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Determination of Derived Release Limits by the Concentration Factor Method

Byung Woo Kim, Byeung Kyu Kim* and Jeong Ho Lee
Korea Advanced Energy Research Institute
*Sung Kyun Kwan University
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농축인자법에 의한 유도방출 기준 설정

김병우 · 김병규* · 이정호
한국에너지연구소
*성균관대학교
(1985.7.23 접수)

Abstract

Some kinds of methods have been applied to regulate the exposure doses by the radioactive effluents from nuclear power plants. The essential one is primary dose equivalent limit recommended by the ICRP. When the primary limit cannot be applied directly for regulation, there have been dose equivalent index in case of external exposure, or maximum permissible concentration, annual limit on intake, derived air concentration and maximum permissible body burden in case of internal exposure. But the derived limit is required from the viewpoint of discharge, for those values are inadequate to control discharge rate directly. This study was carried out to derive the release limit for the Wolsung nuclear power plant by the concentration factor method. This method is based on the assumption of steady state transfer between environment compartments.

요 약

원자력발전소로부터 배출되는 방사성물질에 의한 피폭선량을 규제하는데 있어 몇가지 종류들의 방식들이 적용되어 왔다. ICRP에 의해 권고된 일차 선량 당량 제한치가 가장 근본적인 것이다. 일차 제한치가 직접 적용될 수 없을 때 외부 피폭의 경우 선량당량 지표가 내부피폭의 경우 최대허용농도, 연섭취 제한치 혹은 유도대기 농도 및 최대 신체 부하량등이 이용되어 왔다.

그러나 이 값들은 실제 배출량을 제어하는 견지에서 바로 사용할 수 없어 유도방출 기준치를 구하게 된다. 본 연구에선 월성 원자력발전소에 대해 고려되는 특정환경들 사이의 전달속도가 시간에 독립적인, 장기성 농축인자 방식으로 방출속도의 유도 제한치를 구하였다.

1. Introduction

Nuclear facilities release gaseous and liquid effluents to the environment. Doses by the effluents can be assessed by the exposure limits suggested in the ICRP recommendation No. 9 or No. 26. From the viewpoint of controlling the discharge rate, maximum permissible concentrations or derived release limits can be used to assess the exposures.

Dose limitations and maximum permissible concentrations in 10 CFR 20 were regulated according to the above principles in the United States. In the alternative view-point the IAEA[1] suggested the derived release limits which should take the socio-environmental factors for the specific site into consideration.

In this study concentration factors were assumed independent of time to establish derived limits based on the IAEA suggestion for the Wolsung nuclear power plant using computer codes GASPAR[2] and LADTAP.[3] Those codes assume that the transfer processes are in the steady state between system compartments. Critical group was overall analyzed for every pathway, age group and organ. And then derived release limit was computed about the critical group for every radionuclide on the primary value of ICRP dose limitation. Herein it was assumed that the critical group be in the site boundary to the direction where wind prevailed annually. Long-term models, not short term ones for an accident, were used to estimate the atmospheric and marine diffusion of radioactive effluents.

2. Concept

1) Dose limitation

Dose limit is the value of a quantity which must not be exceeded in radiation protection. Generally there are primary dose equivalent limits, secondary limits, derived limits and authorized limits. The primary limits relate to the dose equivalent, effective dose equivalent, committed dose equivalent or committed effective dose equivalent. These limits applied to the public exposure are dependent on the exposure circumstances and have been recommended by the ICRP.

Secondary limits may be used when the primary dose limits cannot be applied directly. These limits are expressed by the dose equivalent index in the case of external exposure and by annual limits on intake (ALI) in the case of internal exposure.

Derived limits are such ones that the primary limits could be observed if the derived limits are observed. And authorized limits may be established by the competent authority or installation manager, which are usually below the primary limit to leave a safety margin.

2) Derived release limit

Appropriate discharge rates equivalent to the primary dose limits can be determined for a site by analyzing environment systems of overall exposure pathways. Deriving the rates is based on the fundamental requirement that exposure doses of critical group should not exceed the primary limit. These rates are defined as the derived release limits(DRL); the upper limits for the release rate of a single radionuclide from a single source. In deriving the DRL, the intention is to establish a release limit such that adherence to it will provide virtual certainty of compliance with the ICRP recommendation.

