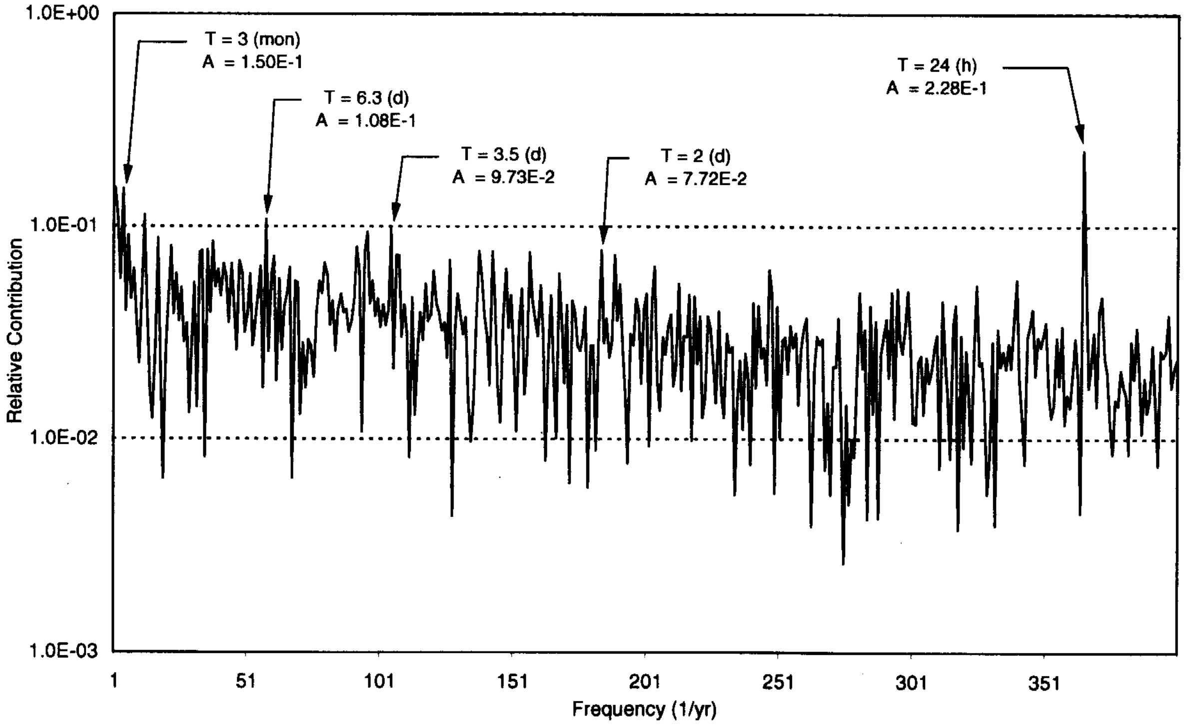

Figure 4. Relative contribution to latent fatal cancer from frequency < 400 (1/yr)

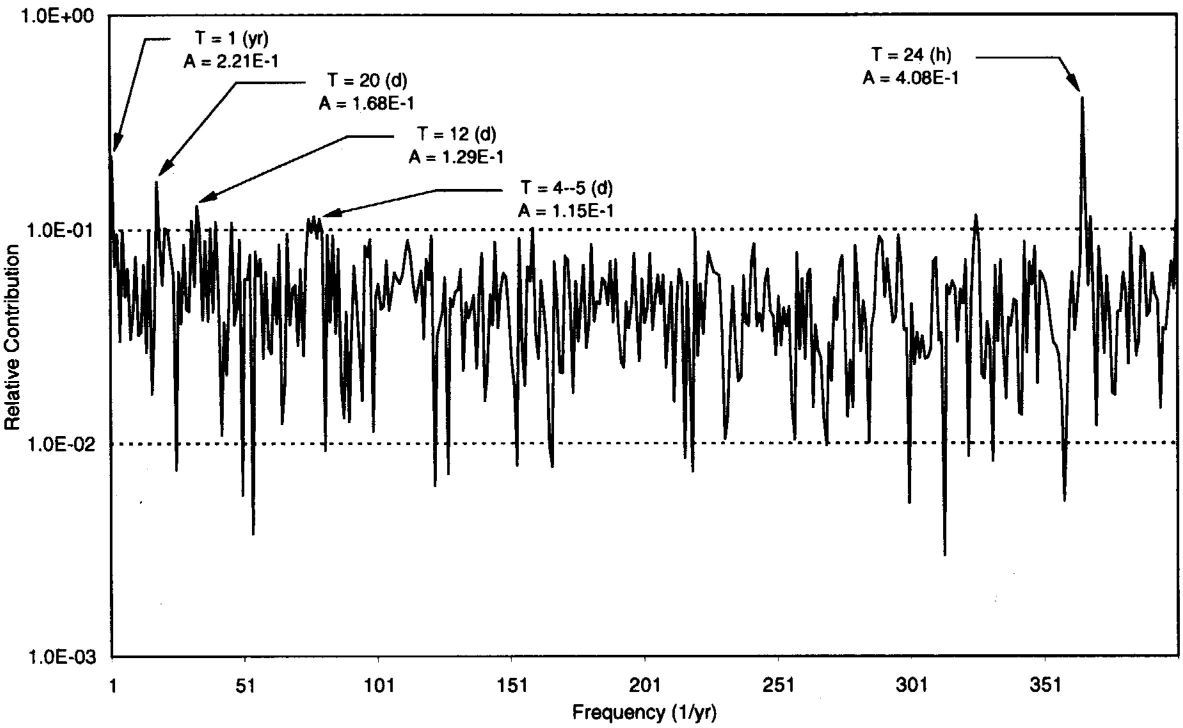

Figure 5. Relative contribution to early morbidity from frequencies < 400 (1/yr)

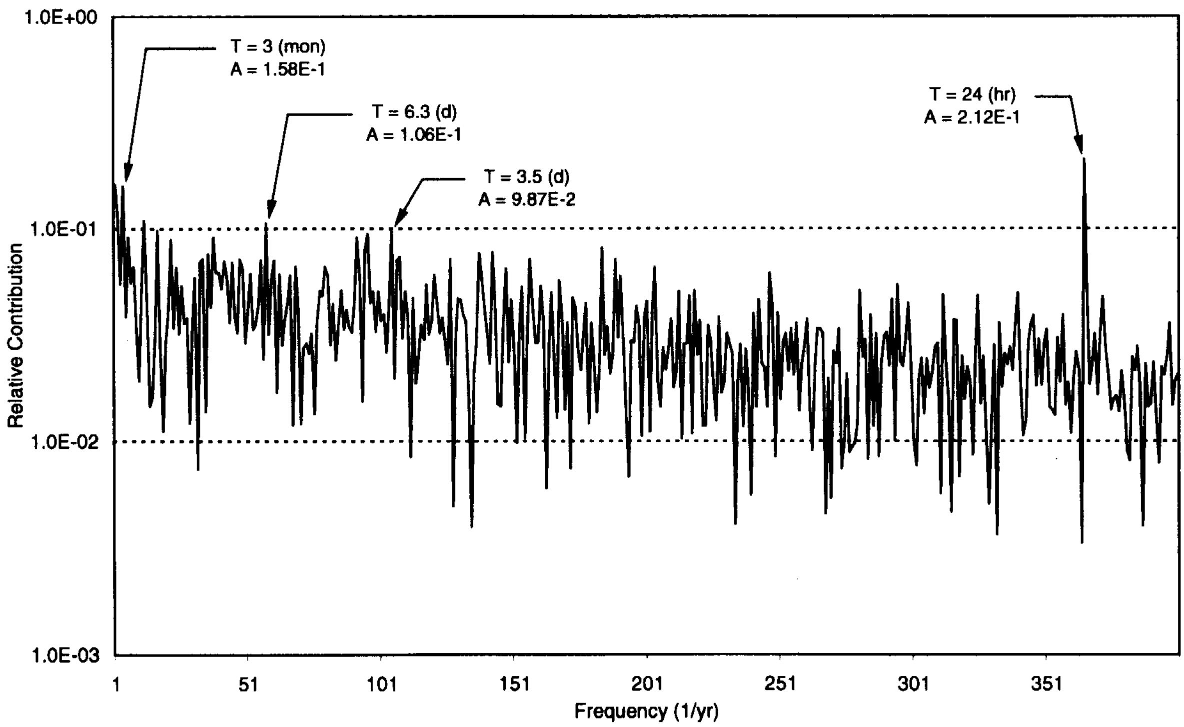

Figure 6. Relative contribution to later somatic effects from frequencies < 400 (1/yr)

3.3 Candidate environmental parameters

In the current Level-3 PSA codes, various schemes of weather sequence categorization are used (1) to reduce significantly the requirements of human and computer resource for the execution of the programs; (2) to depict the complete spectrum of the accident consequences with a manageable number of representative weather sequences. As mentioned above, studies have shown that these schemes or procedures are successful at the first point, but have difficulties at the second point. Since covering the complete spectrum of the consequence is of uppermost importance for a sampling procedure, further studies should be carried out to improve the schemes used currently.

The accident consequences are functions of accident source terms, weather condition, population distribution, land use and emergency protective actions. For a given accident without off-site countermeasures (for the purpose of simplicity), the radiological consequence $\eta_i(x,y)$ can be expressed as:

$$\eta_i(x,y) = F(WS, PD, LU) \tag{1}$$

where:

$\eta_i(x,y)$ = the i-th radiological consequence,
$\eta_i(x,y) \ni$ {early health impacts, latent health impacts};
WS = the sequence of weather conditions after the accident;
PD = distribution of population;
LU = the status of land use.

Let $\chi(x,y,z,t)$ be the concentration of a radioactive nuclide, then time-integrated concentration $\Psi(x,y,0)$ has the form:

$$\Psi(x,y,0) = \int_{T}^{T+\Delta T} \chi(x,y,0,t)dt \tag{2}$$

where:

T = the time at which the plume reach an area of interest;
ΔT = the stopover time of a plume in the area of interest, which is approximately equal to the quotient of the dimension of the area of interest over the travel speed of a puff.

For both early fatality and latent cancer estimations, the consequences are functions of time-integrated concentration of number of people exposed to the passing puff:

$$\eta_i(x,y) = C_i \xi(x,y) \Psi(x,y,0) \tag{3}$$

where:

C_i = conversion constant, a relative coefficient for health risk,

$\xi(x,y)$ = number of people affected at the area of interest.

The time integrals of inverse wind speed and stability parameter are given by:

$$\alpha = \int_{T}^{T+\Delta T} \frac{1}{u(t)} dt \tag{4}$$

$$\beta = \int_{T}^{T+\Delta T} S(t) dt \tag{5}$$

where:

$u(t)$= the sequence of wind speed at an appropriate height;

$S(t)$= the sequence of stability parameter, being defined as a function of the vertical gradient of ambient air temperature $T_a(t)$:

$$S(t) = \frac{g}{T_a(t)} \left[\frac{\partial T_a(t)}{\partial z} + \frac{g}{c_p} \right] \tag{6}$$

C_p= specific heat for air at constant pressure;

g = acceleration due to gravity.

