II. RISK ASSESSMENT

1. Introduction

Hazard (유해성): a probability of adverse effects in a particular situation

Risk (위해도): a measure of the probability

Hazardous vs. Risk (e.g., 총은 유해성이 높다. 닫힌 상자 속의 총은 위해도가 거의 없다. A gun is very dangerous. However, a gun that is contained within a safe or one that does not hold bullets holds almost no threat)

Risk assessment (Quantitative risk assessment)

Risk management: The use of the results of a risk assessment to make policy decisions

2. Risk Perception

- People respond to the hazards they perceive. If their perceptions are faulty, risk management efforts may be misdirected.
- 자동차 사고에 대한 risk 는 아주 잘 계량화되고 있으나, 담배나 음주에 대한 risk 의 계량화는 어려운 문제이다. Some risks are well quantified. For example, the frequency and severity of automobile accidents are well documented. In contrast, the risks resulting from use of alcohol and tobacco are more difficult to document.
- Following Table illustrate different perceptions of risk, i.e., “present risk of death”.

  40 members of LOWV (League of Women Voters):

  30 College of Students

  25 business and professional members of the “Active Club”

  15 Experts

TABLE 5–1 Ordering of Perceived Risk for 30 Activities and Technologies[a]

Source of Risk	Group 1: LOWV	Group 2: College Students	Group 3: Active Club Members	Group 4: Experts
Nuclear power	1	1	8	20
Motor vehicles	2	5	3	1
Handguns	3	2	1	4
Smoking	4	3	4	2
Motorcycles	5	6	2	6
Alcoholic beverages	6	7	5	3
General (private) aviation	7	15	11	12
Police work	9	8	7	17
Pesticides	9	4	15	8
Surgery	10	11	9	5
Fire fighting	11	10	6	18
Large construction	12	14	13	13
Hunting	13	18	10	23
Spray cans	14	13	23	26
Mountain climbing	15	22	12	29
Bicycles	16	24	14	15
Commercial aviation	17	16	18	16
Electric power	18	19	19	9
Swimming	19	30	17	10
Contraceptives	20	9	22	11
Skiing	21	25	16	30
X-rays	22	17	24	7
High school and college football	23	26	21	27
Railroads	24	23	20	19
Food preservatives	25	12	28	14
Food coloring	26	20	30	21
Power mowers	27	28	25	28
Prescription antibiotics	28	21	26	24
Home appliances	29	27	27	22
Vaccinations	30	29	29	25

LOWV = League of Women Voters members.

[a] The ordering is based on the geometric mean risk ratings within each group. Rank 1 represents the most risky activity or technology.

Source: Adapted from: Slovic P., B. Fischoff, and S. Lichtenstein, "Rating risk," *Environment,* vol. 21, pp. 1–20, 1979.

For comparison, Table 5–2 summarizes the risk of dying from some causes of death.

In developing standards for environmental protection, the EPA often selects a lifetime incremental risk of cancer in the range of 10^{-7} to 10^{-4} as acceptable. Table 5–3 shows a comparison of other activities that, based on statistical evidence, yield a risk of 10^{-6}.

Of course, if the risk of dying in one year is increased, the risk of dying from another cause in a later year is decreased. Because accidents often occur early in life, a typical accident

In the case of 'nuclear power', 'Experts' showed relatively low risk perception. However, after the Fukushima Accident in 2011?

리스크의 크기 = 유해성의 강도 x 노출확률

Magnitude of Risk = Strength of Hazard x Probability of Exposure

계산된 리스크의 크기가 같은 값을 가질지라도, 개인이 느끼는 리스크의 크기는 다를 수 있다. 원자력 발전소 사고로 죽을 리스크는 스키를 타다 죽을 리스크보다 훨씬 적지만 일반인이 느끼는 리스크는 원자력 발전소 사고의 경우가 훨씬 크다. 또, 베트남 전쟁에서 군인이 사망할 확률이 오토바이 사고로 사망할 확률과 비슷하나, 역시 체감 리스크는 전자가 훨씬 크다.

Although the estimated magnitude of risk may be the same, the magnitude of risk that one feels may be different. Although the estimated risk of dying from an accident by a nuclear power plant is much lower than that of the death rates from skiing, most people feel as if the risk with a nuclear power plant is much greater. In another example, the possibility of a soldier dying in a war at Vietnam is quite similar to the probability of dying in a motorcycle accident, yet we feel much greater amount of risk with the former.

(예) 1989 년 미국 CBS 의 시사 프로그램 “Sixty minutes”는 “알라”라는 식물성장억제제에 관한 고발 프로그램을 방영한다. “알라”는 유니로열이라는 제조회사가 붙인 상품명으로 원 학술명칭은 다미노자이드이며, 사과의 숙성을 늦춰 출하 시기를 조절할 수 있게 하며 수확전 낙과를 방지하는 효과가 있다.

(Example) In 1989, American TV program “Sixty minutes” on CBS discusses the problem of the plant growth inhibitor “Allah”. Allah is a product by Uniroyal Holdings Inc., with the scientific name being Daminozide, B-9. It slows the apple ripening process and therefore allows the control of its time of harvest, and prevents pre-harvest fruit-drop.

이 프로그램에서는 알라가 발암물질이며, 알라가 뿌려진 사과나 그 사과를 원료로 만든 사과주스를 먹은 걸로 인해 7 세 이하 아동 가운데 5, 300 명이 암에 걸리게 될 것으로 보도한다. 그런데, 미국 전체 어린이는 약 2,200 만명이며 통계에 의하면 이 중이 30%인 약 700 만명은 언젠가는 암에 걸려 죽게 된다. 즉, 알라의 의해 추가되는 발암사망 확률은 0.024%에 불가하다.