When a person may be exposed to several different radio-isotopes by inhalation, ingestion and external radiation, the following criterion must be met to remain within the primary limit.

$$\sum\frac{C_i(\text{air})}{\text{MPC}_i(\text{air})}+\sum\frac{C_i(\text{water})}{\text{MPC}_i(\text{water})}+\sum\frac{\text{external dose(rate)}}{\text{MPD}}\leqq 1 \qquad (1)$$

MPC : Maximum permissible concentration
MPD : Maximum permissible dose

For non-occupational exposure, the ICRP recommended that the MPC's be reduced by a factor of 100 for those isotopes where either the whole body or the hemopoietic tissue or the gonads is the critical organ, and by a factor of 30 for all other isotopes.[4)]

3. Methodology

1) Derivation of release limit by the analysis of critical pathway

Derived limits may be calculated in terms of either discharge rates or levels of environmental contamination. In the former case, the full critical pathway model is used, whereas in the latter case, only the stages of the pathway model are used that involve exposure of man from the critical material.

Analysis in term of discharge rate is done by either the concentration factor method or the more inclusive systems analysis method. To estimate derived limits with the former concentration factor method for annual discharge it is necessary to know the relationship between discharge and the dose commitment for the critical group.

The critical pathway assessment has as its basis an evaluation of the network of all potential exposure pathways. This evaluation is made by using transfer models for the individual pathways, and it is normally possible to identify a small number of potential critical pathways, radionuclides and population group by application of quite crude models. The possible critical pathways are then analyzed more closely using detailed, quantitative models. The aim is to develop a relationship between unit rate of introduction of radioactive material and the resultant radiation dose to potential critical groups, and thus to establish from the ICRP dose limits for members of the public a derived limits, i.e. the annual input of radioactivity of specified composition which will result in a dose commitment in the critical group equal to the recommended annual dose limit.

The end result of a critical pethway analysis can be summarized by a set of numbers f_{jkl} relating the dose commitment from nuclide l in population group j and the unit discharge from source k. A release R_{kl} from source k thus gives a dose commitment H^c_{jkl} in population group j.

$$H^c_{jkl}=f_{jkl}R_{kl} \tag{2}$$

If the maximum f_{jkl} is f'_{jkl} for the critical group j', annual dose limit(ADL) of the ICRP is given as follow;

$$\mathrm{ADL}=f'_{jkl}\cdot R^*_{kl} \tag{3}$$

R^*_{kl} : one release value related to ADL

In the case when a number of nuclides l contribute significantly to the exposure of the critical group j', and these nuclides all relate to the same critical organ, the R^*_{kl} value must satisfy the condition.

$$\mathrm{ADL}=\sum_k\sum_l f'_{jkl}R^*_{kl} \tag{4}$$

And the release value has to satisfy the following condition for all organs m,

$$\mathrm{ADL}_m\geqq\sum_k\sum_l f'_{jklm}R^*_{kl} \tag{5}$$

Resulting R^*_{kl}'s are the derived limits of effluents. This method requires usually computer system to process enormous socio-environmental data block including the transfer rates through the internal and external exposure pathways to man.

2) Transport sequences and concentration factor

Radioactive effluents from source are divided originally into 2-phases of gaseous and liquid states because of behavior differences. Dispersion steps within the overall transport sequences are seperately discussed in the following section owing to the most sensitiveness and uncertainty.

General sequences are schematized in the sites near to shoreline in Fig. 1 and 2 that show the pathways to the human body organs. Pathways are composed of two kind of exposures; external exposure-direct irradiation, and internal exposure-inhalation, ingestion. There are resuspension effects on the contaminated ground by weathering condition and devotion of underground waters which are herein excluded due to minor effect. In case of ingestion pathway, the milk and meat media give a little effect as shoreline activity, swimming and boating do by the irradiation in the Korea situations.

In concentration factor method, transfer process remain relatively constant with time. Thus the general transfer rate is described as follow;

$$f_{12}=C_1/C_2 \tag{6}$$

1 and 2 mean each environment compartment. The f is the transfer factor and C is the concentration.