Based on the atmospheric dispersion models, the following relationships exist normally:

$$\Psi(x,y,0) \propto \alpha \tag{7}$$

$$\Psi(x,y,0) \propto \beta \tag{8}$$

Consequently, the relation expressions are obtained:

$$\eta_i \propto \xi(x,y) \tag{9}$$

$$\eta_i \propto \alpha \tag{10}$$

$$\eta_i \propto \beta \tag{11}$$

In the simplest case, population is distributed uniformly and weather condition is steady, the sampling schemes that consider only initial weather condition will yield satisfactory results.

Assuming that health effects are linearly proportional to the wet deposition onto the ground, the influence of wet deposition on health impacts can be expressed by:

$$\eta_i \propto \omega(x,y) \tag{12}$$

which leads to

$$\eta_i \propto \lambda \tag{13}$$

and

$$\eta_i \propto I \tag{14}$$

where:

$\omega(x,y)$ = precipitation induced flux of radionuclides onto the ground, and is given by:

$$\omega(x,y) = \Lambda \int_0^{\infty} \Psi(x,y,z)dz \tag{15}$$

Λ = washout coefficient, and can be calculated as a function of precipitation intensity *I*, and empirically derived constants, *a* and *b*:

$$\Lambda = aI^b \tag{16}$$

On basis of the discussion above, numerous parameters can be derived. Although these environmental parameters are highly associated with radiological consequences of postulated nuclear accidents, a single one of them does not definitely imply a high level of consequence or a low level. It should be pointed out that it is the joint interaction of population distribution, meteorological conditions and land use with the accidental release that determines the off-site radiological consequence, if no emergency protective actions are taken.

A stratified meteorological sampling scheme would not be able to successfully stratify the meteorological sequences if population distribution were not considered. The meteorological sequence classification of this kind of schemes can never realize the intention of stratification: members within a single group are very similar, the groups themselves are remarkably dissimilar. Indeed, realization of this intention is quite a tough task, in which the trade-off of simplicity and precision should be optimized.

The derived parameters that have been investigated for establishing the new sampling scheme are listed and described in Table 2.

Table 2. Environmental parameters analyzed for establishing the new scheme

No.	Symbol	Definition
1	D	Initial wind direction
2	U	Initial wind speed
3	S	Initial stability class
4	R	Initial precipitation intensity
5	P_10	Cumulated number of exposed people along the trajectory of a puff within 10km
6	S_10	Average stability class along the trajectory of a puff within 10km
7	V_10	Cumulated inverse wind speed along the trajectory of a puff within 10km
8	T_10	Travel time of a puff within 10km
9	R_10	Cumulated amount of rainfall along the trajectory of a puff within 10km
10	P_15	Cumulated number of exposed people along the trajectory of a puff within 15km
11	S_15	Average stability class along the trajectory of a puff within 15km
12	T_15	Travel time of a puff within 15km
13	V_15	Cumulated inverse wind speed along the trajectory of a puff within 15 km
14	R_15	Cumulated amount of rainfall along the trajectory of a puff within 15km
15	P_20	Cumulated number of exposed people along the trajectory of a puff within 20km
16	S_20	Average stability class along the trajectory of a puff within 20km
17	T_20	Travel time of a puff within 20km
18	V_20	Cumulated inverse wind speed along the trajectory of a puff within 20km
19	R_20	Cumulated amount of rainfall along the trajectory of a puff within 20km
20	P_30	Cumulated number of exposed people along the trajectory of a puff within 30km
21	S_30	Average stability class along the trajectory of a puff within 30km
22	T_30	Travel time of a puff within 30km
23	V_30	Cumulated inverse wind speed along the trajectory of a puff within 30km
24	R_30	Cumulated amount of rainfall along the trajectory of a puff within 30km
25	P_50	Cumulated number of exposed people along the trajectory of a puff within 50km
26	S_50	Average stability class along the trajectory of a puff within 50km
27	T_50	Travel time of a puff within 50km

28	V_50	Cumulated inverse wind speed along the trajectory of a puff within 50km
29	R_50	Cumulated amount of rainfall along the trajectory of a puff within 50km
30	P_80	Cumulated number of exposed people along the trajectory of a puff within 50km
31	S_80	Average stability class along the trajectory of a puff within 80km
32	T_80	Travel time of a puff within 80km
33	V_15	Cumulated inverse wind speed along the trajectory of a puff within 80km
34	R_80	Cumulated amount of rainfall along the trajectory of a puff within 80km
35	TP	Integral of production of stopover time in the segments that a puff travels through within 10 km and the number of people in those segments
36	TR	Integral of production of stopover time and rainfall amount
37	TS	Integral of production of stopover time and stability class
38	PR	Integral of production of exposed people and rainfall amount
39	PS	Integral of production of exposed people and stability class
40	RS	Integral of production of stability class and rainfall amount
41	TPR	Integral of production of stopover time, exposed people and rainfall amount
42	TPS	Integral of production of stopover time, exposed people and stability class
43	PRS	Integral of production of stability class, exposed people and rainfall amount
44	TRS	Integral of production of stopover time, stability class and rainfall amount
45	TPRS	Integral of production of stopover time, exposed people, stability class and rainfall amount
46	TrP	Integral of production of travel time and exposed people along the trajectory of a puff within 10 km
47	TrS	Integral of production of travel time and stability
48	TrT	Integral of production of travel time and stopover time
49	TrR	Integral of production of travel time and rainfall amount

3.4 Distribution of environmental parameters

Before an uncertainty analysis can be undertaken, a probabilistic distribution must be assigned to the value of each input parameter [18]. Similarly, a probabilistic distribution must be assigned to each candidate environmental parameter to be used in sampling scheme. The distribution represents the degree of belief that the parameter takes particular values and will be helpful to perform a classification in such a way that the sizes of the groups divided using this parameter will not alter intolerably. As discussed in the section below, there are numerous environmental parameters affecting the off-site radiological consequences. Figures 7 through 10 present the probabilistic distribution of a number of those environmental parameters consistent with the models and methods used in the OSCAAR code system.

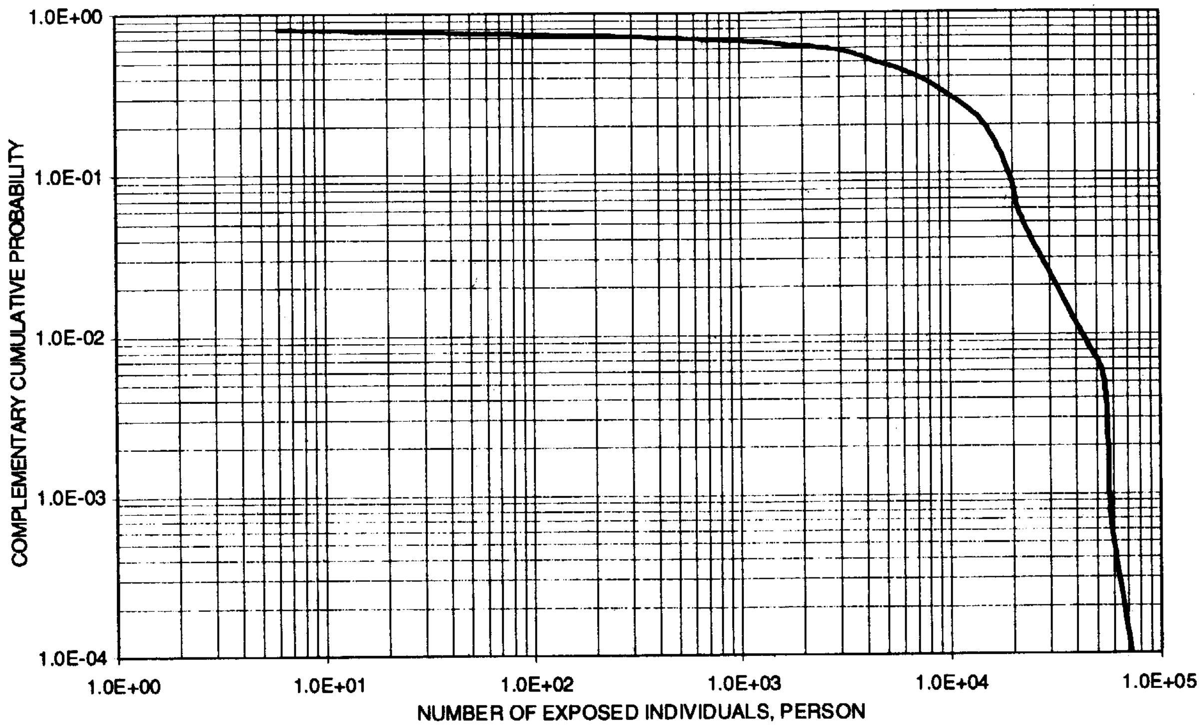

Figure 7. Probabilistic distribution of number of exposed individuals

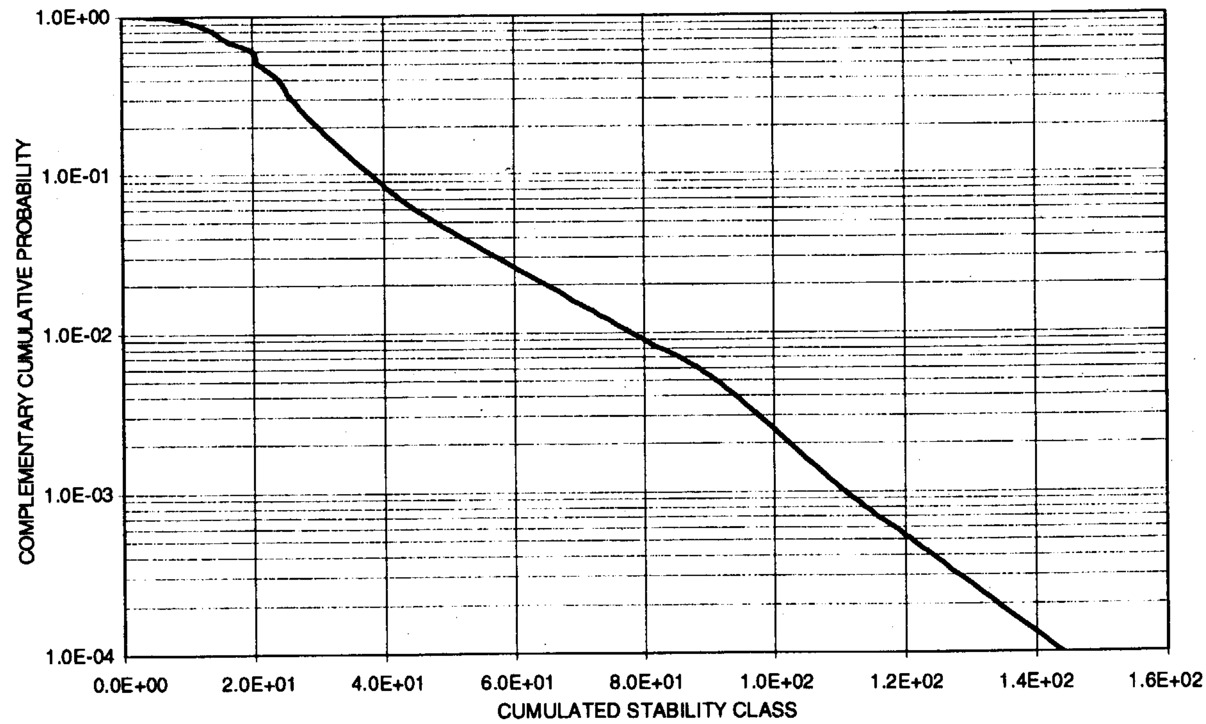

Figure 8. Probabilistic distribution of stability class integration to the extent of 10km