The program claims that “Allah” is carcinogenic, and that any apple or products incorporating apples that have been touched by “Allah” will affect consumers, giving cancer to approximately 5,300 kids under the age of 7. However, there are approximately 22,000,000 (22 million) children in the United States, and according to statistics, approximately 30% (~7,000,000 children) will die of cancer eventually. That is, the increased chance of death caused by “Allah” being the carcinogen is only 0.024%.

체감 리스크 = 유해성의 강도 x 증폭계수

Risk felt by subject = Strength of Hazard x Degree of Amplification

증폭계수: 사회적 분노반응, 공포반응 등과 같은 주관적 요소로 특히, 공포반응은 유해성의 강도가 클수록 선택의 여지가 적을수록 불확실하고 겪어 본 일이 없을수록 커진다. 예, 담배는 발암 원인의 약 1/3, 한국 사람은 4 명 중에 한명이 암으로 죽는다. 따라서, 흡연은 최소한 목숨의 1/12 이 달린 문제임. 흡연보다 인간광우병은 훨씬 적은 리스크이나 느끼는 리스크는 훨씬 클 수 있다.

Degree of Amplification (Society Response): Subjective factors such as societal anger and fear, and especially fear may increase depending on increased levels of hazard, decreased controllability over the situation, and inexperience. For instance, cigarettes are the cause approximately 1/3 of all carcinogenic cancers, and 1 in 4 Korean people die of cancer. Furthermore, smoking is a problem that entails at least 1/12 of people’s lives. Cigarette smoking may affect at minimum 1/12 of someone’s life, but Mad Cow Disease, which has a much smaller risk, may cause much larger feelings of risk.

An example of risk assessment,

(given) In the United States, 3.9 million deaths per year

541,532 were cancer-related

(solution) the risk of dying from caner in U.S. is

$$\frac{541,532}{3.9\times10^{6}} = 0.14$$

the annual risk (assuming a 70-year life expectancy and ignoring age factors)

$$\frac{0.14}{70} = 0.002$$

Then, the life-time risk of death from all causes is? 1.0 (100%)

U.S. EPA selects a lifetime incremental risk of cancer in a range of 10^{-7} to 10^{-4} as acceptable. (작업환경기준치는 일반환경기준치에 비하여 높게 설정됨)

Annual Risk of Death from Selected Common Human Activities

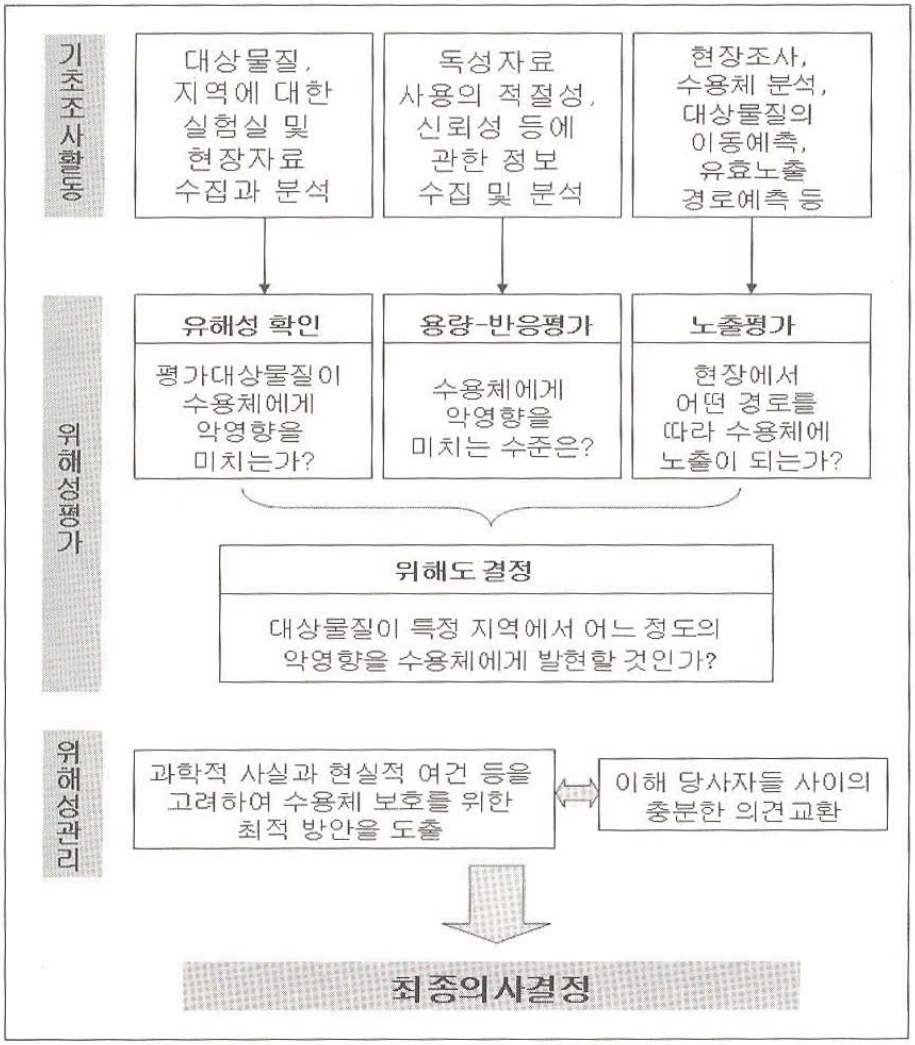
Cause of Death	Number of Deaths in Representative Year	Individual Risk per Year
Black lung disease (coal mining)	1,135	8×10^{-3}, or 1/125
Heart attack	654,092	2.2×10^{-3}, or 1/450
Cancer	550,270	1.9×10^{-3}, or 1/525
Coal mining accident	180	1.3×10^{-3}, or 1/770
Fire fighting	—	3×10^{-4}, or 1/3,333
Motor cycle driving	4,553	7.9×10^{-4}, or 1/1,270
Motor vehicle	43,947	1.5×10^{-4}, or 1/6,682
Truck driving	480	10^{-4}, or 1/10,000
Falls	18,535	6.3×10^{-5}, or 1/15,800
Football (averaged over participants)		4×10^{-5}, or 1/25,000
Home accidents	25,000	1.2×10^{-5}, or 1/83,333
Bicycling (assuming one person per bicycle)	784	7.8×10^{-6}, or 1/128,000
Air travel: one transcontinental trip/year		2×10^{-6}, or 1/500,000

