職安法化學暴露危害管理
—作業場所暴露評估與管理技術

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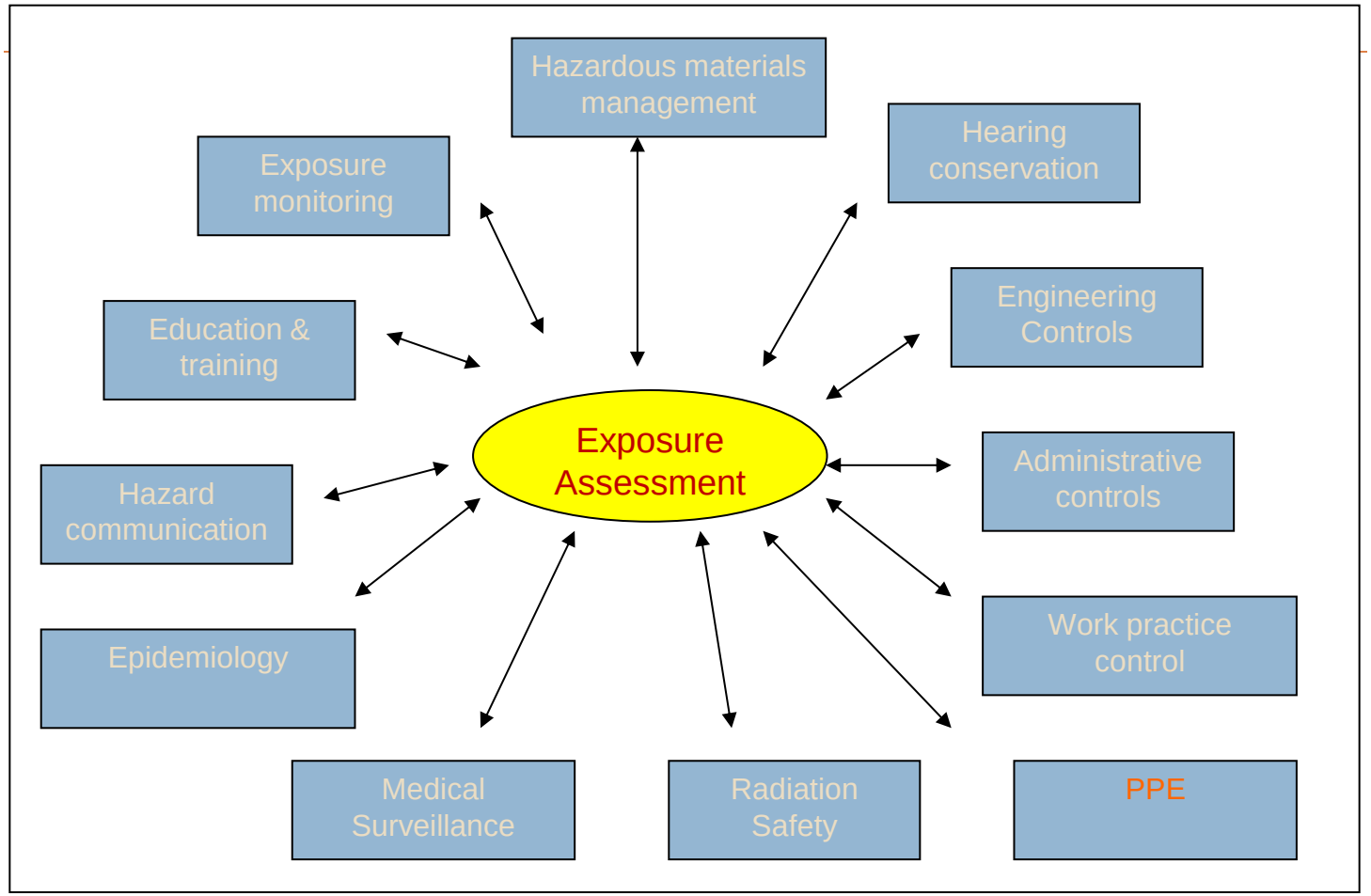


Fig Exposure assessment’ s central role in industrial hygiene program management (Mulhausen and Damiano, 1998)

我國化學品管理現況

- Chemicals currently used in industries: 79,000
- Chemicals with GHS classifications: 19,000
- Chemicals with PELs: 491
- Chemicals required for EM: 117