As shown in Fig. 3, "immersion in plume" pathway can be expressed,

$$\begin{aligned} &f_{\text{source-organ or body}} \\ &=(f_{\text{source-atmosphere}})\,(f_{\text{atmosphere-organ or body}}) \\ &=(\chi/Q)\times(\text{Dose rate}/\chi)=\text{const.} \end{aligned} \tag{7}$$

Herein, χ/Q is atmospheric diffusion factor, and dose rate/χ is dose conversion factor for concerned exposure target (skin or body). If the constant is known, dose rate can be calculated with diffusion factor obtained by the eq. (9).

In another example of vegetation ingestion,

$$\begin{aligned} &f_{\text{source-organ}} \\ &=(f_{\text{source-atmosphere}})\,(f_{\text{atmosphere-vegetation}}) \\ &\quad\times(f_{\text{vegetation-organ}}) \\ &=(\chi/Q)\,(D/\chi)\ \ (\text{Dose rate}/D) \\ &=((D/Q)\ \ (\text{Dose rate/D}) \\ &=\text{const.} \end{aligned} \tag{8}$$

D/Q is obtained by the eq. (10).

Similarly as the above examples, all the exposure pathways can be analyzed by the concentration factor method. At every case the constant has its own value showing the transfer characteristics between every compartment.

To drive the release limits, thers is a requirement that the final dose rate in the sequences should be below the MPD in Fig. 3. Another requirement in view of intake rate is indicated as a secondary references.

Calculation models of exposure are same as the methods of the U.S. Regulatory Guide 1. 109.[15] And age groups of men are subdivided into infant (0-1 yr.), child (1-11 yrs.), teenager (12-18 yrs.) and adult (over 18 yrs.). Each of these is again subdivided into 8 body organs-total body, skin, lung, gastro-intestinal tract, thyroid, kidney, liver and bone.

3) Dispersion model

To analyze the diffusion of the gaseous and liquid effluents, fluid dynamics are seperately applied; aero-dynamics in the atmosphere and marine hydro-dynamics in the sea. Differently in the accident case of short term, long term (a year) dispersion is analyzed in the viewpoint of statistical averaging, so that makes the approximation easy.

In the atmosphere, transport of radioactive effluents depends on the weathering conditions, sea breeze and terrain hight. Modeling technique is changed considerably according to the scales of target areas-synoptic, meso and micro scales. Usually mesoscale approach is recommended in the area of 80 km radius considered for dose assessment due to nuclear facilitie's effluents.

The modeling is affected by the second variable of time period. For short term analysis, it is required for diffusion coefficients to be compensated for the terrain height, and for wind direction change to be estimated including meandering phenomena, circulation by sea breeze. For long term analysis, wind direction change is assessed only by the frequency (wind rose) in statistical viewpoint. So the Gaussian model can be adopted without severe deviations, assuming that the concentration is distributed evenly in a sector. This model requires the empirical values of atmospheric diffusion parameters, σ_y and σ_z which are the function of atmospheric stability, composed of 6 classes, and downwind distance.

Radionuclides released in air-borne effluents will deposit on the ground to some extent with the exception of the noble gases, which depend on the physical and chemical form of the radionuclide, the nature of ground surface, the wind speed, and the amount of the precipitation. Deposition occurs first by dry deposition-sedimentation, diffusion and impaction-, diffusion and chemical reaction. Washout by rain is negligible for radioiodines and small particles less than a few micro-meter diameter.

Herein the Sagendorf equation[5] was adopted for atmospheric diffusion approximation as follow;

$$\chi(x)=\frac{f}{2\pi x/n}\int_{-\infty}^{\infty}\frac{Q}{\pi\sigma_y\sigma_z u}\exp\left[-\left(\frac{y^2}{2\sigma_y{}^2}+\frac{h^2}{2\sigma_z{}^2}\right)\right]dy \quad (9)$$

$\chi(x)$: radionuclide concentration at downwind distance x, Ci/m^3
Q: discharge rate, Ci/sec
σ_y,σ_z: horizontal and vertical diffusion parameter, m
f: fraction of wind frequency
h: release height, m
u: average wind speed, m/sec

From the above equation, the ground level release ($h=0$) was assumed. And the dry deposition was calculated as follow;

$D/Q=$(relative deposition rate) (fraction of the release into the sector)/(appropriate cross wind distance) (10)