Sources: National Center for Health Statistics, 2004.
Selected data from: NHTSA, 2005; Hutt, 1978; and Rodricks and Taylor, 1983.

3. Risk Assessment (위해성 평가)

어떤 물질이 위해성을 발현하려면 (1) 그 물질의 농도가 노출허용수준을 초과해야 하며, (2) 그 물질이 수용체로 전달될 수 있는 노출경로가 있고, (3) 전달된 물질과 접촉하는 수용체가 존재해야 한다.

In order for a compound to be considered hazardous, it must 1) exceed the recommended amount of safety, 2) has a way of spreading 3) have pathways to expose receptors to the compound.



<그림 Ⅲ-5-1> 위해성 평가 및 관리의 주요 요소 및 과정(NRC/NAS 1983으로부터 수정)

* NRC(National Research Council)/NAS(National Academy of Science)

Data collection and Evaluation (기초조사)

Toxicity Assessment (유해성/독성 평가)

Exposure Assessment (노출 평가)

Risk Characterization (위해도 결정)

- Risk assessment is site-specific.

3.1 Data Collection and Evaluation

- gathering and analyzing site-specific data relevant to human health concerns for the purpose of identifying substances.
- gathering background and site information, the preliminary identification of potential human and ecosystem exposure through sampling, and the development of a sample collection strategy
- Background information

  (1) possible contaminants

  (2) concentrations of the contaminants in key sources and media of interest, characteristics of sources, and information related to the chemical's release potential

  (3) characteristics of the environmental setting that could affect the fate, transport, and persistence of the contaminants
- A conceptual model of pathways and exposure points can be formed from the background data and site information.

3.2 Toxicity Assessment

- The process of determining the relationship between the exposure to a contaminant and the increased likelihood of the occurrence or severity of "adverse effects", Hazardous identification + Dose-response evaluation
- Hazardous identification: determines (1) whether exposure to a contaminant causes increased adverse effects for humans and (2) to what level of severity
- Dose-response evaluation: relate the dose of information to the incidence (발생율) of adverse reactions in an exposed population

- Types of tests: *vivo* test vs. *vitro* test

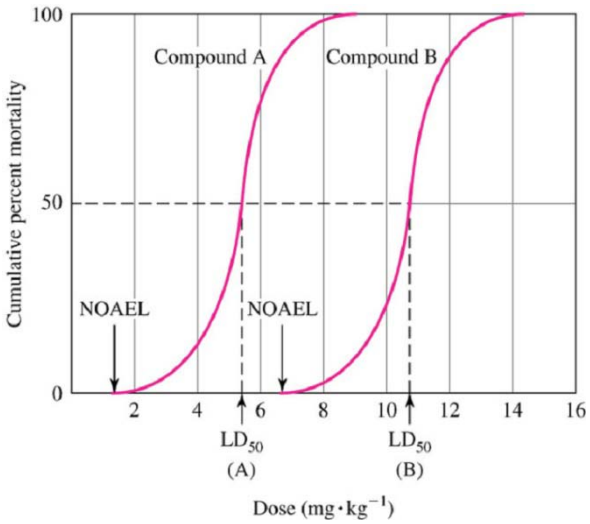
  Vivo test (using laboratory animals such as rats, swine, etc.): (a) expensive and time consuming, (b) unsuitable for a rapid evaluation of site-specific risks, (c) ethical issues, (d) difficulty to confidently extrapolate the results from in *vivo* test to humans.