以往作業環境監測面臨之問題 (1)

- 法規規範應實施監測之物質有限（117）：
  - 物理性因子(含噪音與綜合溫度熱指數)
  - 化學性因子(含48種有機溶劑、34種特定化學物質、鉛作業場所、四烷基鉛作業場所、粉塵及二氧化碳)
    (Others?)
- 491種已訂定PELs之物質不一定有測定分析方法，依法亦不需執行作業環境監測 (if monitoring => acceptable?)
- 無PELs之物質缺乏監測資料 (including both quali- and quantitative)

以往作業環境監測面臨之問題 (2)

- 採樣策略因事業單位之要求，無法反映實際暴露狀況 (Goals ?)
- 只允許作業環境監測(other methods?)
- 小型企業未能確實執行作業環境監測 (cost ?)
- 雖執行作業環境監測，但測定樣本數不足 (required sample size?)
- 依法執行但數據大多低於檢測下限 (fixed monitoring frequency?)

以往作業環境測定面臨之問題 (3)

- 作業環境監測結果未進行統計分析 (Data analysis?)
- 作業環境監測結果未應用於現場改善建議 (EM Report?)
- 檢查機構實質檢查 (Manpower?)
- 環境監測素質(Professional Engineer vs. Technician)
- 劣幣逐良幣 (Market vs. Ethics?)
- …….