In the ocean, modeling techniques for estimating radionuclide transport are affected great by temporal and spatial variability in flow. This variability results from two major factors. The first one is the influence of astronomical tidal currents, and the second is the influence of meteorological driving forces. If the averaging time is long compared to the tidal period, tidal currents cannot contribute the advective transport, since their contributions to the mean flow field have been removed by the

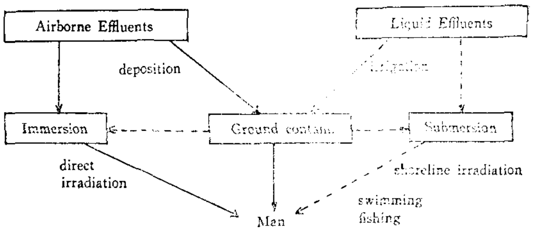


Fig. 1. External Exposure Pathways(irradiation)

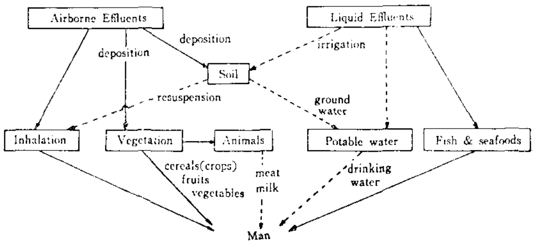


Fig. 2. Internal Exposure Pathways(ingestion) Pathways...were considered unimportant in Korea environment

averaging. Meteorological forces include not only the major effects of meso-and synoptic-scale system but the minor effects of seasonal temperature deviation.

But, for general discharges removed from the shoreline, Gaussian-like solutions to the steady state diffusion equation may be adopted as follow;[6]

$$\chi=\frac{w}{2\pi u\sigma_y\sigma_z}f(\sigma_z,z,z_s,\ d)\ f(\sigma_y,y,y_s) \quad (11)$$

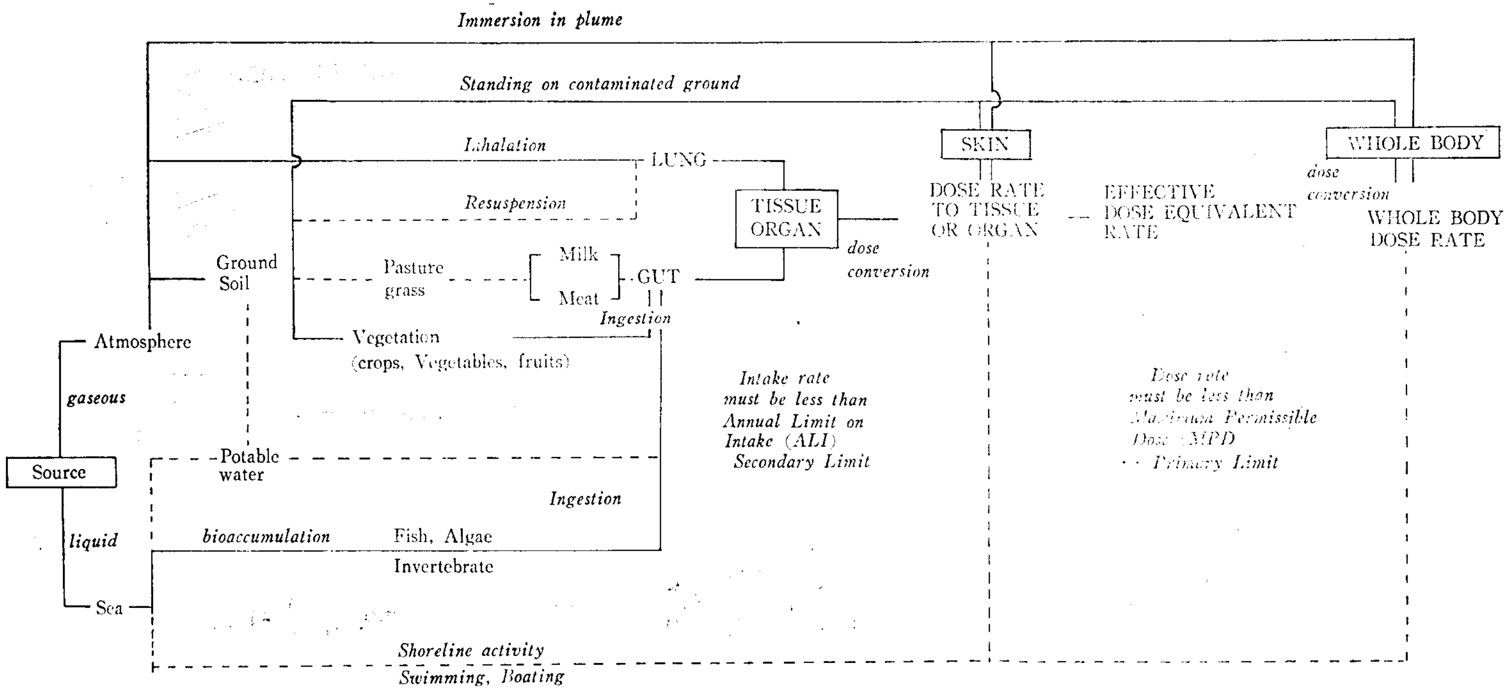
χ: non decaying concentration of radionuclide, Ci/m^3
w: image source of strength, Ci/sec
u: stream velocity
σ_y: lateral diffusion parameter, $\sqrt{\frac{2\varepsilon_y x}{u}}$
ε_y: lateral turbulent diffusion coefficient
σ_z: vertical diffusion parameter, $\sqrt{\frac{2\varepsilon_z x}{u}}$
ε_z: vertical turbulent diffusion coefficient
y_s,z_s: lateral & vertical location of discharge
d: constant depth

