Journal of the Korean Nuclear Society
Volume 16, Number 3, September, 1984

An Off-Site Consequence Modeling for Accident Using Monte Carlo Method

Chang Sun Kang and Sae Yul Lee

Seoul National University
(Received April 12, 1984)

몬테칼로 방법을 사용한 사고후 영향 평가모델

강 창 순 · 이 세 열

서울대학교
(1984. 4. 12 접수)

Abstract

A new model is presented in order to evaluate the risk from a nuclear facility following accidents directly combining the on-site meteorological data using the Monte Carlo Method. To estimate the radiological detriment to the surrounding population-at-large (collective dose equivalent), in this study the probability distribution of each meteorological element based upon on-site data is analyzed to generate atmospheric dispersion conditions. The random sampling is used to select the dispersion conditions at any given time of effluent releases. In this study it is considered that the meteorological conditions such as wind direction, speed and stability are mutually independent and each condition satisfies the Markov condition. As a sample study, the risk of KNU-1 following the large LOCA was calculated. The calculated collective dose equivalent in the 50 mile region population from the large LOCA with 50 percent confidence level is 2.0×10^2 man-sievert.

요 약

원자력발전소 사고 후 그 위험도를 평가하는 새로운 방법으로 몬테칼로 방법을 제시한다.

본 연구에서는 발전소 주위의 주민에게 주는 방사선의 영향를 평가하기 위하여 공기중의 확산계산에 부지에서 측정한 기상조건을 직접 사용하고 있다. 사고가 일어나는 순간에서의 확산조건은 주어진 기상자료로 부터 분석된 pdf에 의하여 결정되고 그이후의 조건(풍향, 풍속, 안정도)은 마르코프 조건을 만족 시킨다고 가정하였다. 예제로써 KNU-1의 냉각재 상실사고를 분석한 결과 50마일내의 주민이 받는 선량은 50퍼센트 신뢰도를 갖고 200 man-Sv이다.

1. Introduction

In order to estimate the risk from a nuclear power plant, it is required to analyze the effect of radioactive effluents to the environment, especially to the population-at-large, during an accident. The risk is defined as the product of probability of occurrence and environmental consequences (collective dose equivalent if solely caused by radiation exposure) per occurrence. When we calculate the collective dose equivalent from the release of gaseous radioactive materials, the problem is how to apply the meteorological conditions which would affect the diffusion and transport of gaseous radioactive materials in the air. In the conventional method,[1,2] it is impossible to reflect the time-dependent variation of meteorological conditions since it uses the values equivalent to those in the U.S. Reg. Guides 1.3 and 1.4 or the percentile values obtained from the distribution of atmospheric dispersion factors (X/Q's), which are mainly used to assess the maximum individual doses. This approach is not appropriate in calculating collective dose equivalents and tends to overestimate the potential risk from the fairly extended releases associated with some postulated accidents. To overcome this handicaps of the conventional method, on-site meteorological data (Feb. 1, 1979~Jan. 31, 1981) are analyzed in such a way that the Monte-Carlo method could be used in applying atmospheric dispersion conditions.

The method is based on the assumption that the selection of meteorological conditions at any given time following the initiation of an accident may be adequately described as a random process. Transition matrices of each meteorological data and, through random process, each element of meteorological conditions was obtained at each time step. These probabilistic meteorological conditions were used in the calculation of X/Q's and consequently the collective dose equivalent. As a sample study, the risk of KNU-1 following the large LOCA was calculated. In order to compare the results of this method, the conventional method and the dsoe matrix method[3] were performed under the same conditions.

2. Risk Modeling for Accidents

2-1. Meteorological Data Reduction

Two years' meteorological data of Ko-Ri site from February 1, 1979 through January 31, 1981 were measured every fifteen minutes, which include wind speed, wind direction and Pasquill stability class. These data were averaged to hourly meteorological data for this study. The calm condition was included in the hourly data only when it appeared three quarters or more (i.e., 45 minutes or more). Otherwise the average of non-calm conditions represented the hourly data of that time interval.

Wind speed and direction are not defined in the calm condition. For this study, the wind speed equal to the threshold velocity of the wind measuring equipment (0.1m/sec) was used for the calm condition and the wind direction was selected according to the sector frequency distribution of the lowest velocity class (less than 1.5m/sec). The wind speed was divided into seven groups as shown in Table 1, where each group speed was averaged.