作業環境測定之定義

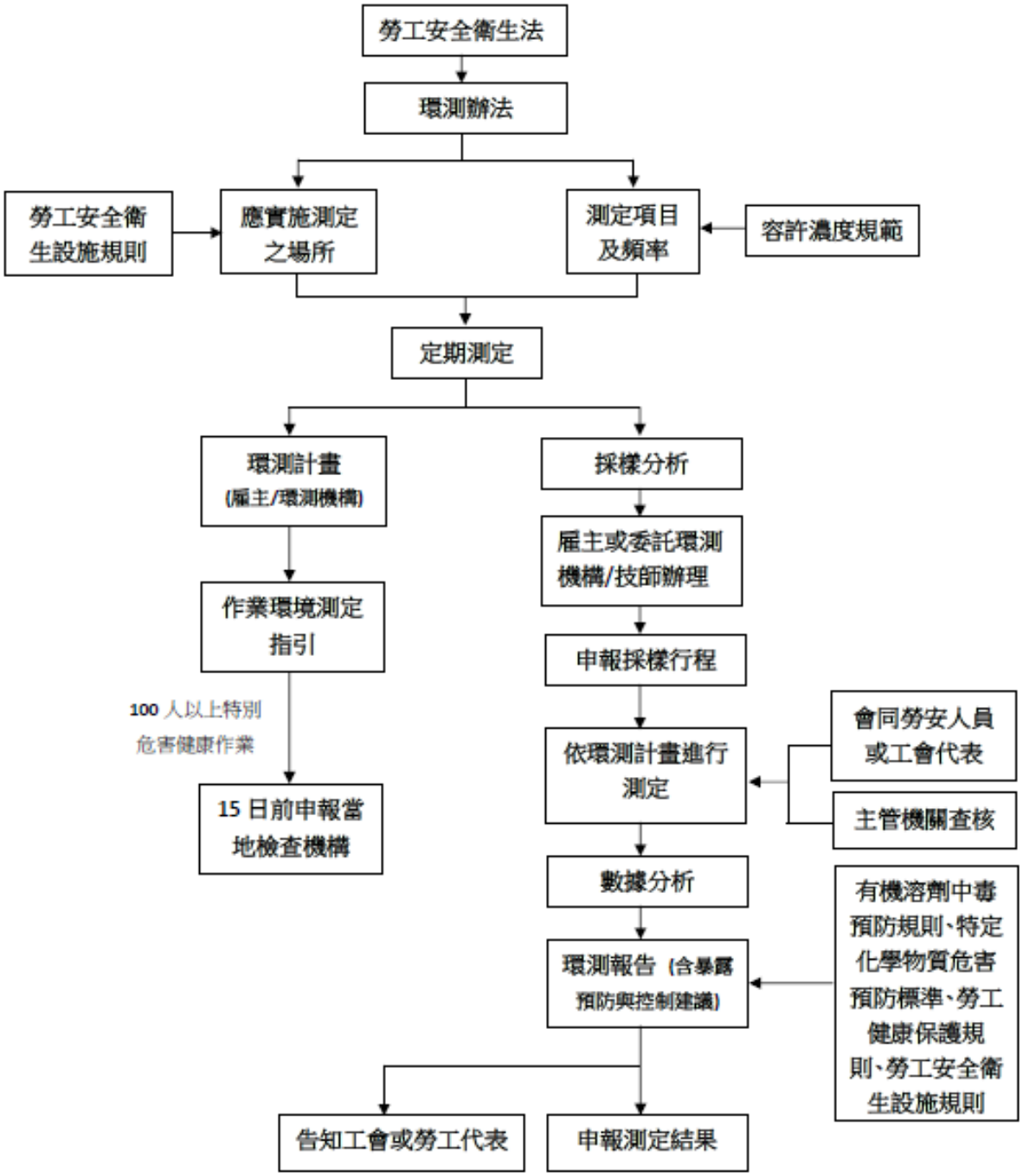
- 依據『勞工作業環境監測實施辦法』的定義：

  為掌握勞工作業環境實態

  及評估勞工暴露狀況

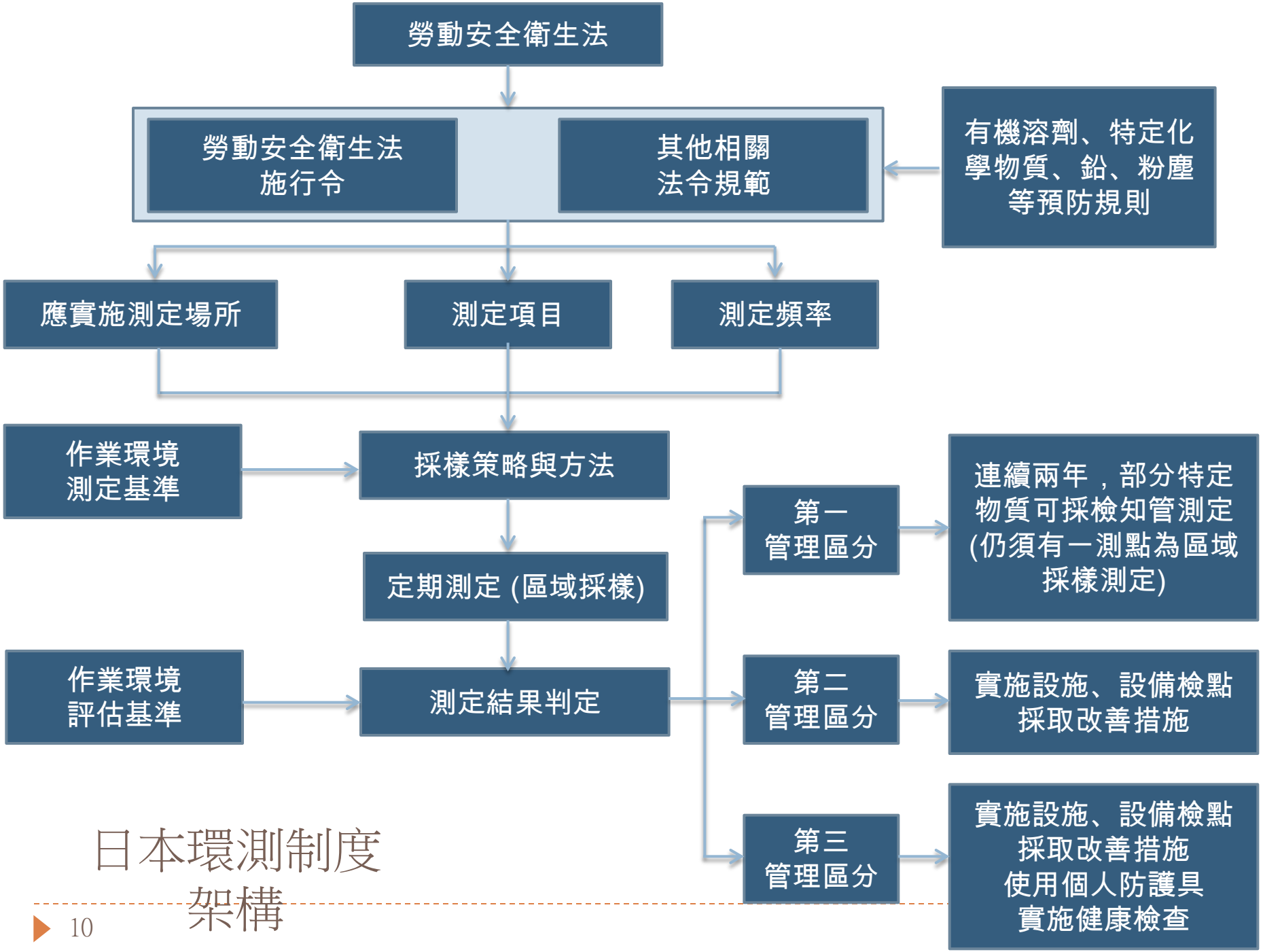
  所實施之規劃、採樣、分析或儀器測量

我國現行環測制度整體架構



國外作法—日本

- 相關法規
  - 勞動安全衛生法 (Industrial Safety and Health Law)
  - 勞動安全衛生法施行令 (Enforcement Order of the Industrial Safety and Health Law)
  - 作業環境測定基準 (Working Environment Measurement Standards)
  - 作業環境評估基準 (Working Environment Evaluation Standards)
  - 有機溶劑中毒預防規則 (Ordinance on Prevention of Organic Solvent Poisoning)
  - 鉛中毒預防規則Ordinance on Prevention of Lead Poison
  - 特定化學物質危害預防標準 (Ordinance on Prevention of Hazards Due to Specified Chemical Substances)
  - …


勞動安全衛生法
勞動安全衛生法
施行令
其他相關
法令規範
有機溶劑、特定化
學物質、鉛、粉塵
等預防規則
應實施測定場所
測定項目
測定頻率
作業環境
測定基準
採樣策略與方法
定期測定 (區域採樣)
作業環境
評估基準
測定結果判定
第一
管理區分
連續兩年，部分特定
物質可採檢知管測定
(仍須有一測點為區域
採樣測定)
第二
管理區分
實施設施、設備檢點
採取改善措施
第三
管理區分
實施設施、設備檢點
採取改善措施
使用個人防護具
實施健康檢查