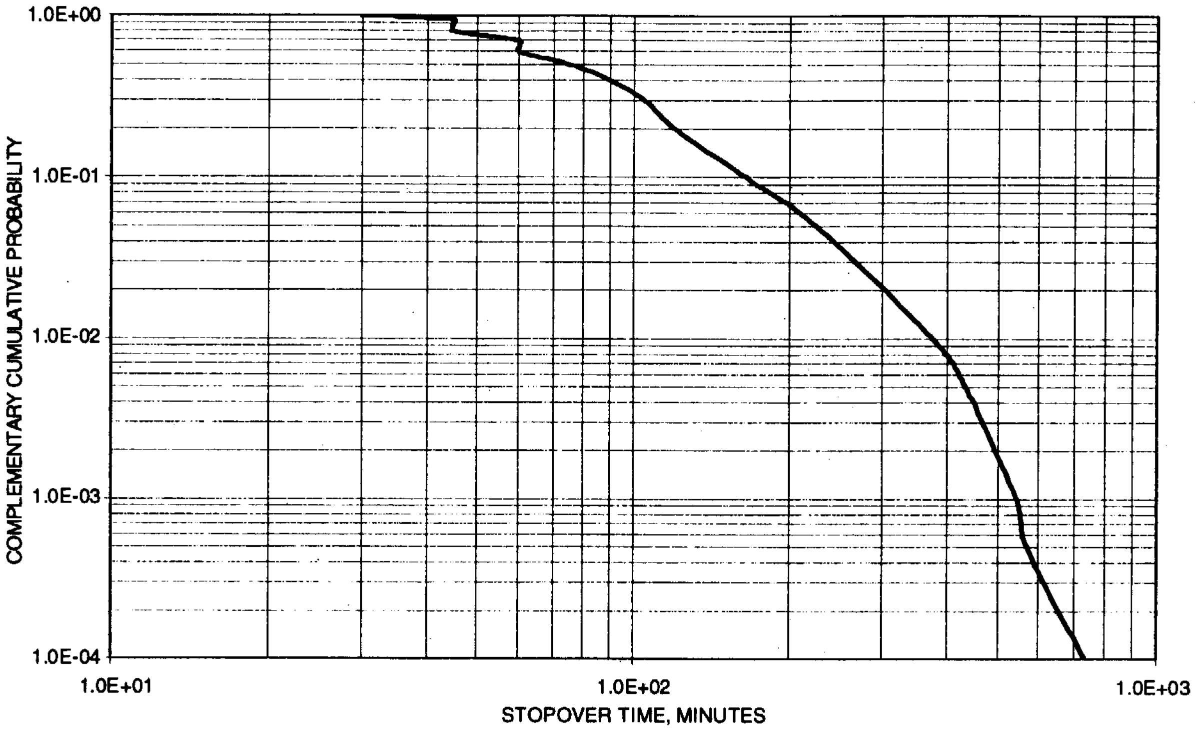

Figure 9. Probabilistic distribution of stopover time

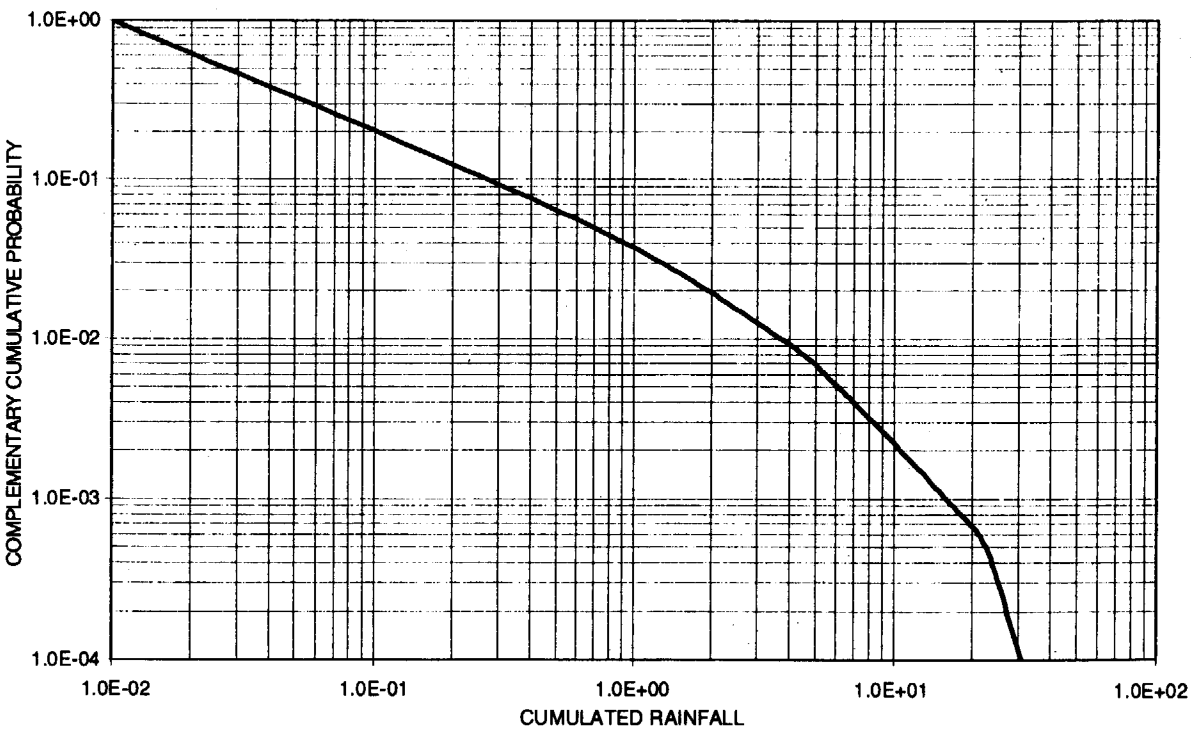

Figure 10. Probabilistic distribution of cumulated rainfall within 10km

Figure 7 is the probabilistic distribution of exposed population along the passage of a dispersing puff. The accumulation of exposed population is conducted till the puff center reaches 10 km. It would be interesting to notice that this curve is quite similar to the CCDF curves of health consequences. A sharp drop appears when the number of exposed people reaches a certain level. This phenomenon indicates that if an equal interval of number of exposed people is used to classify meteorological sequences some groups may have a large amount of members while others may have few members. As a result, the uncertainty of the assessment will be amplified.

Cumulated stability class is calculated along the trajectory of a puff till some travel distances. The calculation result for travel distance of 10 km is provided in Figure 8. It is demonstrated that the probabilistic distribution of cumulated stability class is a typical exponential distribution. For intervals of same value of cumulated stability class, number of sequences decreases continuously as the value of cumulated value itself increases. However, the value of cumulated stability class may be up to over 140. This signifies that the puff may ramble in the immediate vicinity of the nuclear facility for a time longer a number of hours under extremely stable atmospheric conditions.

Travel time of a puff before it reaches some distance is numerically equal to the cumulated stopover time of the puff in the segments along the trajectory. Figure 9 is probabilistic distribution of travel time calculated for a travel distance of 10 km. The maximum travel time to 10 km is about 20 hours.

Shown in Figure 10 is the probabilistic distribution of cumulated precipitation till the puff travels 10 km. The curve declines almost linearly on the double-log plot. This may be explained by the fact that heavy rains occur seldom in the area of concern.

3.5 Association of consequences with some environmental parameters

3.5.1 Measure of association level

A measure of the degree of association of a pair of bivariate random variables *(X, Y)*, in appropriate circumstance, is the correlation coefficient *Corr(X, Y)*, which is defined as below:

$$Corr(X,Y) = \frac{Cov(x,y)}{Var(X)Var(Y)} \tag{17}$$

where,

$Cov(X,Y)$ = the covariance of X and Y;
$Var(X)$ = the variance of X, and
$Var(Y)$ = the variance of Y.

For a sample of n pairs of observations (x_1, y_1), ..., (x_n, y_n) from a Normal distribution with unknown correlation coefficient $Corr(X, Y)$, the sample correlation coefficient r can be determined by the following formula:

$$r = \frac{\sum_{i=1}^{n} x_i y_i - n\bar{x} \bullet \bar{y}}{(\sum_{i=1}^{n} x_i^2 - n\bar{x}^2)(\sum_{i=1}^{n} y_i^2 - n\bar{y}^2)} \tag{18}$$

where,

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \ , \quad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

When it is desired to test whether the observed correlation coefficient indicates that the data are really related, the appropriate null hypothesis is

$$H: \quad Corr(X,Y) = 0$$

Apparently, a sufficiently large absolute value of r would tend to discredit the null hypothesis. Since the sampling distribution of this, on the null hypothesis, is Student's distribution on the n-2 degrees of freedom, the question "how large" may be easily answered in terms of the transform

$$t = \frac{r}{\sqrt{(1-r^2)}}\sqrt{(n-2)} \tag{19}$$

According to formula (19), large absolute values of r result in large absolute values of t. Because the sampling distribution of t is symmetrical about the value 0, we obtain the following tail-area definition of the Significance Level, SL:

$$\begin{aligned} SL &= P(T \geq |t| + T \leq -|t|) \\ &= 2P(T \geq |t|) \end{aligned} \tag{20}$$

where:

T = the value of Student's distribution on n-2 degree of freedom;

t = value calculated with formula (19) based on the observed sample correlation coefficient r.

The interpretation of the significance Level (Lloyd, 1984) is shown in Table 3.