And dilution factor, D_F is given by

$$D_F=w/\chi q_p \quad (12)$$

q_p: volumetric discharge rate of the effluents

From the empirical results, long term dilution



Pathways (............) give so little effects in the Wolsung site.

Fig. 3. Schematic Description of Exposure Pathways Considered for the Concentration Factor Method in the Wolsung Site.

factors would be about twice those calculated from equation(11). Herein, the dilution factor was chosen as unity for the conservativeness.

4. Results and Discussion

As discussed above, concentration factormethod requires wide range of investigations relating to every pathway concerned. Firstly the concentration of radionuclide should be known at a position to estimate the effects of direct irradiation and inhalation including ingestion. Thus the meteorological data are to be processed.

And it is necessary to know agricultural productivities, consumption rates and transfer rates as well as so many parameters including dose conversion and bioaccumulation factors.

Based on these investigations on socio-enviromment, doses for unit discharge of every radionuclide were computed for every pathway, age group, organ and tissue.

1) Socioenvironmental analysis

Within 80km radius from the Wolsung nuclear power plant, total population was 5,683,000 in 1980 and the density was 2.84×10^{-4} person/m^2.[7)]

Table 1 shows consumption and inhalation rates selected to estimate the internal exposure by ingestion and inhalation. Consumption rates were the surveyed value in the vicinity of the Wolsung site.[8)] Shoreline, swimming and boating times were assumed for the typical behavior of Korean. Inhalation rate was the value established for the reference Korean.[8),9),10)] Average productivities of agricultural and marine food were surveyed and analyzed, seperately within 80km radius of the site and at major fishing ports. As a result for the land, average production of vegetation (including the crop), milk and meat were 5.57×10^{-2}kg/m^2.yr, 4.22×10^{-3}l/m^2.yr, and 2.25×10^{-3} kg/m^2.yr, respectively.

The important transfer parameters were shown at the Table 2. There are many factors like dose conversion and bioaccumulation factors, which are uncertain typically to determine owing to structural and metabolic differences.