日本環測制度架構

國外作法—日本

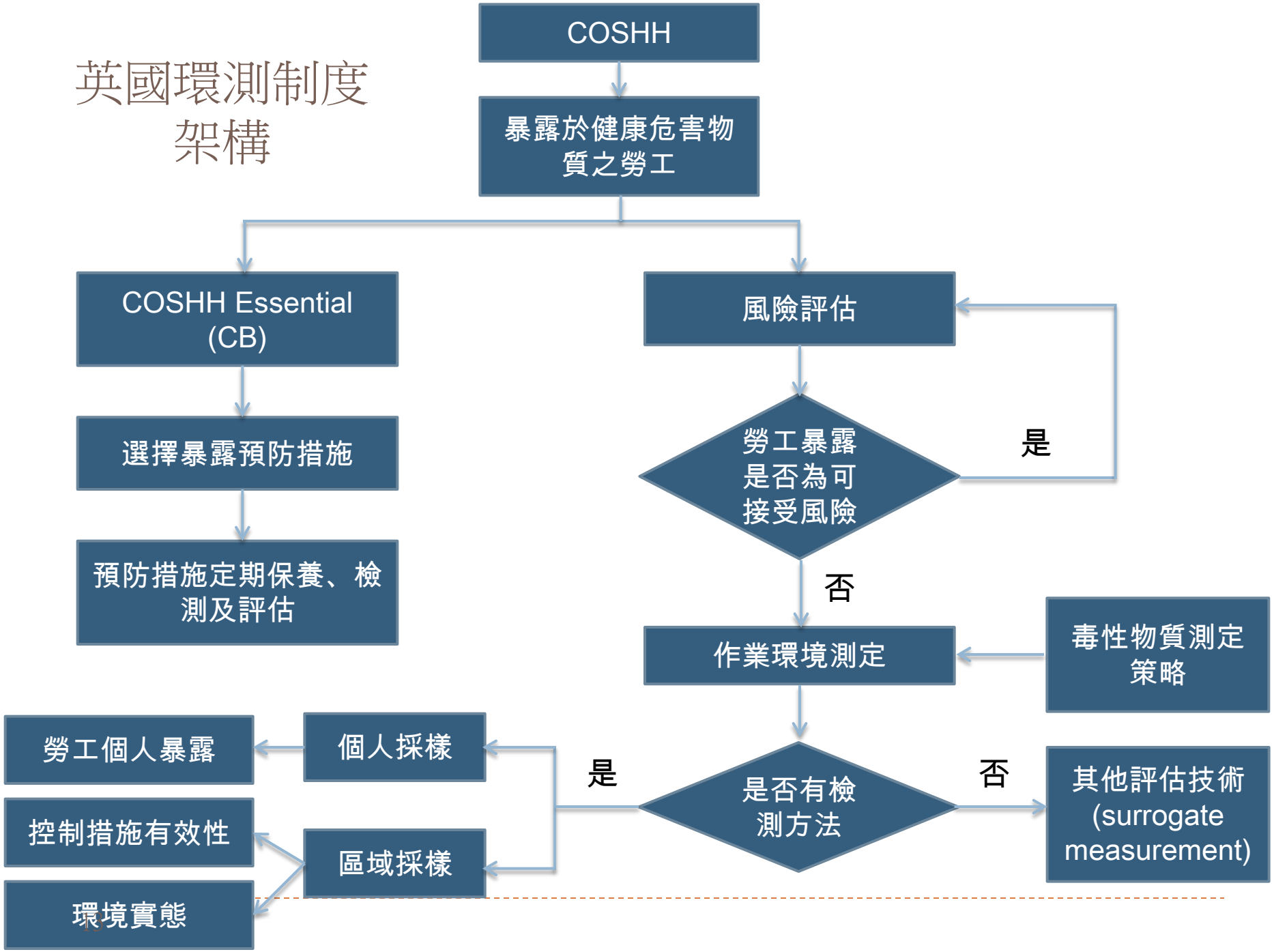
Substances listed below may be measured using a detector tube.

1. Acetone
2. Isoprovpyl alcohol
3. Isopentyl alcohol (otherwise known as isoamyl alcohol)
4. Ethyl ether
5. Xylene
6. Cresol
7. Chlorobenzene
8. Chloroform
9. Isobutyl acetate
10. Isopropyl acetate
11. Ethyl acetate
12. n-Butyl acetate
13. Carbon tetrachloride
14. Cyclohexanone
15. 1,2-Dichloroethylene (otherwise known as acetylene chloride)
16. N, N-Dimethylformamide
17. Styrene
18. Tetrachloroethylene (otherwise known as perchlorethylene)
19. 1,1,1-Trichloroethane
20. Trichloroethylene
21. Tolune
22. Carbon disulfide
23. 2-Butanol
24. Methyl cyclohexanone

國外作法—英國

- 相關法規
  - 安全衛生管理規則 (The Management of Health and Safety Regulations)
  - 健康危害物控制規則 (The Control of Substances Hazardous to Health Regulations, COSHH)
  - 健康危害物控制規則實施規範 (Approved Codes of Practice, ACOP)
  - 毒性物質測定策略(Monitoring Strategies for Toxic Substance)

英國環測制度架構


COSHH
暴露於健康危害物質之勞工
COSHH Essential (CB)
選擇暴露預防措施
預防措施定期保養、檢測及評估
風險評估
勞工暴露是否為可接受風險
是
否
作業環境測定
毒性物質測定策略
是否有檢測方法
是
否
其他評估技術 (surrogate measurement)
個人採樣
區域採樣
勞工個人暴露
控制措施有效性
環境實態