Table 3. Conventional interpretation of Significance Level (SL)

SL	Interpretation
>0.1	Observations consistent with the hypothesis H
~0.05	Possible significant. Some doubt cast on the truth of H
~0.02	Significant. Rather strong evident against H
~0.01	Highly significant. H is almost certainly invalidated

Let (u_i,v_i) be the corresponding rank numbers of n pairs of observed values (x_i, y_i), $(i=1,...,n)$, then $u_i=1$ when x_i is the largest, $u_i=2$ when x_i is the second largest and etc.; $v_i=1$ when y_i is the largest, $v_i=2$ when y_i is the second largest and etc, ties being assigned the appropriate average rank. Y is normally a multi-attribute function, i.e. $Y=Y(X, X', X'',...)$, therefore the Partial Ranking Difference Correlation Coefficient (r_s) is defined as (Press et al., 1989):

$$r_s = \frac{\sum_{i=1}^{n}(u_i-\bar{u})^2\sum_{i=1}^{n}(v_i-\bar{v})^2}{\sqrt{\sum_{i=1}^{n}(u_i-\bar{u})^2\sum_{i=1}^{n}(v_i-\bar{v})^2}} \tag{21}$$

The correlation coefficient mentioned in the previous section is also known as Pearson's Correlation Coefficient (r) or product-moment coefficient of correlation. Compared with r, r_s will be more appropriate for analyzing data of enormous fluctuation or minute alteration.

3.5.2 Response of consequences to various environmental parameters

The calculation results of significance level indicate that almost all the parameters analyzed for establishing the new sampling scheme are certainly associated with the consequences. The Spearman ranking difference correlation coefficients between the environmental parameters analyzed and radiological consequences are given in Figures11 through 15. The definitions of the parameters in these figures are described in Table 2. Rt_10 represents cumulated rain time until the puff leaves the region of 10 km from the release point.

In Figure 11, Spearman rank correlation coefficient is shown for early fatality and various environmental parameters. The correlation coefficient is positive most of the parameters, P, S, PS, PST, S_15 and S_20 being parameters of the highest correlation coefficient values. TrT and U0 are in negative correlation with early fatality because larger value of TrT implies a puff has stayed in lower population region for a longer time and initial dilution is intensified when wind blows hard. Nevertheless, the absolute values of the correlation coefficient for these two parameters are not so large as the ones for such parameters as S and PS. It is very interesting to note that the correlation between early fatality and initial wind direction is not as high as expected. This demonstrates that the wind field is not homogeneous at coastal sites and sophisticated dispersion models (for example, trajectory puff model) should be applied in assessment code systems for more realistic estimation of air concentration and health effects. Figures 16 and 17 are typical trajectories of s puff wandering and gadding about in the area of interest.

The Spearman rank correlation coefficient between early morbidity and the environmental parameters are shown in Figure 12. It can be seen from this figure that the most sensitive parameters to early morbidity are P, PS, PST, P_40. U0 and TrT are negatively correlated with early morbidity. The cumulative parameters seem at higher level of association with early morbidity. Initial wind direction does not show high level correlation with early morbidity. The overall pattern of Figure 12 is quite similar to that of Figure 11. This indicates that a good sampling for early fatality will be also good for early morbidity. The correlation coefficient of initial wind direction turns out to be positive.

The Spearman rank correlation coefficient calculation results for latent fatal cancer are plotted in Figure 13. Compared with Figure 11, the overall appearance of Figure 13 does not alter much. Although the absolute value of correlation coefficient for initial wind speed is still relatively small, latent fatal cancer is more sensitive to initial wind speed than early health effects do. The environmental parameters involving exposed population are the most sensitive ones.

Figure 14 illustrates the response of latent somatic effects to the environmental parameters selected. This figure is nearly a duplication of Figure 13. Therefore a sampling scheme suitable to latent fatal cancer assessment will be proper for latent somatic effects assessment. Parameters that are composed of number of exposed people are the most sensitive.

The calculation results for hereditary effects are shown in Figure 15. Exposed population related parameters exhibit higher association level than the others, though they are not so high as in the cases of latent cancer and latent somatic effects. However, the Spearman rank correlation coefficient of the others is enlarged more or less.

From the discussion made above, a number of conclusions can be drawn under the meteorological, population distribution conditions and accident assumptions for this work. Environmental parameters related to the exposed population are so highly associated with the off-site radiological consequences that a meteorological sampling scheme can not neglects them. Average stability class is also an outstanding indicator to the consequences. A distance of 20 km from the release point is long enough to evaluate early health effects, while longer distances may be justified for late health effects such as latent fatal cancer and latent somatic effects. Radiological consequences seem much more sensitive to cumulative quantities than initial ones.