2) Atmospheric and oceanic diffusion

Meteorological data during two years(1982~1983) were processed to compute the wind frequency and atmospheric diffusion factor around the Wolsung site. Terrain effect and land-sea breeze phenomena were not considered. Land region locates counterclockwise from NE to WSW, whose terrain height are around 200m within the radius of 15km. But the vertical dispersion coefficient increase could be neglected by a little change, which would cause less dose devotion. And land-sea breeze effect to concen-

Table 1. Maximum (Average) Cosumption Rate.[8)]

Production and activity (year base)	Infant	Child	Teenager	Adult
Crops (kg)	—	366.2 (142.3)	604.6 (234.9)	646.4 (213.5)
Vegetables (kg)	—	41.9 (28.9)	68.3 (47.8)	73.9 (43.4)
Milk (l)	31.9	31.9 (16.4)	65.7 (32.9)	60.6 (31.8)
Meat (kg)	—	33.8 (10.6)	55.8 (17.5)	59.7 (15.9)
Fish (kg)	—	75.9 (23.2)	125.5 (38.3)	134.0 (34.8)
Algae (kg)	—	4.0 (1.7)	6.6 (2.8)	7.1 (2.6)
Shoreline (hr)	—	120.0 (8.3)	180.0 (47.0)	350.0 (9.5)
Swimming (hr)	—	9.4 (9.4)	18.9 (18.9)	2.0 (2.0)
Boating (hr)	—	—	—	11.0 (11.0)
Inhaltion (m^3)	1400.0	2900.0(2900.0)	6200.0(6200.0)	6200.0(6200.0)

Table 2. Characteristic Values of Major Factors and Parameters Adopted for the Calculation of Exposure Dose.[10,15]

Factor and parameters	Value
Discharge rate of the liquid effluents	1337.5 ft^3/sec
Shore width factor	0.5
Mixing ratio[6]	1.0
Environmental transit time from release to receptor	24 hrs
Transfer constant from water to sediment	7.2×10^{-2}/kg-hr
Fraction of crops and fruits grown in garden of interest	7.6×10^{-1}
Fraction of leafy vegetables grown in garden of interest	1.0
Period of vegetation exposure during growing season (pastured grass: crop)	440 : 2160 hrs
Transport time from animal feed-milk-man	2 days
Time delay between harvest of vegetables crops and ingestion (veget.: crop)	24 : 1440 hrs
Average time from slaughter of meat animal to consumption	20 days
Effective surface density of soil (in 15cm depth)	240 kg/m^2
Fraction of deposited activity retained on crops, vegetables and pastured grass	2.5×10^{-1}
Period of long term buildup for activity in sediment or soil	15 yrs
Attenuation factor accounting for shield	0.7
Total population within 80 km radius[8]	5,683,000
Composition of age groups (adult: teenager: child)[7]	0.58 : 0.17 : 0.25

Based on the maximum individual.

tration accumulation usually occurs beyond the concerned area.[11]

Table 3 shows the atmospheric diffusion parameters to be computed with about 70 thousand meteorological data based on 15 min. These results obtained by the equation(9) show the maximum value to the direction NNE onshore. When the stack height is below the 75m, the concentration profiles changed a little do not give considerable effect on the exposure dose beyond the radius of 500m from the source.[12] It was assumed that the critical group be located in the site boundary, which is 914m in the Wolsung site. Thus the maximum individual dose should be caused to this NNE direction in the site boundary.

This result can be verified by the Table 4 which shows the wind frequencies. The NNE direction with the largest diffusion factor relates directly to the frequent direction SSW in the

Table 3. Atmospheric Diffusion Factors at the Site Boundary (914m), Wolsung, 1981~1982. Unit: sec/m^3

Dieection	χ/Q	Direction	χ/Q
N	2.230E-06	S	3.090E-06
NNE	4.370E-06	SSW	3.320E-06
NE	3.720E-06	SW	1.520E-06
ENE	2.890E-06	WSW	1.010E-06
E	1.810E-06	W	5.240E-07
ESE	2.750E-06	WNW	6.200E-07
SE	2.030E-06	NW	5.160E-07
SSE	3.450E-06	NNW	1.180E-06

Table 4. Gross Wind Rose for the Wolsung Site, 1981~1982.

Direction	%	Direction	%
N	9.7	S	5.0
NNE	9.1	SSW	11.0
NE	3.2	SW	7.9
ENE	2.0	WSW	6.0
E	1.0	W	5.1
ESE	1.0	WNW	12.3
SE	0.9	NW	10.4
SSE	2.1	NNW	11.3

* Calm codition has 1.6% frequency.