  Vitro test (simulate parameters such as pH and chemistry, representative of the human digestive tract include stomach and small intestine): "bioaccessibility (생물접근성, e.g., solubilized)" ≥ "bioavailability (생물이용성, e.g, absorbed in biological membrane)"

- Dose: the mass of chemical received by an animal or exposed individual

  The unit of dose is not constant. e.g., mg/kg = parts per million, or where the dose is administered over time, e.g., mg/kg,day

- Dose-Response Curve (용량-반응 평가): (Figure 5-2, Gaussian cumulative-frequency curve)



  LD_{50} (반수치사량): lethal dose for 50% of the animals

  NOAEL (no observed adverse effect level, 최대무작용량)

  RfD (Reference dose, 참고섭취량) or ADI (Acceptable daily intake, 일평균섭취량) for noncarcinogens: without appreciable risk, obtained by (NOAEL)/(Safety factor)

일반적인 safety factor = 100 (동물과 사람의 차이 10 x 개인 차이 10), 독성 평가 과정에서 정보가 불충분하거나 측정이 곤란한 경우에는 추가로 x2, x5, x10 을 하기도 함

The normal safety factor of 100 (the difference between humans and animals x10 individual differences x10), and if the available information to determine the toxicity of the substance is insufficient, addition x2, x5, x10 may apply

TABLE 5–6 RfDs for Chronic Noncarcinogenic Effects for Selected Chemicals[a]

Chemical	Oral RfD ($mg \cdot kg^{-1} \cdot day^{-1}$)	Chemical	Oral RfD ($mg \cdot kg^{-1} \cdot day^{-1}$)
Acetone	0.1	Phenol	0.6
Barium	0.05	PCB	
Cadmium	0.0005	Aroclor 1016	7.0×10^{-6}
Chloroform	0.01	Aroclor 1254	2.0×10^{-6}
Cyanide	0.02	Silver	0.003
1,1-Dichloroethylene	0.009	Tetrachloroethylene	0.01
Hydrogen cyanide	0.02	Toluene	0.2
Methylene chloride	0.06	1,2,4-Trichlorobenzene	0.02
Pentachlorophenol	0.03	Xylenes	2.0

[a] Values are frequently updated. Refer to IRIS for current data.
Source: U.S. Environmental Protection Agency IRIS database, 1996.

TABLE 5–4 Glossary of Toxicological Terms

Acute toxicity	An adverse effect that has a rapid onset, short course, and pronounced symptoms.
Cancer	An abnormal growth process in which cells begin a phase of uncontrolled growth and spread.
Carcinogen	A cancer-producing substance.
Carcinomas	Cancers of epithelial tissues. Lung cancer and skin cancer are examples of carcinomas.
Chronic toxicity	An adverse effect that frequently takes a long time to run its course and initial onset of symptoms may go undetected.
Genotoxic	Toxic to the genetic material (DNA).
Initiator	A chemical that starts the change in a cell that irreversibly converts the cell into a cancerous or precancerous state. Needs to have a promoter to develop cancer.
Leukemias	Cancers of white blood cells and the tissue from which they are derived.
Lymphomas	Cancers of the lymphatic system. An example is Hodgkin's disease.
Metastasis	Process of spreading or migration of cancer cells throughout the body.
Mutagenesis	Mutagens cause changes in the genetic material of cells. The mutations may occur either in somatic (body) cells or germ (reproductive) cells.
Neoplasm	A new growth. Usually an abnormally fast-growing tissue.
Oncogenic	Causing cancers to form.
Promoter	A chemical that increases the incidence to a previous carcinogen exposure.
Reproductive toxicity	Decreases in fertility, increases in miscarriages, and fetal or embryonic toxicity as manifested in reduced birth weight or size.
Sarcoma	Cancer of mesodermal tissue such as fat and muscle.
Subacute toxicity	Subacute toxicity is measured using daily dosing during the first 10% of the organism's normal life expectancy and checking for effects throughout the normal lifetime.
Teratogenesis	Production of a birth defect in the offspring after maternal or paternal exposure.

EXAMPLE 5–1 An experiment was developed to ascertain whether a compound has a 5% probability of causing a tumor. The same dose of the compound was administered to 10 groups of 100 test animals. A control group of 100 animals was, with the exception of the test compound, exposed to the same environmental conditions for the same period of time. The following results were obtained:

Group	Number of Tumors	Group	Number of Tumors
A	6	F	9
B	4	G	5
C	10	H	1
D	1	I	4
E	2	J	7

No tumors were detected in the controls (not likely in reality).

Solution The average number of excess tumors is 4.9%. These results tend to confirm that the probability of causing a tumor is 5%.

If, instead of using 1000 animals (10 groups × 100 animals), only 100 animals were used, it is fairly evident from the data that, statistically speaking, some very anomalous results might be achieved. That is, we might find a risk from 1–10%.

Note that a 5% risk (probability of 0.05) is very high in comparison with the EPA's objective of achieving an environmental contaminant risk of 10^{-7} to 10^{-4}.

At low dosage, the slope of the dose-response curve can be represented by a “slope factor (SF, kg,day/mg)”. For example, for a dose-response curve (Mortality vs. Dose (mg/kg,day)). Values are updated by IRIS (Integrated Risk Information System, EPS) etc. “No threshold(임계치)” ? In the case of carcinogens, marginal value is not considered.
발암물질의 경우에는 임계치를 인정하지 않는다.