Using these hourly data, the probability density distribution of each meteorological element (wind direction, speed and stability) was computed to generate the probability density functions (pdf's) which were used for selecting the initial meteorological conditions for atmospheric dispersion following the onset of an accident through random process. It is obtained

Table 1. Wind Speed Groups

Group (U_i)	Upper Limit (m/sec)
U_1	0.1
U_2	1.5
U_3	4.5
U_4	7.5
U_5	10.5
U_6	15.5
U_7	>15.5

Table 2. Frequency Distribution (Kori On-Site Data 2/1/79-1/31/81)

Direct		Speed		Stability	
θ_i	$f(\theta_i)$	U_k	$f(U_k)$	S_m	$f(S_m)$
NNE	855	U_1	303	A	47
NE	1,660	U_2	1,075	B	105
ENE	537	U_3	6,594	C	344
E	478	U_4	5,623	D	4,562
ESE	385	U_5	2,918	E	9,091
SE	478	U_6	920	F	2,429
SSE	427	U_7	111	G	966
S	959				
SSW	1,305				
SW	2,004				
WSW	978				
W	1,605				
WNW	1,031				
NW	1,377				
NNW	1,322				
N	1,840				
calm	303				
Total	17,544				

simply by counting the number of times that meteorological condition i occurs. For example, the probability that the wind direction θ_i appears at the initiation time of a postulated accident can be expressed by

$$P(\theta_i)=\frac{f(\theta_i)}{N};\ N=\sum_i f(\theta_i),$$

where $f(\theta_i)$ is the number of observations of condition θ_i.

Table 2 shows the frequency distribution of each meteorological element based on the hourly computed data. 16 wind directions (averaged of 22.5°), 7 wind speeds and 7 stability classes (Pasquill Category) are presented for meteorological conditions θ_i, U_k and S_m, respectively. Hence the following relationship exists

$$N=\sum_{i=1}^{16} f(\theta_i)=\sum_{k=1}^{7} f(U_k)=\sum_{m=1}^{7} f(S_m).$$

2-2. Transition Matrix

The use of random sampling is proposed in this work to select the meteorological conditions at any given time following the initiation of an accident to evaluate the atmospheric dispersion of radioactive effluent releases. The conditions at the onset of an accident are selected based on the probability density functions as shown in Table 2. However, the selection of the subsequent conditions following the accident, the transition matrices should be formulated.

In formulating the matrices, the meteorological condition, wind direction (θ), wind speed (u) and stability (s) are first considered mutually independent. Consider the wind direction θ which may be described at any time as being in one of a set of 16 mutually exclusive and collectively exhaustive states $\theta_1, \theta_2, \cdots, \theta_{16}$. According to a set of probabilistic rules, the wind direction θ may, at certain discrete instants of time, undergo state transition. Let $\theta_i(n)$ be the event that the wind direction is in state θ_i immediately after the nth transition. The probability of this event may be written as $P\ (\theta_i(n))$. Each trial in the general process of the discrete-state and discrete-transiton type may be described by transition probabilities of the form

$$P(\theta_j(n)\,|\,\theta_a(n-1)\theta_b(n-2)\theta_c(n-3)\cdots)$$

where $1\leq j, a, b, c, \cdots\leq 16$; $n=1, 2, 3, \cdots$.

These transition probabilities specify the probabilities associated with each trial, and they are conditional on the entire past history of the process. If the transition probabilities for a series of dependent trials satisfy the Markov condition:

$$P(\theta_j(n)\,|\,\theta_a(n-1)\theta_b(n-2)\theta_c(n-3)\cdots)$$
$$=P(\theta_j(n)\,|\,\theta_a(n-1))$$

for all $n, j, a, b, c, \cdots$, the conditional probability that the wind direction will be in the state θ_j immediately after the next transition, given that the present state of the process is θ_i, becomes

$$\theta_{ij}=P(\theta_j(n)\,|\,\theta_i(n-1)) \quad 1\leq i, j\leq 16$$

where θ_{ij} is independent of n and is the element of the ith row and jth column in a 16×16 transition matrix $[\theta]$. Assuming each of meteorological conditions θ, u, and s is said to be a discrete-state and discrete-transition Markov process, then the corresponding transition matrices $[\theta]$, $[U]$, and $[S]$ are fomulated, where the conditionl transition probabilities (i.e. matrix elements) are $\theta_{ij}=P(\theta_j(n)\,|\,\theta_i(n-1))$, $u_{kl}=P(u_l(n)\,|\,u_k(n-1))$, and $s_{mq}=P(s_q(n)\,|\,s_m(n-1))$, respectively, and i, j, k, l, m, and q denote the states. Tables 3 through 5 show the conditional