Table 5. Exposure and Critical Group for Unit Ci Discharge of Gaseous Effuents

Radionuclide	Critical organ	Critical age group	Dominant pathway	Exposure dose (mrem/Ci. yr)
H3	T. Body	Child	Veget. Ingest.	6.968E-04
C14	T. Body	Child	Veget. Ingest.	1.184E-01
Mn54	T. Body	Child	Ground depos.	8.542E-01
Fe55	T. Body	Child	Veget. Ingest.	9.398E-02
Fe59	G.I. Tract	Adult	Meat Ingest.	1.183E+00
Co58	G.I. Tract	Adult	Veget. Ingest.	6.314E-01
Co60	T. Body	Child	Ground depos.	1.251E+01
Sr90	Bone	Child	Veget. Ingest.	7.817E+02
I131	Thyroid	Infant	Milk Ingest.	1.335E+02
I133	Thyroid	Infant	Milk Ingest.	1.588E+00
Cs137	T. Body	Adult	Ground Depos.	1.099E+01
Ar41	T. Body	Adult	Plume Immer.	6.510E+04
Kr85	Skin	Adult	Plume Immer.	1.420E-04
Kr87	T. Body	Adult	Plume Immer.	4.360E-04
Xe133	T. Body	Adult	Plume Immer.	2.170E-05
Xe135	T. Body	Adult	Plume Immer.	1.330E-04

wind rose. Consequently the critical pathway should be found in this direction.

General approach was applied by the Gaussian-like solution to investigate the marine diffusion. Dilution factor, D was assumed conservatively to be unity. The more dilution factor, the less conc. of radioactive effluent at a position. The dilution factor, for example, at 10km down-current is approximately 7 for a 52m^3/sec (1830 ft^3/sec) discharge. And volumetric discharge rate was used with 37.87m^3/sec (1337.5ft^3/sec).

When the D_F is assumed as constant, radioactive concentration can be determined by eq. (12), not eq. (11). But it is noticed that mixing ratio (reciprocal of dilution factor) depends on the hydrological dispersion model employed like eq. (11). And it can be compensated by an appropriate flow-field frequency functions for more correct estimation.

3) **Critical pathway for every radionuclide**

As shown in Figure 3, there are many exposure pathways. In the case of gaseous effluents, four kinds of pathways were considered such as plume immersion, ground contamination, inhalation, and ingestion (seperately of crop and vegetable, milk, and meat). And doses were computed for four age groups and eight body organs to estimate the critical group. In the case of liquid effluents, four kinds of pathways were included such as investion (seperately of fish, algae and invertebrate), shoreline deposit, swimming and boating. And infant was excluded in the age group for ingestion pattern.

It was considered that there were no other pathways which might provide a significant contribution (about 10% additional dose) to the total dose due to a unique condition. Thus the critical pathways were analyzed by investigating the exposure of every organ from only the above pathways for unit dischage (1 Ci/yr) of every radionuclide.

Table 5 shows the critical organ and pathway for major radionuclide of gaseous effluent. It's the result to be analyzed with the dose calculation model of Reg. guide 1.109, U.S. by the concentration factor method mentioned. Every radionclide gives its own characteristic effect to

Table 6. Exposure and Critical Group for Unit Ci Discharge of Liquid Effluents.

Rationuclide	Critical organ	Critical age group	Dominant pathway	Exposure dose (mrem/Ci. yr)
H3	T. Body	Child	Fish Ingest.	1.220E-05
Mn54	G. I. LLI.	Adult	Fish Ingest.	1.340E+00
Fe55	Liver	Child	Fish Ingest.	1.180E+00
Fe59	G.I. LLI.	Adult	Fish Ingest.	1.140E+01
Co58	G.I. LLI.	Adult	Fish Ingest.	2.640E-01
Co60	T. Body	Adult	Shore. Depos.	4.870E-01
Br83	T. Body	Teenager	Swimming	3.170E-07
Sr90	Bone	Teenager	Fish Ingest.	2.730E+00
Zr95	G.I. LLI.	Adult	Fish Ingest.	8.720E-01
Tc99m	G.I. LLI.	Child	Algae Ingest.	9.170E-04
Te127	G. I.LLI.	Teenager	Algae Ingest.	1.360E-02
Te129	T. Body	Teenager	Swimming	3.260E-06
I131	Thyroid	Child	Algae Ingest.	2.090E+01
I133	Thyroid	Child	Algae Ingest.	2.440E+00
Cs137	T. Body	Adult	Fish Ingest.	5.350E-01
Ba140	G.I. LLI.	Adult	Algae Ingest.	1.620E-01