Toxicity is a very relative term depending on the individual and species.
동물실험을 통해 얻은 독성정보의 한계: (1) 동물은 일반적으로 체중이 커지면 독성물질의 체중 당 대사능력도 커지는 경향. 예, 모르모트의 다이옥신 LD_{50} 는 0.6~2.1 μg/kg 이나 햄스터의 다이옥신 LD_{50} 는 1,000~5,000 μg/kg. 반대로 비소는 사람이 동물보다 더 민감. “사람은 큰 쥐가 아니다”
Through *in vivo* experiments, we have gained one piece of information concerning toxicity. In general, the heavier an animal is, the higher metabolic capacity for toxic substances. For example, a guinea pig’s dioxin LD_{50} is 0.6~2.1 μg/kg or a hamster’s dioxin LD_{50} is 1,000~5,000 μg/kg. On the contrary, humans are more sensitive or susceptible to arsenic. “Humans are not big rats”

TABLE 5–5 Slope Factors for Potential Carcinogens[a]

Chemical	CPS_0 (kg · day · mg^{-1})	CPS_i (kg · day · mg^{-1})
Arsenic	1.5	15.1
Benzene	0.029	0.029
Benzo(*a*)pyrene	7.3	N/A
Cadmium	N/A	6.3
Carbon tetrachloride	0.13	0.0525
Chloroform	0.0061	0.08
Chromium (VI)	N/A	42.0
DDT	0.34	0.34
1,1-Dichloroethylene	0.6	0.175
Dieldrin	16.0	16.1
Heptachlor	4.5	4.55
Hexachloroethane	0.014	0.014
Methylene chloride	0.0075	0.00164
Polychlorinated biphenyls	7.7	N/A
2,3,7,8-TCDD[b]	1.5×10^5	1.16×10^5
Tetrachloroethylene[b]	0.052	0.002
Trichloroethylene[c]	w	0.006
Vinyl chloride[b]	1.9	N/A

CPS_0 = cancer potency slope, oral; CPS_i = cancer potency slope, inhalation; w = withdrawn from IRIS.

[a] Values are frequently updated. Refer to IRIS and HEAST for current data.

[b] *Annual Health Effects Assessment Summary Tables* (HEAST) U.S. Environmental Protection Agency, 540/R-94/036, 1994.

[c] U.S. Environmental Protection Agency, National Center for Environmental Assessment http://www.epa.gov/ncea

Source: With the exceptions noted this information is taken from the U.S. Environmental Protection Agency, IRIS database, October 1996.

3.3 Exposure Assessment

- To estimate the magnitude of exposure to chemicals of potential concern. The magnitude of exposure is based on chemical intake and pathways of exposure.

TABLE 5–7 Potential Contaminated Media and Corresponding Routes of Exposure

Media	Routes of Potential Exposure
Groundwater	Ingestion, dermal contact, inhalation during showering
Surface water	Ingestion, dermal contact, inhalation during showering
Sediment	Ingestion, dermal contact
Air	Inhalation of airborne (vapor phase) chemicals (indoor and outdoor)
	Inhalation of particulates (indoor and outdoor)
Soil/dust	Incidental ingestion, dermal contact
Food	Ingestion

2. The magnitude of exposure from the pathway is low, or
3. The probability of exposure is low and incidental risk is not high

There are two methods of quantifying exposure: point estimate methods and probabilistic

Reasonable maximum exposure (RME) in the point estimate methods

- RME: the highest exposure that is reasonably expected to occur and is intended to be a conservative estimate within the range of possible exposures
- (1) estimate exposure concentrations by direct measurements or indirect prediction and (2) estimate CDI (chronic daily intake, mg/kg,day) or AD (adsorbed dose, mg/kg,day) using the residential exposure equations for various pathways (Table 5-8)

Leach tests for soil-contaminants partitioning

- Synthetic Precipitation Leaching Procedure (SPLP) (USEPA): for groundwater infiltration
- Field Leach Test (FLT) (USGS): for surface runoff
- Leaching Procedures for Subsequent Chemical and Ecotoxicity Testing (LP-SCET) (ISO): Ecotoxicity estimation

TABLE 5–8 Residential Exposure Equations for Various Pathways

Ingestion in drinking water

$$CDI = \frac{(CW)(IR)(EF)(ED)}{(BW)(AT)} \quad (5\text{–}10)$$

Ingestion while swimming

$$CDI = \frac{(CW)(CR)(ET)(EF)(ED)}{(BW)(AT)} \quad (5\text{–}11)$$

Dermal contact with water

$$AD = \frac{(CW)(SA)(PC)(ET)(EF)(ED)(CF)}{(BW)(AT)} \quad (5\text{–}12)$$

Ingestion of chemicals in soil

$$CDI = \frac{(CS)(IR)(CF)(FI)(EF)(ED)}{(BW)(AT)} \quad (5\text{–}13)$$

Dermal contact with soil

$$AD = \frac{(CS)(CF)(SA)(AF)(ABS)(EF)(ED)}{(BW)(AT)} \quad (5\text{–}14)$$

Inhalation of airborne (vapor phase) chemicals

$$CDI = \frac{(CA)(IR)(ET)(EF)(ED)}{(BW)(AT)} \quad (5\text{–}15)$$

Ingestion of contaminated fruits, vegetables, fish and shellfish

$$CDI = \frac{(CF)(IR)(FI)(EF)(ED)}{(BW)(AT)} \quad (5\text{–}16)$$

where ABS = absorption factor for soil contaminant (unitless)
AD = absorbed dose (in mg · kg^{-1} · day^{-1})
AF = soil-to-skin adherence factor (in mg · cm^{-2})
AT = averaging time (in days)
BW = body weight (in kg)
CA = contaminant concentration in air (in mg · m^{-3})
CDI = chronic daily intake (in mg · kg^{-1} · day^{-1})
CF = volumetric conversion factor for water = 1 L · 1000 cm^{-3}
= conversion factor for soil = 10^{-6} kg · mg^{-1}
CR = contact rate (in L · h^{-1})
CS = chemical concentration in soil (in mg · kg^{-1})
CW = chemical concentration in water (in mg · L^{-1})
ED = exposure duration (in years)
EF = exposure frequency (in days · $year^{-1}$ or events · $year^{-1}$)
ET = exposure time (h · day^{-1} or h · $event^{-1}$)
FI = fraction ingested (unitless)
IR = ingestion rate (in L · day^{-1} or mg soil · day^{-1} or kg · $meal^{-1}$)
= inhalation rate (in m^3 · h^{-1})
PC = chemical-specific dermal permeability constant (in cm · h^{-1})
SA = skin surface area available for contact (in cm^2)

Source: Reprinted from: *Risk Assessment Guidance for Superfund.* Volume 1, *Human Health Evaluation Manual* (part A). U.S. Environmental Protection Agency, EPA/540/1-89/002, 1989.