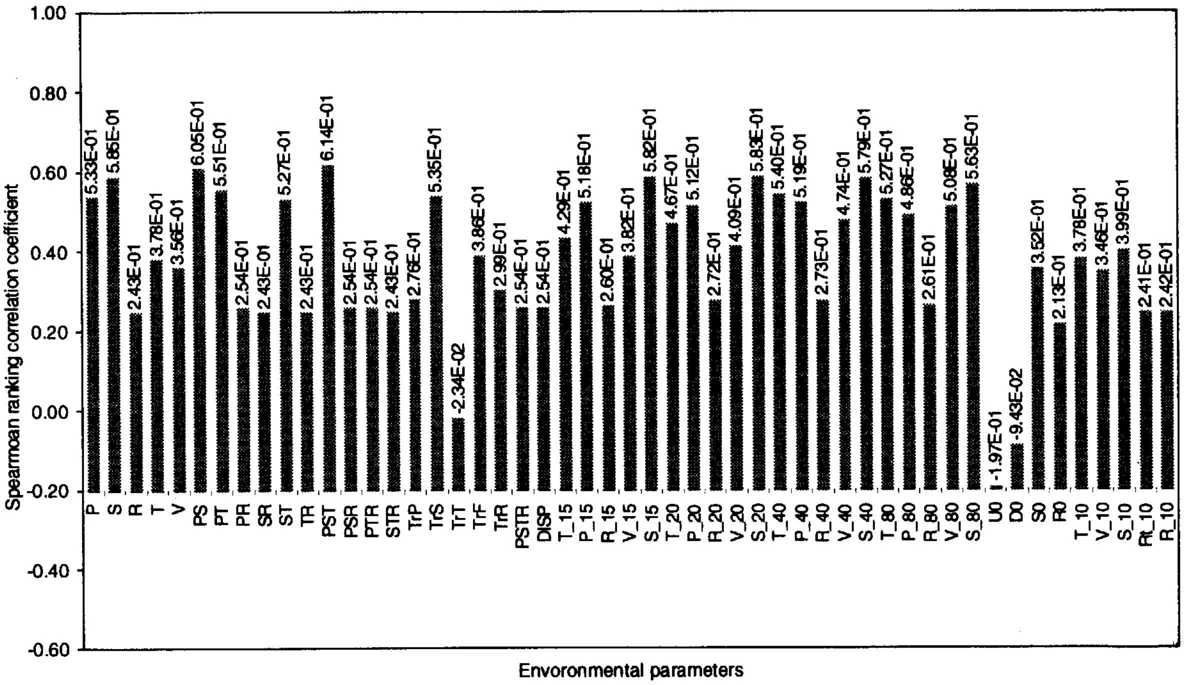

Figure 11. Response of early fatality to various environmental parameters

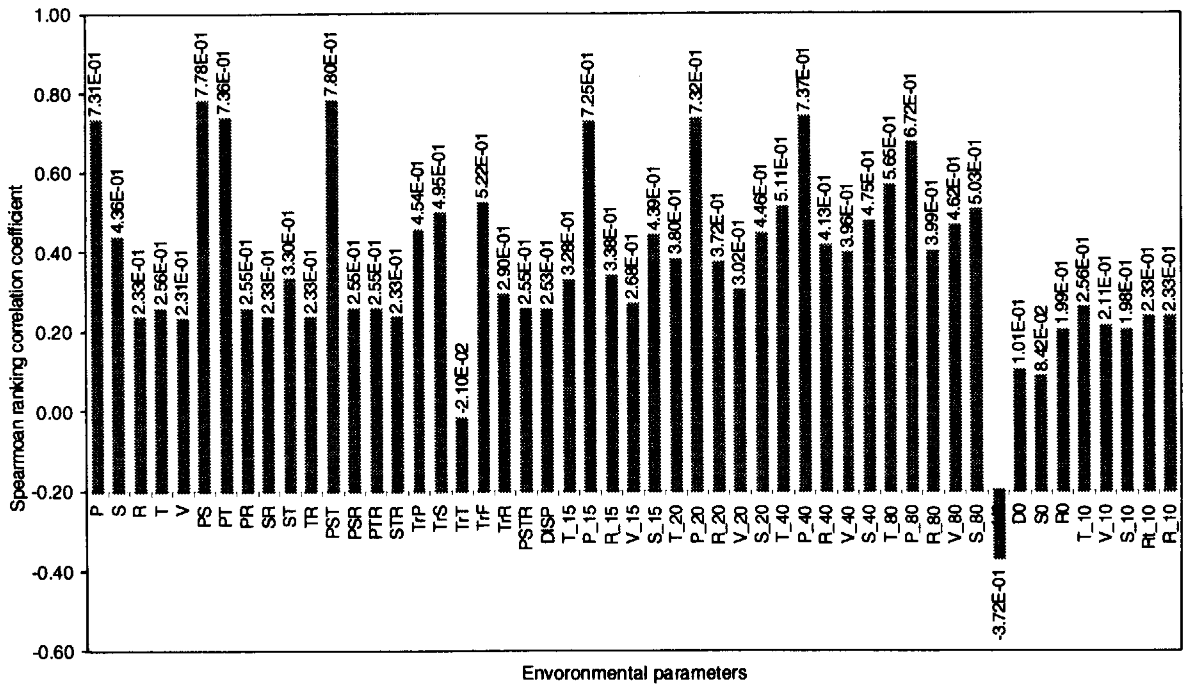

Figure 12. Response of early morbidity to various environmental parameters

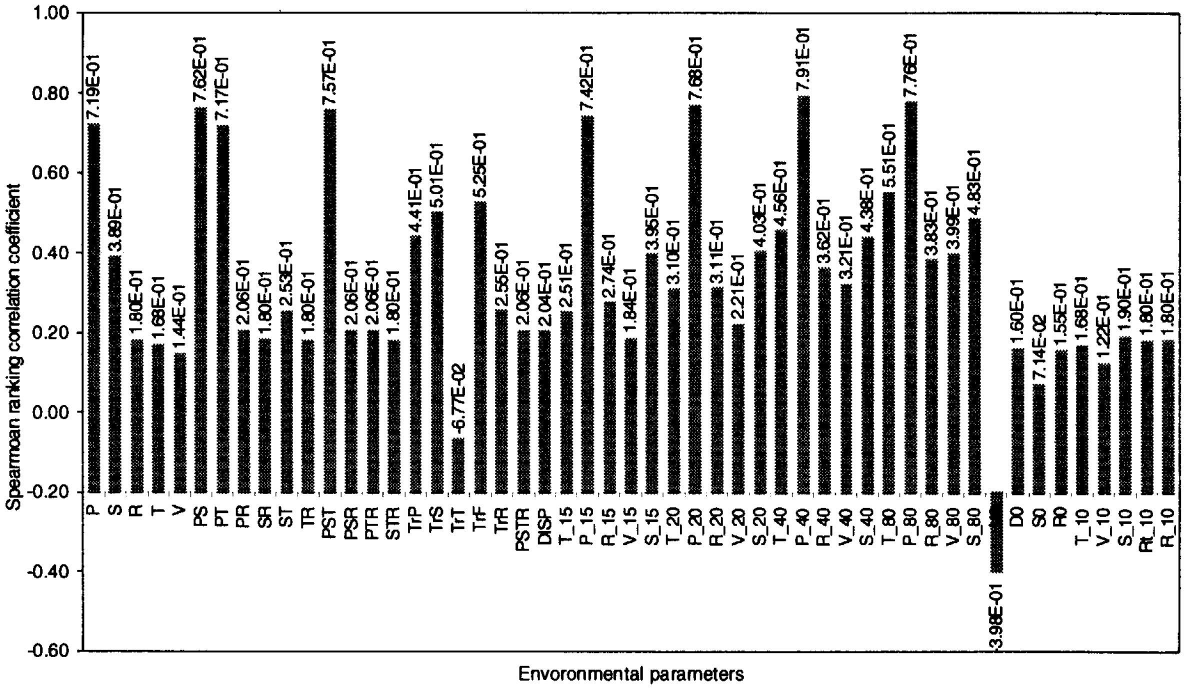

Figure 13. Response of latent fatal cancers to various environmental parameters

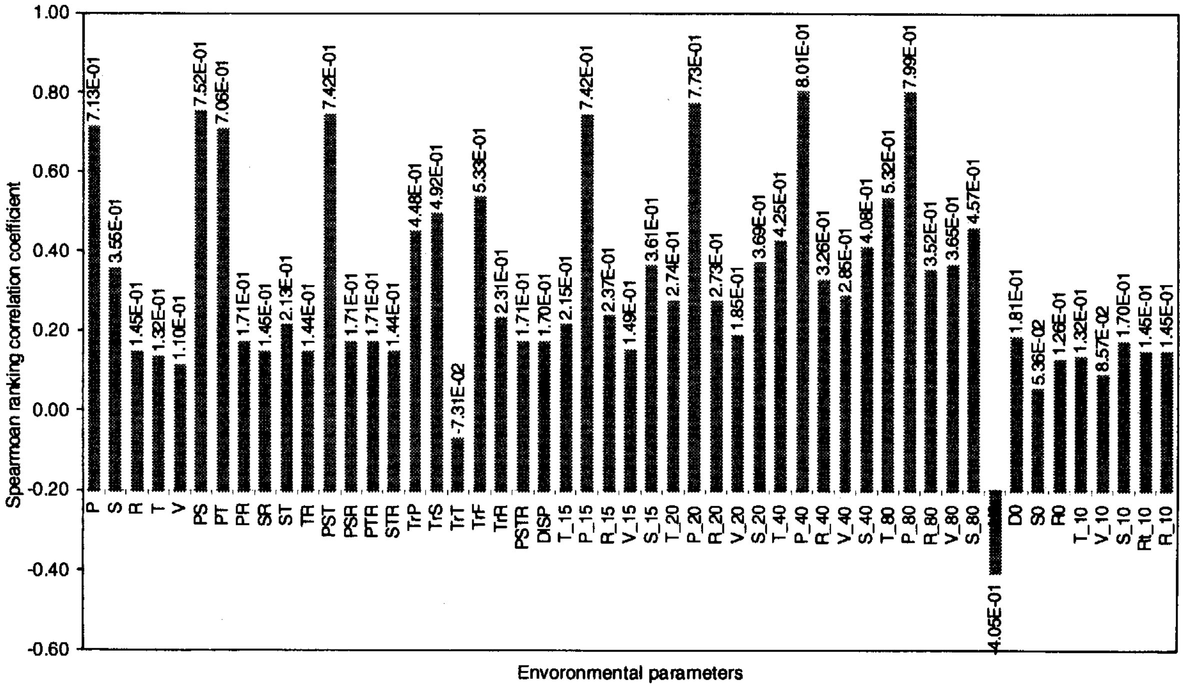

Figure 14. Response of latent somatic effects to various environmental parameters