Table 3. Conditional Probability Distribution of Wind Direction

	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	N
NNE	445	164	20	8	17	0	6	2	36	2	2	35	4	43	6	64
NE	173	1,236	103	20	12	5	4	6	26	5	4	42	4	12	10	20
ENE	36	125	204	77	21	6	11	2	20	5	4	17	0	11	1	7
E	2	35	57	249	60	21	12	6	10	7	1	9	5	5	3	5
ESE	45	31	17	48	78	76	20	12	13	7	6	11	4	14	4	17
SE	1	11	12	22	43	212	100	42	17	12	6	13	3	3	3	1
SSE	6	5	2	7	19	64	134	122	35	17	7	9	5	10	2	2
S	9	7	10	4	10	34	59	543	196	50	17	14	6	14	4	2
SSW	40	9	21	8	13	11	30	109	597	310	46	27	14	19	17	51
SW	1	2	3	6	8	15	18	42	209	1,350	251	75	17	14	11	7
WSW	4	5	3	4	9	14	10	20	33	147	411	252	46	25	14	4
W	14	16	13	4	22	10	9	21	24	75	155	861	228	74	39	70
WNW	1	5	5	9	5	7	7	18	14	19	39	151	496	194	64	14
NW	7	6	15	10	9	11	14	16	32	12	26	65	157	722	212	97
NNW	6	6	12	5	22	6	3	13	14	4	10	27	46	188	732	244
N	69	19	50	6	55	9	9	5	46	7	11	27	13	63	216	1,251

Table 4. Conditional Probability Distribution of Wind Speed

	U_1	U_2	U_3	U_4	U_5	U_6	U_7
U_1	133	94	73	3	0	0	0
U_2	105	478	472	18	2	0	0
U_3	64	495	4,924	1,068	37	6	0
U_4	0	8	1,093	3,819	681	22	0
U_5	0	0	30	700	1,960	226	2
U_6	1	0	2	15	237	639	26
U_7	0	0	0	0	1	27	83

Table 5. Conditional Probability Distribution of Wind Stability

	A	B	C	D	E	F	G
A	13	10	17	7	0	0	0
B	9	21	30	28	15	2	0
C	15	21	53	175	63	16	1
D	8	30	150	2,829	1,464	75	6
E	2	18	78	1,387	6,782	771	53
F	0	5	15	119	715	1,282	293
G	0	0	1	17	52	283	613

transition probability distributions of wind direction, wind speed and wind stability, respectively, for the two years' on-site data.

2-3. Collective dose equivalent

The collective dose equivalent (man-sievert) in a population following an accident is defined by

$$S=\int_{r} drH(r)\cdot P(r)$$

where $H(r)$ is the dose equivalent (sievert) to an individual located at r due to effluent releases following the accident, and $P(r)$ is the exposed population distribution at r. The individual dose equivalent, $H(r)$ is given by

$$H(r)=\int_{0}^{\infty} dt \sum_{i}^{\text{nuclides}} Q_i(t)\cdot \frac{X}{Q}(r,t)\cdot (DF)_i$$

where $Q_i(t)$ is the time-dependent release rate (curies per sec.) of radioactive isotope i following the accident, $\frac{X}{Q}(r,t)$ is the atmospheric dispersion factor (sec/m^3) calculated at r using the continuous plume model at a given time t, and $(DF)_i$ is the dose conversion factor for isotope i (sievert-m^3/Ci-sec).

For calculation of the collective dose equivalent in a population, the region was extended up to 50 miles from the site and the 50 mile radius region was divided into 160 subregions (16 directional and 10 distances). In this case the collective dose equivalent in the population up to 50 mile radius region is given by

$$S=\sum_{i=1}^{10}\cdot\sum_{j=1}^{16} H_{ij}\cdot P_{ij}$$

where H_{ij} is the averaged dose equivalent to an individual in the sector ij, P_{ij} is the number of population in the given sector, and subscripts i and j denote 10 distances and 16 directional compass points, respectively.

3. Results and Recommendations

The collective dose equivalent in the population within 50 miles of KNU-1 was calculated for 720 hours following the initiation of the large LOCA. The calculated total body collective dose equivalent in the 50 mile region population for 30 days following this accident with 50 and 95 percent confidence levels are 2.0×10^2 and 7.2×10^2 man-sievert, respectively. For simplicity, radioactive noble gases were only considered. And the results using two other methods are compared in Table 6. As shown in the table, the conventional method overestimates the doses as expected and the dose matrix method gives the similar results as the Monte-Carlo method, but it required a lot more computation time and memories.

This method can be applied to the risk calculation of all accident types as well as in the normal operating condition. However, the continuous Gaussian Plume model may not be sufficient in Kori site since there are many adjacent high hills and valleys around the site and the diffusion model used for the open terrain may fail to describe the correct dispersion of gaseous radioactive materials in the air.

Table 6. Comparison of Results

	50% value (Man-Sievert)	95% value (Man-Sievert)
Monte-Carlo Method	2.0×10^2	7.2×10^2
Dose-Matrix Method	1.3×10^2	8.6×10^2
Conventional Method	3.0×10^2	1.7×10^3

References

1. U.S. Regulartory Cuide 1.3, USNRC.
2. U.S. Regulartory Guide 1.4, USNRC.
3. C.S Kang, J. Kor. Nuc. Soc. 11(2), 1974.
4. "Preliminary Safety Analysis Report", For KNU-5 & 6.