TABLE 6–8 EPA Recommended Values for Estimating Intake

Parameter	Standard Value
Average body weight, adult female	65.4 kg
Average body weight, adult male	78 kg
Average body weight, child	
6–11 months	9 kg
1–5 years	16 kg
6–12 years	33 kg
Amount of water ingested daily, adult[a]	2.3 L
Amount of water ingested daily, child[a]	1.5 L
Amount of air breathed daily, adult female	11.3 m^3
Amount of air breathed daily, adult male	15.2 m^3
Amount of air breathed daily, child (3–5 y)	8.3 m^3
Amount of fish consumed daily, adult	6 $g \cdot day^{-1}$
Water swallowing rate, swimming	50 $mL \cdot h^{-1}$
Skin surface available, adult male	1.94 m^2
Skin surface available, adult female	1.69 m^2
Skin surface available, child	
3–6 years (average for male and female)	0.720 m^2
6–9 years (average for male and female)	0.925 m^2
9–12 years (average for male and female)	1.16 m^2
12–15 years (average for male and female)	1.49 m^2
15–18 years (female)	1.60 m^2
15–18 years (male)	1.75 m^2
Soil ingestion rate, children 1–6 years	100 $mg \cdot day^{-1}$
Soil ingestion rate, persons > 6 years	50 $mg \cdot day^{-1}$
Skin adherence factor, gardeners	0.07 $mg \cdot cm^{-2}$
Skin adherence factor, wet soil	0.2 $mg \cdot cm^{-2}$
Exposure duration	
Lifetime	75 years
At one residence, 90th percentile	30 years
National median	5 years
Averaging time	(ED)(365 days $\cdot$ $year^{-1}$)
Exposure frequency (EF)	
Swimming	7 days $\cdot$ $year^{-1}$
Eating fish and shell fish	48 days $\cdot$ $year^{-1}$
Exposure time (ET)	
Shower, 90th percentile	30 min
Shower, 50th percentile	15 min

[a] 90th percentile.

Source: U.S. EPA, 1989, 1997, 2004.

EXAMPLE 5–2 Estimate the chronic daily intake CDI of benzene from exposure to a city water supply that contains a benzene concentration equal to the drinking water standard. The allowable drinking water concentration (maximum contaminant level, MCL) is 0.005 mg · L^{-1}. Assume the exposed individual is an adult male who consumes water at the adult rate for 70 years, that he is an avid swimmer and swims in a local pool (supplied with city water) 3 days a week for 30 min and has been doing so since he was 30 years old. He takes a long shower every day. Assume that the average air concentration of benzene during the shower is 5 μg · m^{-3} [7]. From the literature, it is estimated that the dermal uptake from water is 0.0020 $m^3 \cdot m^{-2} \cdot h$ (This is PC in Table 5–8. PC also has units of meters per hour or centimeters per hour.) and that direct dermal absorption during showering is no more than 1% of the available benzene because most of the water does not stay in contact with skin long enough [8].

Solution From Table 5–7, we note that five routes of exposure are possible from the drinking water medium: (1) ingestion, dermal contact while (2) showering and (3) swimming, (4) inhalation of vapor while showering, and (5) ingestion while swimming.

We begin by calculating the CDI for ingestion (Equation 5–10).

$$\text{CDI} = \frac{(0.005\ \text{mg} \cdot \text{L}^{-1})(2.0\ \text{L} \cdot \text{day}^{-1})(365\ \text{days} \cdot \text{year}^{-1})(70\ \text{years})}{(70\ \text{kg})(70\ \text{years})(365\ \text{days} \cdot \text{year}^{-1})}$$

$$= 1.43 \times 10^{-4}\ \text{mg} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$$

The ingestion rate (IR) and body weight (BW) were selected from Table 5–9.

Equation 5–12 may be used to estimate absorbed dose while showering.

$$\text{AD} = \frac{(0.005\ \text{mg} \cdot \text{L}^{-1})(1.94\ \text{m}^2)(0.0020\ \text{m} \cdot \text{h}^{-1})(0.20\ \text{h} \cdot \text{event}^{-1})}{(70\ \text{kg})(70\ \text{years})}$$

$$\times \frac{(1\ \text{event} \cdot \text{day}^{-1})(365\ \text{days} \cdot \text{year}^{-1})(70\ \text{years})(10^3\ \text{L} \cdot \text{m}^{-3})}{(365\ \text{days} \cdot \text{year}^{-1})}$$

$$= 5.54 \times 10^{-5}\text{mg} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$$

But only about 1% of this amount is available for adsorption in a shower because of the limited contact time, so the actual adsorbed dose by dermal contact is

$$\text{AD} = (0.01)(5.54 \times 10^{-5}\ \text{mg} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}) = 5.54 \times 10^{-7}\ \text{mg} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$$

The surface area (SA) and exposure time were obtained from Table 5–9. The permeability constant was given in the problem statement. The exposure time is estimated by converting a long shower of 12 min to hours (12/60 = 0.2).