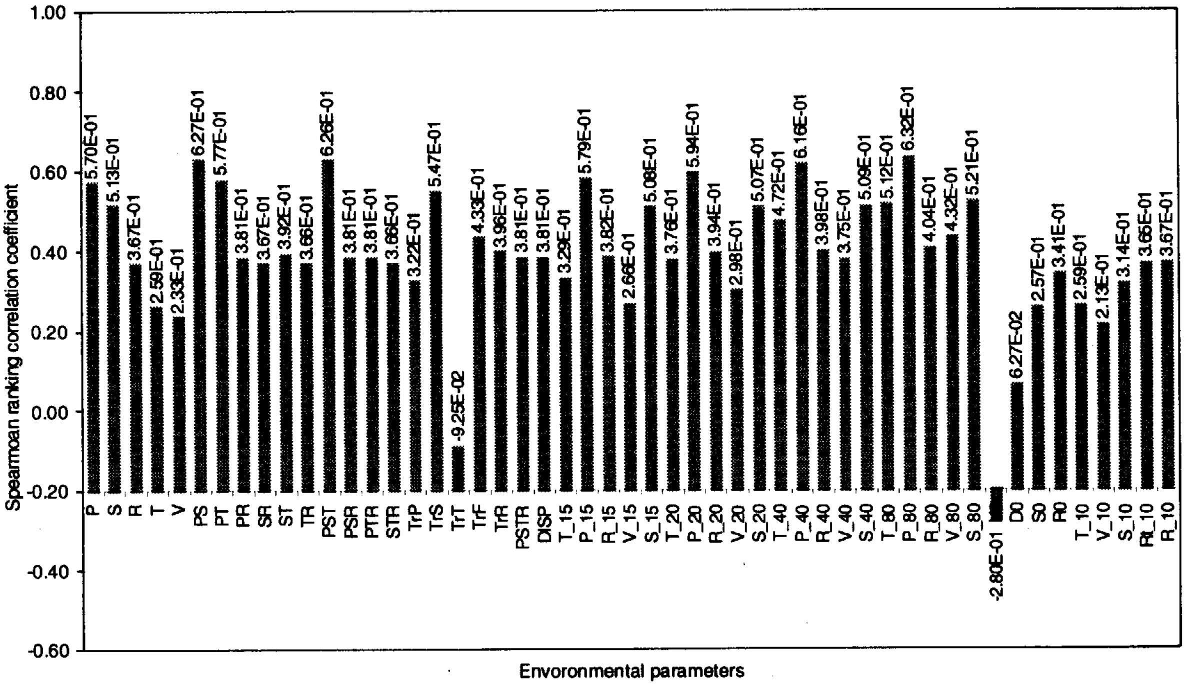

Figure 15. Response of hereditary effects to various environmental parameters

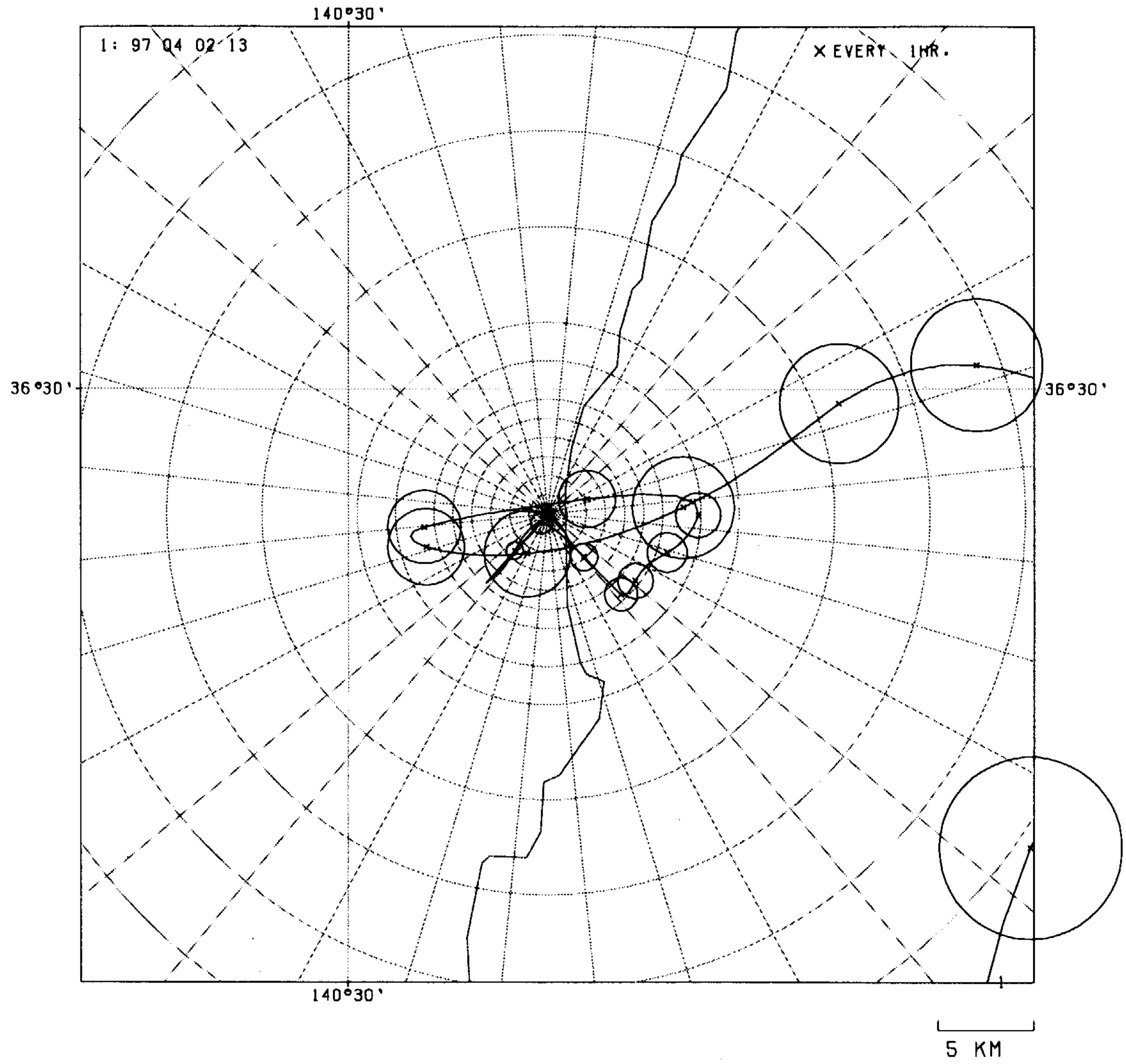

Fig. 16 Puff_1/2

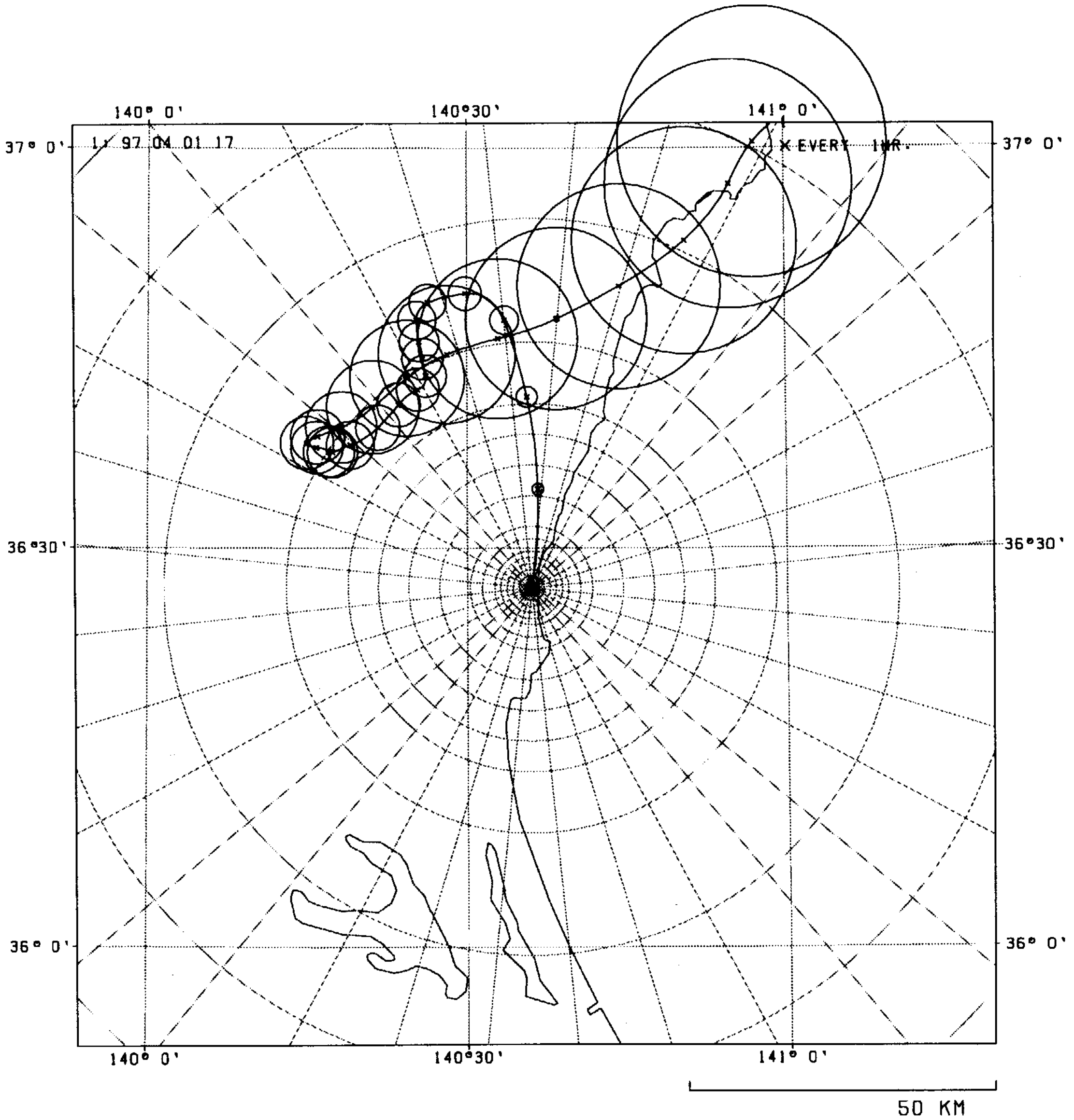

Fig. 17 Puff_2/2

4. CLASSIFICATION AND SAMPLING SCHEME

4.1 Objectives of classification

That uncertainty of consequence assessment of a postulated nuclear accident escalates rapidly as the consequences increase is one notable feature of some meteorological sampling schemes. Extraordinary uncertainty appears at the end of CCDF curves, the data standing for rare meteorological sequences of minute probability but disastrous consequences. Because of their tremendous influence on absolute assessment uncertainty, the rare cases should be paid special attention to if a complete spectrum of consequence is to be depicted and overall uncertainty to be curtailed significantly.

In this work, the classification of meteorological sequences is aimed at the reduction of the uncertainty due to rare cases that may lead to catastrophic impacts. Therefore, screening procedures was applied to get a relative small group of meteorological sequences that covers as many "POTENTIAL" rare cases as possible.

4.2 Coarse classification

Coarse classification of the one year's worth of meteorological sequences were made using some environmental parameters that were chosen on the basis of association level analysis discussed in the subsections above. Breakpoints of the environmental parameters were determined according to their distribution and the relationship between them and consequences. Since different environmental parameters observe different distributions, as is shown by the figures in the section above, specific grouping techniques were adapted for each of the parameters. For example, when the sequences were divided into groups with respect to different levels of cumulative exposed population. A partition of two steps was performed: (1) the complete range of cumulative exposed population was logarithmically quadrisected, then (2) the two middle sections were merged and quadrisected logarithmically again. Eventually, a predetermined number of subsets of meteorological sequences was obtained for each environmental parameter selected in this study. In Table 4, the coarse classification results are listed for the accident scenario assumed.

Table 4. An example of coarse partition results

Para.	Item	Level A	Level B	Level C	Level D	Level E	Level F
P_20	Num.	192	541	4133	1221	746	1927
	Max.	6.58E+01	2.79E+02	8.71E+03	6.96E+03	8.90E+03	1.98E+04
S_20	Num.	147	912	695	722	3479	2805
	Max.	1.80E+02	1.87E+03	3.88E+03	9.98E+03	1.04E+04	1.98E+04
R_20	Num.	7331	110	665	253	104	297
	Max.	1.63E+04	2.24E+03	8.89E+03	5.54E+03	5.32E+03	1.98E+03

Note: Num. and Max. represent number of sequences and the maximum value of early fatality in each group, respectively.

It is illustrated in Table 4 that when the levels of P_20 and S_20 increase the maximum of early fatality exhibits a tendency to increase monotonously. Therefore, these two parameters can be used to stratify meteorological sequences in such a manner that meteorological sequences leading to higher value of early fatality will be placed in higher stratum. If we consider the higher strata are more important and allocate more samples to them then a better results of consequence assessment will be obtained.

Table 5. An example of joint partition of the whole set of sequences

S_20 Level	Item	P_20 Level					
		A	B	C	D	E	F
A	Name	A1	B1	C1	D1	E1	F1
	Num.	17	23	103	3	1	0
	Max.	2.12E+00	5.24E+01	1.82E+02	1.41E+02	8.08E+01	---
B	Name	A2	B2	C2	D2	2	F2
	Num.	47	181	635	32	9	8
	Max.	1.71E+01	7.24E+01	1.78E+03	1.16E+03	1.31E+03	1.87E+03
C	Name	A3	B3	C3	D3	E3	F3
	Num.	34	111	438	54	28	30
	Max.	9.24E+00	6.75E+01	1.66E+03	2.36E+03	3.88E+03	1.48E+03
D	Name	A4	B4	C4	D4	E4	F4
	Num.	18	51	373	96	50	134
	Max.	5.27E+01	8.06E+01	3.52E+03	3.53E+03	8.90E+03	9.98E+03
E	Name	A5	B5	C5	D5	E5	F5
	Num.	30	53	1326	695	387	988
	Max.	3.84E+01	2.79E+02	6.57E+03	6.96E+03	6.38E+03	1.04E+04
F	Name	A6	B6	C6	D6	E6	F6
	Num.	46	122	1258	341	271	767
	Max.	6.58E+01	1.33E+02	8.71E+03	6.47E+03	4.98E+03	1.98E+04

Table 5 shows an example of meteorological sequence classification using P_20 and S_20 levels jointly. Three obvious characteristics can be seen from this table. Firstly, the highest level of early fatality is linked to those sequences of values of P_20 or S_20 at the highest level. Secondly, the lowest level of early fatality is linked to those sequences of values of P_20 or S_20 at the lowest level. Finally, there are some similar subgroups in respect of early fatality resulting from the sequences in them, and it would be better to merge them.

Early fatality resulting from any postulated nuclear accident would be generally within a few orders of magnitude because nuclear power plants are normally located in the area of relatively low population density. Provided meteorological sequences is classified using the method given in Table 6, a stratified series of grand weather classes is hopeful to be achieved, Table 7 listing the result under computation conditions adopted in this study.

Table 6. Method to classify meteorological sequences

S_20	P_20					
	P_20A	P_20B	P_20C	P_20D	P_20E	P_20F
S_20A	1	2	2	2	2	2
S_20B	1	2	3	3	3	3
S_20C	2	2	3	3	3	3
S_20D	2	3	3	4	4	4
S_20E	2	3	4	4	4	4
S_20F	2	3	4	4	4	4

Table 7. Characteristics of early fatality estimates in weather classes obtained using the method described in Table 6.

Item	Class A	Class B	Class C	Class D
Maximum of early fatality	1.71E+01	1.80E+02	3.88E+03	1.98E+04
Number of sequences	98	516	1833	6313

The classifications discussed above are based on a few of cumulative environmental parameters and should be considered as coarse classifications. One specific value of such a parameter is not an indication of one specific value of early fatality. In fact, one specific value of one of the parameters covers a variety of exposure situations that lead to different levels of health effects. Therefore, screening procedures have to be introduced so as to move the sequences of lower health effects to lower groups and move sequences of higher health effects to higher groups.

An investigation into the consequence calculation results reveals some interesting phenomena. Early fatality will be decreased significantly the released radioactive materials spend longer time in the vicinity of the accidental facility. For a certain value of cumulative exposed population, a meteorological sequence is more disastrous if the accumulation time is shorter. Precipitation is a important contributor to lager values of early fatality. When a puff encounters rain in a heavily populated area after a brief travel under stable atmospheric condition the early fatality may be extremely high. Smaller values of cumulative exposed population need larger values of average stability class along the passage of a puff to result in high levels of early fatality.