Table 8. Derived Release Limits (DRL) for the Gaseous and Liquid Radionuclides

Radicnuclide	DRL gaseous (Ci/yr)	DRL liquid (Ci/yr)	Radionuclide	DRL geseous (Ci/yr)	DRL liquid (Ci/yr)
H3	7.176E+05	4.098E+07	Te127	—	1.103E+05
C14	4.223E+03	—	Te129	—	4.601E+08
Mn54	5.854E+02	1.119E+03	I131	1.124E+01	1.435E+02
Fe55	5.320E+30	1.271E+03	I133	9.446E+02	1.230E+03
Fe59	1.268E+03	1.976E+02	Cs137	4.549E+01	9.346E+02
Co58	2.376E+03	5.682E+03	Ba140	7.269E+03	9.259E+03
Co60	3.997E+01	1.027E+03	Ar41	7.680E+05	—
Br83	—	1.577E+09	Kr85	2.113E-07	—
Sr90	3.838E+00	1.099E+03	Kr87	1.147E-06	—
Zr95	1.244E+03	1.720E+03	Xe133	2.304E+07	—
Tc99m	2.426E+06	1.636E+06	Xe135	3.759E+06	—

the body organs as follows. Noble gases like Xe 133, 135, Kr 87 and Ar 41 act mostly by the direct irradiation of radioactive plume and a little by the ground contamination. These kinds of plumes give exposures to the skin or the total body. Iodine 131 and 133 act by the inhalation or ingestion of vegetation and give major effect on thyroid. In the case of particulates, their behaviors are different each other; Sr-90 to the bone by the ingestion of vegetation, Cs-137 to bone or liver by the ingestion of milk or vegetation, Mn-54 to the total body by the irradiation on contaminated ground, and Fe-59 to the G.I. tract by the ingestion of meat or vegetation, less by ground contamination. Special case is for tritium and C-14. Tritium has no effect by the plume and ground deposition pathways, but same effects to the all organs except the bone by the other pathways.

Table 6 shows the similar characteristics, but a few differences result in the different pathways for the liquid effluents.

4) **Derived release limit**

Dose conversion was made by the use of block data suggested by G.R. Hoenes[13] and computer codes-GASPAR and LADTAP based on the U. S. NRC regulatory guides. Dose limitations recommended by the ICRP are different in each case of exposure organ. It is not the critical organ even if the exposure of a organ is more than others'. Thus reasonable weighting should be given to every organ, based on the differences of dose limits for every organ.

In Table 7 the derived release limits were shown for the both cases of gaseous and liquid effluents, which were the results analyzed by the concentration factor method in the Wolsung site. These values are the upper limits for the release rate of each single radionuclide from a single source. For the combined release of radionuclides, the criterion of equation (1) should be kept. But real-time based control of the release has difficulty dependent on the time variance in keeping the criterion. Thus a safety margin should be placed on these derived release limits to consider the above time factor including socio-environmental changes. Usually 1% of the derived limits used to be selected as operating target conservatively.[14]

Referring to the concept of critical pathway, scale and selectivity can be considered. If the microscale view point is given to analyze food-chains, ingestion pathway only can be selected usually for the discharge of Cs and Sr which have characteristic metabolic features. But the pathways should be analyzed overall in the case of deriving the release limit.

5. Conclusion

Based on the primary dose equivalents, derived release limit was computed for the Wolsung plant by the analysis of overall exposure pathways on concentration factor method. This limit is the upper discharge rate that only radionuclide can be released from single source keeping the primary limit. In the real case of combined exposures by several radiocuclides, the criterion suggested at equations(5) should be kept. To avoid conservatively the uncertainty of discharge rate variant to time, the operating limit was recommended to be established by some percentile of the derived limits.

To estimate the critical group which assumed to be located in the site boundary of the Wolsung plant, atmospheric and marine diffusion phenomena were investigated by appropriate models. Overall analysis of pathways made it possible to find the critical organ and pathway for every radionuclide.

These derived limits have a considerable reality in applying to the actual operating for these are the limits which are derived by considering real characteristics of environment and based on discharge rate.

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