The adsorbed dose for swimming is calculated in the same fashion.

$$\text{AD} = \frac{(0.005\ \text{mg} \cdot \text{L}^{-1})(1.94\ \text{m}^2)(0.0020\ \text{m} \cdot \text{h}^{-1})(0.5\ \text{h} \cdot \text{event}^{-1})}{(70\ \text{kg})(70\ \text{years})}$$

$$\times \frac{(3\ \text{events} \cdot \text{week}^{-1})(52\ \text{weeks} \cdot \text{year}^{-1})(40\ \text{years})(10^3\ \text{L} \cdot \text{m}^{-3})}{(365\ \text{days} \cdot \text{year}^{-1})}$$

$$= 3.38 \times 10^{-5}\ \text{mg} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$$

In this case, because there is virtually total body immersion for the entire contact period and because there is virtually an unlimited supply of water for contact, there is no reduction for availability. The value of ET is computed from the swimming time (30 min = 0.5 h · event^{-1}). The exposure frequency is computed from the number of swimming events per week and the number of weeks in a year. The exposure duration (ED) is calculated from the lifetime and beginning time of swimming = 70 − 30 years = 40 years.

The inhalation rate from showering is estimated from Equation 5–15.

$$\text{CDI} = \frac{(5\mu\text{g}\cdot\text{m}^{-3})(10^{-3}\ \text{mg}\cdot\mu\text{g}^{-1})(0.833\ \text{m}^3\cdot\text{h}^{-1})(0.20\ \text{h}\cdot\text{event}^{-1})}{(70\ \text{kg})(70\ \text{years})} \times \frac{(1\ \text{event}\cdot\text{day}^{-1})(365\ \text{days}\cdot\text{year}^{-1})(70\ \text{years})}{(365\ \text{days}\cdot\text{year}^{-1})}$$

$$= 1.19 \times 10^{-5}\ \text{mg}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$$

The inhalation rate (IR) is taken from Table 5–9 and converted to an hourly basis.

For ingestion while swimming, we apply Equation 5–11.

$$\text{CDI} = \frac{(0.005\ \text{mg}\cdot\text{L}^{-1})(50\ \text{mL}\cdot\text{h}^{-1})(10^{-3}\ \text{L}\cdot\text{mL}^{-1})(0.5\ \text{h}\cdot\text{event}^{-1})}{(70\ \text{kg})(70\ \text{years})} \times \frac{(3\ \text{events}\cdot\text{week}^{-1})(52\ \text{weeks}\cdot\text{year}^{-1})(40\ \text{years})}{(365\ \text{days}\cdot\text{year}^{-1})}$$

$$= 4.36 \times 10^{-7}\ \text{mg}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$$

The contact rate (CR) was determined from Table 5–9. Other values were obtained in the same fashion as those for dermal contact while swimming.

The total exposure would be estimated as

$$\text{CDI}_\text{T} = 1.43 \times 10^{-4} + 5.54 \times 10^{-7} + 3.38 \times 10^{-5} + 1.19 \times 10^{-5} + 4.36 \times 10^{-7}$$

$$= 1.90 \times 10^{-4}\ \text{mg}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$$

From these calculations, it becomes readily apparent that, in this case, drinking the water dominates the calculation for benzene intake.

What kinds of pathways can be added in Korea? e.g., public bath

3.4 Risk Characterization

- to collaborate qualitative and quantitative conclusions about risk
- For the quantitative risk assessment for a single compound with low-dose cancer risk (< 0.01) by a single route,

  Risk = (intake)(slope factor)
- For the quantitative risk assessment for a single compound with high-dose cancer risk (> 0.01) by a single route,

  Risk = 1 – exp[-(intake)(slope factor)]
- For noncarcinogenic toxicity, “Hazardous Index (HI, 위험성지수)”

  $$\text{HI} = \frac{\text{Intake}}{\text{RfD}}$$

  The estimated ratio does not represent any probability. If HI > 1, there may be concern for potential effects.

- For multiple substances (i) and pathways (j).

  $\text{Risk}_T = \sum \text{risk}_{ij}$

  여러 물질들이 인체내에서 일으킬 수 있는 상승효과 일명, “칵테일 효과”는 일단 없는 것으로 전제

  Synergistic effects offered by many substances within the body; for now, no “cocktail effect”

- Hazardous index for multiple substances (i) and pathways (j)

  $\text{Hazardous Index}_T = \sum \text{HI}_{ij}$

- Uncertainty: Should the risk from a carcinogen that causes liver cancer be added to the risk from a compound that causes stomach cancer? Adding risks are a conservative approach.

EXAMPLE 5–3 Using the results from Example 5–2, estimate the risk from exposure to drinking water containing the MCL for benzene.

Solution Equation 5–21 in the form

$$\text{Total exposure risk} = \sum \text{risk}_j$$

may be used to estimate the risk. Because the problem is only to consider one compound, namely benzene, $i = 1$ and others do not need to be considered. Because the total exposure from Example 5–2 included each of the routes of concern for drinking water, that is, all j's, the final sum may be used to compute risk. The slope factor is obtained from Table 5–5. The risk is

$$\text{Risk} = (1.90 \times 10^{-4}\ \text{mg} \cdot \text{kg}^{-1} \cdot \text{day}^{-1})(2.9 \times 10^{-2}\ \text{kg} \cdot \text{day} \cdot \text{mg}^{-1})$$
$$= 5.5 \times 10^{-6}$$

This is the total lifetime risk (70 years) for benzene in drinking water at the MCL. Another way of viewing this is to estimate the number of people that might develop cancer. For example, in a population of 2 million,

$(2 \times 10^6)(5.5 \times 10^{-6}) = 11$ people might develop cancer

This risk falls within the EPA guidelines of 10^{-4} to 10^{-7} risk. It, of course, does not account for all sources of benzene by all routes. Nonetheless, the risk, compared with some other risks in daily life, appears to be quite small.