4.3 Population-related stratified sampling scheme

On the basis of discussion and analysis in the previous subsection, a population-related stratified meteorological sequences sampling scheme was established. This scheme consists of the following procedures:

1) Determination of analysis scale,
2) Calculation of derived environmental parameters,
3) Coarse partition of meteorological sequences,
4) Annexation of similar subgroups,
5) Screening sequence groups of larger early fatality,
6) Allocation of sample number, and
7) Sampling.

4.3.1 Determination of analysis scale

Off-site radiological consequences are the interaction of accidental release, meteorological condition the dispersing puff experienced and population distribution. The effected area of a nuclear accident differs from those of the ethers. Hence, specific spatial and temporal scale a derived environmental parameter has to be determined according to source term of the postulated nuclear accident under investigation. For example, two travel distances were selected for the postulated accident adopted in this work. One is 20 km, the other is 15 km.

4.3.2 Calculation of derived environmental parameters

The sampling scheme set forth in this work is unlike some existing sampling schemes, which utilize initial weather conditions and do not account for population distribution explicitly. In this sampling scheme, a number of derived environmental parameters were applied in meteorological sequences sampling for probabilistic consequence assessment. This new scheme requires longer time to classify the sequences than the existing ones. However, the computation time increment is quite limited on up-to-date PCs. Perhaps, there may be other derived environmental parameters that are more appropriate for the stratification of meteorological sequences, though the derived parameters used in this study proved to be able to improve the probabilistic assessment. The derived environmental parameters applied in the scheme are given below:

(1) Cumulative exposed population along the trajectory of the puff till it travels 20 km.
(2) Cumulative exposed population along the trajectory of the puff till it travels 15 km.
(3) Average atmospheric stability class along the trajectory of the puff till it travels 20 km.
(4) Average atmospheric stability class calculated along the trajectory of the puff till it travels 15 km, travel distance being used as weighting factor.
(5) Cumulative stopover time multiplied by population exposed along the passage of the puff till it travels 20 km, travel distance being used as weighting factor.
(6) Cumulative amount of rainfall multiplied by population exposed along the trajectory of the puff till it travels 20 km, travel distance being used as weighting factor.

After calculation of the derived environmental parameters, their distributions are analyzed in order to obtain proper breakpoints dividing the meteorological sequences.

4.3.3 Coarse partition of meteorological sequences

In the light of distribution analysis of the relevant derived environmental parameters and the impacts of these parameters on radiological consequences, a set of breakpoints were defined for each of them. Coarse partition of meteorological sequences was conducted using P_20 and S_20 jointly. As a result, a matrix of subgroups is obtained, as shown in Table 5. Among the member of the matrix, some are similar in respect of health effects. These similar subgroups should be annexed for further treatment.

4.3.4 Annexation of similar subgroups

Taking into account the relative importance the different subgroups in probabilistic consequence assessment, similar subgroups that acquired by coarse partition are annexed so that a series of strata can be obtained. In this work, the resultant series is composed of 9 strata. Stratum 1 is the collection of sequences that are related with both Level 6 P_20 and the highest two levels of S_20. Stratum 9 is comprised by all the sequences of the lowest level of P_20. The residual 7 strata are distributed between Stratum 1 and Stratum 9, as is shown in Table 8.

The maximum values of early fatality in of these strata are apt to change monotonously. Since it seems reasonable to expect higher consequence for higher P_20 values, P_20 was used as the major parameters for sequence stratification.

Table 8. Stratification of meteorological sequences

S_20	P_20					
	P_20A	P_20B	P_20C	P_20D	P_20E	P_20F
S_20A	9	8	8	8	8	7
S_20B	9	8	7	6	5	4
S_20C	9	7	7	6	4	3
S_20D	8	7	5	3	2	2
S_20E	8	6	3	3	2	1
S_20F	8	6	3	3	2	1

Table 9. Statistics of a sample stratification meteorological sequences

Stratum	Sequence	Min(EF)	Max(EF)	Average	Rel. SDEV
1	50	6.48E+01	1.98E+04	4.10E+03	1.11E+00
2	1871	1.50E-02	9.98E+03	9.02E+02	1.37E+00
3	1100	0.00E+00	9.98E+03	5.39E+02	1.80E+00
4	70	1.36E+00	8.90E+03	6.45E+02	1.77E+00
5	3298	0.00E+00	5.29E+03	2.09E+02	1.95E+00
6	89	0.00E+00	2.36E+03	1.51E+02	2.46E+00
7	1549	0.00E+00	3.52E+03	5.83E+01	3.23E+00
8	541	0.00E+00	2.79E+02	1.50E+01	1.42E+00
9	192	0.00E+00	6.58E+01	5.83E+00	2.04E+00

Note: (1) Max(EF) and Min(EF) represent the maximum and minimum values of early fatality in a stratum.

(2) Rel. SDEV represents the standard deviation of early fatality divided by the average value in a stratum.

4.3.5 Screening sequence groups of larger early fatality

Other derived environmental parameters are used to screening the strata that are potentially have very high values of early fatality. The purpose if screening is to move sequences that are likely to lead to larger consequences to a higher stratum, and those likely leading to smaller consequences a lower stratum. If the sizes of the strata possibly linked to severe consequences are diminished, the probabilistic assessment will turn out to more realistic, and a better depiction of the full spectrum of consequence will hopeful. Table 9 is the classification results under the conditions adopted in this study. It can be seen from this table that the stratification features are quite remarkable among the strata obtained by the new classification scheme. The variability of early fatality seems acceptable in the strata.

4.3.6 Allocation of number of samples

Meteorological sequence sampling schemes have been developed to depict the whole range of radiological consequences of postulated nuclear accidents with a manageable number of meteorological sequences. The number of samples should be defined in accordance to the code system used and the available computer resource. In the case of application of the OSCAAR code system on a Pentium III, sample number between 100 and 200 is practicable.

The probability of rare cases that are potential to cause extremely severe off-site radiological consequences ought to be very high in Stratum 1 and Stratum 2, relative large number of samples are allocated in them. Meteorological sequences are sampled in the other strata in proportion to their sizes. A minimum number of sequences will be selected for strata having very small number of sequences so that the strata can be described properly. Nevertheless, the number of samples for a stratum can never be in excess of the size of that stratum.

4.3.7 Sampling

Once the number of samples is determined for each of the strata, meteorological sequences will be labeled for sampling. The occurrence probability of the sampled sequences is estimated with the number of sequences sampled in and the size of a stratum. If the size of Stratum 1 is small enough, the full spectrum of radiological consequence will be portrayed. A cluster of CCDF curves is given in Figure 18. Compared with the CCDF curve clusters produced by some other sampling schemes, the new scheme seems probable to yield more realistic results for Level-3 PSA. Some statistic quantities are listed in Table 10 for the sake of convenient comparison between different sampling schemes.

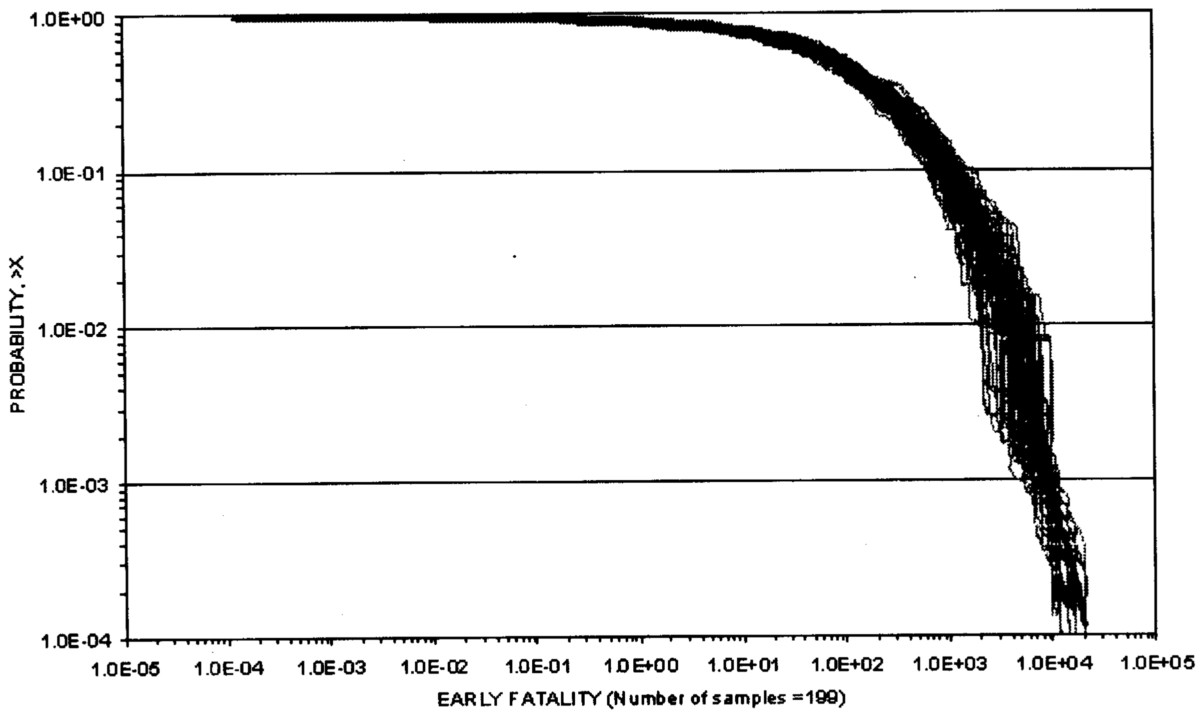

Figure 18. CCDF curves produced with different seeds of random number.

Table 10. Comparison of the early fatality CCDF by the new scheme with the "TRUE" values

Item	TRUE value (all the sequences sampled)	POP_STRA		STRA	
		Mean	SDEV	Mean	SDEV
EXP	3.82E+02	3.83E+02	5.87E+01	3.82E+02	6.07E+01
50.00%	8.62E+01	8.47E+01	1.42E+01	8.53E+01	1.45E+01
90.00%	9.91E+02	9.68E+02	2.01E+02	9.76E+02	1.96E+02
95.00%	1.75E+03	1.72E+03	4.77E+02	1.71E+03	3.93E+02
99.00%	4.59E+03	4.38E+03	1.27E+03	4.19E+03	1.24E+03
99.90%	9.11E+03	8.37E+03	1.45E+03	7.08E+03	2.60E+03
99.99%	1.67E+04	1.63E+04	2.85E+03	7.35E+03	3.35E+03

Note: POP_STRA and STRA represent the new scheme and another stratified sampling scheme, respectively. "TRUE" values mean the output of calculating all 8760 the meteorological sequences.

It is shown in Table 10 that the performance of the new meteorological sampling scheme is satisfactory, especially at high levels of percentile. For instance, the average 99.99 percentile of early fatality is almost the same as the "TRUE" value, the standard deviation is also rather small. This indicates that the new sampling scheme is able to realistically depict the full spectrum of radiological consequences resulting from postulated nuclear accidents.