CVM (contingent valuation method, 가상시장평가법): 설문을 통해 WTP (willing to pay, 지불의사액) 등을 조사하여 환경가치를 계량화하는 방법. 환경가치나 건강가치를 과학의 문제가 아닌 정치의 문제로 풀려는 한계. 예를 들면, 원자력 발전소에 대해 일반 시민이 느끼는 risk 는 전문가가 느끼는 risk 보다 훨씬 크므로 원자력발전소 건설에 부정적인 여론을 유발한다. CVM 은 정책 결정의 좋은 도구가 될 수 있다.

CVM (contingent valuation method): A method to measure the environmental value. WTP (willing to pay) is estimated through surveys. There are limits to derive a solution of a health and environmental issue through political means as opposed to scientific means. For example, the public's sentiments of risk regarding nuclear power plants exceeds the risk felt by an expert in the area, and therefore the public sentiment is a negative factor in further developments of nuclear power plants. WTP may be a good tool for a decision making in the case.

4. Risk Management

- "Zero risk" cannot be established. (e.g., Even banning the production of PCBs does not remove those that already permeate our environment.)
- Risk management is performed to decide the magnitude of risk that is tolerable in specific circumstances.
- Policy decision weighs (1) the results of the risk assessment against (2) the costs of risk reduction techniques, and (3) benefits of risk reduction as well as (4) public acceptance.
- Risk manager's options are to (1) change environment (remediation, treatment, etc.), (2) modify the exposure (limiting intakes or access, banning of chemicals, etc.), or (3) compensate for the effect. A final choice is a blend of the options.

Risk 와 Benefit 의 동시 고려: 1962 년 레이첼 카슨이 "Silent Spring"에서 DDT 의 치명적인 생태 독성을 호소한지 10 년 뒤 미국은 DDT 를 금지하였다. DDT 가 합성되기 전에는 비소, 수은, 납 등의 성분이 든 화학약품이 살충제로 사용되었으나, 이런 농약들은 사람이나 동물에게 중독을 일으키거나 급성 부작용을 일으켰다. 그러나, DDT 는 포유동물에는 거의 아무런 피해가 없었다. 10 years after Rachel Carson described the life-threatening affects of DDT in her 1962 book "Silent Spring", USA banned the usage of DDT. Before DDT was created, chemical pesticides composed of arsenic, mercury, and lead was used. However, these pesticides often caused sudden side effects in humans and animals. But DDT barely had any negative effects on mammals.

1996 년 DDT 의 사용을 금지한 남아프리카공화국에서는 말라리아 발생이 연간 5,000 건에서 50,000 건으로 증가했고, 스리랑카의 말라리아 감염자 수도 1960 년대 초 수십명에서 DDT 를 금지한 후 1968 년 100 만명, 1969 년 250 만명이 말라리아에 걸렸다. 결국, 세계보건기구는 2006 년 9 월 5 일 DDT 를 실내에 소량 뿌리는 것은 권장한다는 권고를 발표했다. 말라리아 모기의 방제를 위해서 취해진 조치이다. 이와 같이, risk 와 benefit 을 동시

에 고려하여 종합적으로 판단해야 하는 쉽지 않은 일이다.

In South Africa, which banned the usage of DDT in 1996, saw a dramatic increase of Malaria cases from 5,000 to 50,000, and Sri Lanka, which banned DDT in 1968, saw an increase in Malaria cases from tens to 1 million, and in 1969 saw 2.5 million cases. Eventually, the WHO (World Health Organization) announced on September 5th of 2006 that small amounts of DDT usage indoors is permitted. This was an action taken to prevent additional cases of Malaria. Thus, making an acceptable conclusion that considers both the risks and benefits is a very difficult process.

과제의 시급성과 우선순위에 따라 정책 선택은 달라진다: 시민들의 건강을 위해 미세먼지를 줄이고자 한다면 경유차보다 휘발유차를 장려해야 하나, 지구온난화를 억제하기 위해서는 연비가 좋은 경유차를 장려해야 한다. 국토가 넓어 쓰레기 매립지를 만드는데 어려움이 없으나 수자원이 부족한 나라에서는 천기저귀보다 종이기저귀가 바람직할 수도 있다. 사회나 국가의 환경용량과 가용기술에 따라 해답이 되는 기술이나 정책은 다를 수 있으며, 현재의 해답이 기술 발전의 속도와 방향에 따라 장래에는 바람직하지 않을 수도 있다.

The political response changes depending on the urgency of problem and priority: For the health of the citizens, Gasoline cars that emit less fine particulate matters are encouraged more so than Diesel cars, but in consideration of global warming, Diesel cars that have better gas mileage should be used more. In some countries which have enough land area but less water resource, paper diapers may be a better alternative to cloth diapers. Depending on the environmental capacity and the available technology, the technique and policies may change, but the current solution to the problems may not be the optimal in future based on the growth rate and direction of technology.