5. CONCLUSIONS

In this work, the OSCAAR code system was executed for a year's worth of hourly meteorological data for a postulated nuclear accident, which had been used for some international comparisons of Level-3 PSA codes. Spectral distribution was analyzed for different health consequences. The variation characteristics of health effects as a result of the postulated accident were discussed. Distribution of a variety of environmental parameters was investigated. With the computer programs developed for this work, responses of the health effects to some of the environmental parameters were studied. Finally, a new sampling scheme of meteorological sequence was established for the application of the OSCAAR in Level-3 PSA, and the results of the new scheme were compared with the so-called "TRUE" values.

Based on the calculation and comparisons of this work, the following conclusive remarks can be drawn:

(1) Periodic variation is quite noticeable for health effects resulting from postulated nuclear accident. Diurnal change of the consequences is the most outstanding feature. This may explains why cyclic sampling method can produce better results than the former version of stratified sampling scheme.

(2) Variation of the consequences is far from harmonic fluctuation, though periodic features are displayed by the spectral analysis. Accordingly, cyclic sampling scheme tends to pick up common sequences more frequently and to overlook rare cases leading to severe radiological consequences.

(3) The health effects are more dependent on a number of cumulative environmental parameters than initial weather condition. Population distribution is one factor that can not be neglected in constructing a sampling scheme. Without proper account for population distribution, the initial intention of stratified sampling scheme can not be realized, variation between groups might be smaller than that within the single group. Therefore, larger uncertainty appears in the assessment results of the previous stratified sampling schemes.

(4) The population-related stratified sampling scheme performs quite well under the situations adopted in this study. It is able to make a reasonable probabilistic assessment for postulated nuclear accidents. The averages of the percentile are close to the "TRUE" values, especially at high levels of percentile. The uncertainty may be markedly reduced.

The work described in this report is a preliminary study. Further studies are needed. For example, objective methods should be studied to determine spatial and temporal scales for the cumulative environmental parameters; verification of this population-related stratified sampling scheme should be carried out with different accident scenarios and environmental circumstances.

Acknowledgment

This work was sponsored by the Science and Technology Agency (STA) Scientist Exchange Program. The authors would like to express thanks to all the people who have contribute to this work. Special thanks are given to Messrs. MURAMATSU Ken and KOBAYASHI Kensuke for their helps making this work be carried out successfully.

References

CEC (1990). Cosyma: A New Programme Package for Accident Consequence Assessment. EUR 13028, a joint report by Kernforschungszentrum Karlsruhe GmbH (FRG) and National Radiological Protection Board (UK).

CEC (1986). Methods for Assessing the Off-site Radiological Consequences of Nuclear Accidents. EUR 10243, Luxembourg: EC.

CEC (1994). Probabilistic Accident Consequence Assessment Codes - Technical report of the second international comparison - , a joint report by the European Commission and the OECD Nuclear Energy Agency. EUR 15109, Luxembourg: EC.

Hasmann, I., Jones, J.A., Van der Steen, J. and Van Wonderen, E. (1996). Experience with COSYMA in an international intercomparison of probabilistic accident consequence assessment codes. Nuclear Technology, 113, 291-303.

Hemming, C.R., Ferguson, L., Broomfield, M. and Kelly, G.N. (1983). The Consequences of Accidental Releases of Radioactive Material in Extreme Conditions. NRPB-M79 (London, HMSO).

Homma, T., Liu, X-H. and Tomita, K. (2000). Uncertainty and Sensitivity of Accident Consequence Assessment on Meteorological Sampling Schemes. in Proceedings of the 5th International Conference on Probabilistic Safety Assessment and Management, p.2753-2758, Osaka, November, 2000.

IAEA, Special Topics Related to Level-3 PSA/Dose Calculation, J4-TC-835.3, Report of a technical committee meeting held at the IAEA, Vienna, August 25-29, 1997. Vienna, 1997

Jones, J.A., Mansfield, P.A. and Crick, M.J. (1995). Uncertainty Analysis of the Predicted Consequences of Nuclear Accidents using the NRPB code MARC-2A. NRPB-R274 (London, HMSO).

Jow, H-N, Sprung, J.L., Rollstin, J.A., Ritchie, L.T., Chanin, D.I. (1990). MELCOR Accident Consequence Code System (MACCS). NUREG/CR-4691 Vol. 2, Albuquerque, NM.

Kim, D.H. (1998). privite communication, Tokai/Japan.

Liu, X-H, Homma, T. (2001). Variation of Radiological Consequences under Various Weather Conditions, JAERI-Tech 2001-054.

Lloyd, E. (1984). *Statistics*, Volume VI Part A of Handbook of Applied Mathematics, John Wiley & Sons, Chichester.

NEA/CEC (1994). Probabilistic Accident consequence assessment codes - Second international comparison - Overview report. NEA/OCED, Paris.

NRPB (1993). CONDOR 1: A Probabilistic Consequence Assessment Code Applicable to Releases of Radionuclides to the Atmosphere. NRPB-R258 (London, HMSO).

Panitz, H.J., Matzerath, C. and Pasler-Sauer, I. (1989). UFOMOD Atmospheric Dispersion and Deposition. KfK-4332, Kernforschungszentrum Karlsruhe GmbH, Karlsruhe, Germany.

Press, W.H., Flannery, B.P., Teukolsky S.A., Vetterling, W.T. (1989). *Numerical Recipes - The Art of Scientific Computing*, Cambridge University Press, Cambridge.

Ritchie, L.T., Aldrich, D.C. and Blond, R.M. (1981). Weather Sequence Sampling for Risk Calculations. Transactions of the American Nuclear Society, Vol. 38, p. 113.

Tellieria, D.M., Salles, M.A. (1997). Contribution of meteorological sampling schemes to uncertainty in PC COSYMA calculations. in "Special Topics related to Level-3 PSA/Dose calculations", report of a technical committee meeting held at the IAEA, Vienna, August 25-29, 1997.

USNRC (1975). Reactor Safety Study, An Assessment of Accident Risk in U.S. Commercial Nuclear Power Plants, WASH-1400, NUREG-75/014.

Van Wonderen, E., Van der Steen, I. and Hasemann, I. (1994). COSYMA:Users Intercomparison Exercise. EUR 15108, Luxembourg: EC.

Winkler, R.L. and Hays, W.L. (1975). *Statistics: Probability, Inference, and Decision.* Holh, Rinehart and Winston, New York.

国際単位系(SI)と換算表

表1　SI基本単位および補助単位

量	名　称	記　号
長　　さ	メートル	m
質　　量	キログラム	kg
時　　間	秒	s
電　　流	アンペア	A
熱力学温度	ケルビン	K
物 質 量	モル	mol
光　　度	カンデラ	cd
平 面 角	ラジアン	rad
立 体 角	ステラジアン	sr

表2　SIと併用される単位

名　称	記　号
分，時，日	min，h，d
度，分，秒	°，′，″
リットル	l，L
トン	t
電子ボルト	eV
原子質量単位	u

1 eV=1.60218×10^{-19} J

1 u=1.66054×10^{-27} kg

表5　SI接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

表3　固有の名称をもつSI組立単位

量	名　称	記号	他のSI単位による表現
周　波　数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	m·kg/s^2
圧力，応力	パスカル	Pa	N/m^2
エネルギー，仕事，熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位，電圧，起電力	ボルト	V	W/A
静 電 容 量	ファラド	F	C/V
電 気 抵 抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁　　束	ウェーバ	Wb	V·s
磁 束 密 度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光　　束	ルーメン	lm	cd·sr
照　　度	ルクス	lx	lm/m^2
放　射　能	ベクレル	Bq	s^{-1}
吸 収 線 量	グレイ	Gy	J/kg
線 量 当 量	シーベルト	Sv	J/kg

表4　SIと共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

1 Å= 0.1 nm=10^{-10} m

1 b=100 fm^2=10^{-28} m^2

1 bar=0.1 MPa=10^5 Pa

1 Gal=1 cm/s^2=10^{-2} m/s^2

1 Ci=3.7×10^{10} Bq

1 R=2.58×10^{-4} C/kg

1 rad = 1 cGy = 10^{-2} Gy

1 rem = 1 cSv = 10^{-2} Sv

(注)

1. 表1－5は「国際単位系」第5版，国際度量衡局 1985年刊行による。ただし，1 eV および 1 u の値は CODATA の1986年推奨値によった。
2. 表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。
3. bar は，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。
4. EC閣僚理事会指令では bar，barn および「血圧の単位」mmHg を表2のカテゴリーに入れている。

換　算　表

力	N(=10^5 dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　1 Pa·s(N·s/m^2)= 10 P(ポアズ)(g/(cm·s))

動粘度　1 m^2/s= 10^4 St(ストークス)(cm^2/s)

圧力	MPa(=10 bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062 × 10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322 × 10^{-4}	1.35951 × 10^{-3}	1.31579 × 10^{-3}	1	1.93368 × 10^{-2}
	6.89476 × 10^{-3}	7.03070 × 10^{-2}	6.80460 × 10^{-2}	51.7149	1

エネルギー・仕事・熱量	J(=10^7 erg)	kgf・m	kW・h	cal(計量法)	Btu	ft・lbf	eV
	1	0.101972	2.77778 × 10^{-7}	0.238889	9.47813 × 10^{-4}	0.737562	6.24150 × 10^{18}
	9.80665	1	2.72407 × 10^{-6}	2.34270	9.29487 × 10^{-3}	7.23301	6.12082 × 10^{19}
	3.6 × 10^6	3.67098 × 10^5	1	8.59999 × 10^5	3412.13	2.65522 × 10^6	2.24694 × 10^{25}
	4.18605	0.426858	1.16279 × 10^{-6}	1	3.96759 × 10^{-3}	3.08747	2.61272 × 10^{19}
	1055.06	107.586	2.93072 × 10^{-4}	252.042	1	778.172	6.58515 × 10^{21}
	1.35582	0.138255	3.76616 × 10^{-7}	0.323890	1.28506 × 10^{-3}	1	8.46233 × 10^{18}
	1.60218 × 10^{-19}	1.63377 × 10^{-20}	4.45050 × 10^{-26}	3.82743 × 10^{-20}	1.51857 × 10^{-22}	1.18171 × 10^{-19}	1

1 cal = 4.18605 J (計量法)

　= 4.184 J　(熱化学)

　= 4.1855 J　(15 °C)

　= 4.1868 J (国際蒸気表)

仕事率　1 PS (仏馬力)

　= 75 kgf·m/s

　= 735.499 W

放射能	Bq	Ci
	1	2.70270 × 10^{-11}
	3.7 × 10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58 × 10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

(86年12月26日現在)

Study on a New Meteorological Sampling Scheme Developed for the OSCAAR Code System