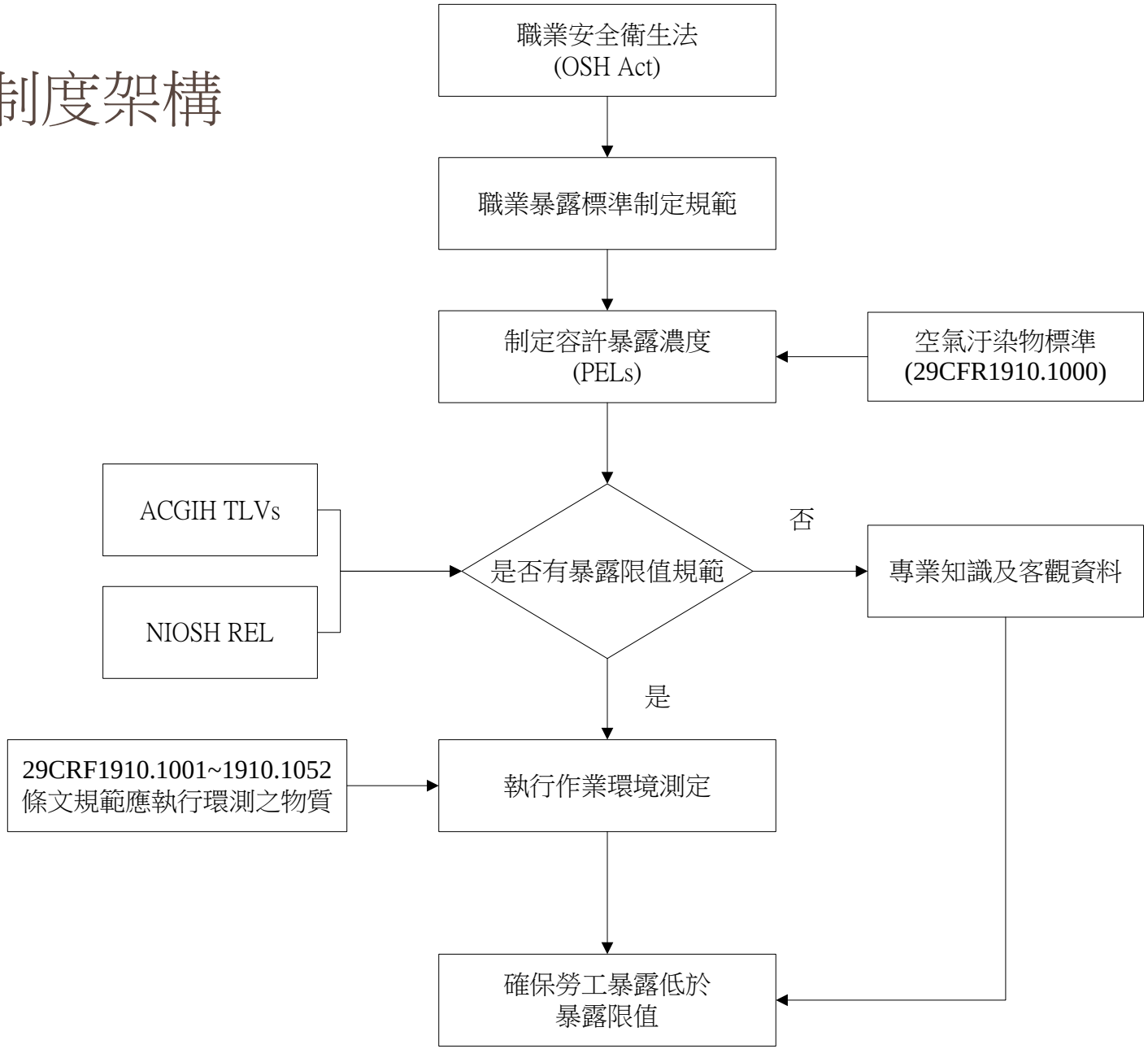
國外作法—英國

- 測定頻率：
  - The monitoring shall be conducted on a regular basis
    - *Workplace atmospheres —Guidance for the assessment of exposure by inhalation to chemical agents for comparison with limit values and measurement strategy*
      - 64 weeks if the occupational exposure concentration does not exceed 1/4 limit value;
      - 32 weeks if the occupational exposure concentration exceeds 1/4 limit value but does not exceed 1/2 limit value;
      - 16 weeks if the occupational exposure concentration exceeds 1/2 limit value but does not exceed the limit value.

國外作法—美國

- 相關法規
  - 職業安全衛生法(Occupational Safety and Health Act, OSH Act)
  - 美國聯邦法規(Code of Federal Regulations)：
    - 29CFR1910

美國環測制度架構


職業安全衛生法
(OSH Act)
職業暴露標準制定規範
制定容許暴露濃度
(PELs)
空氣汙染物標準
(29CFR1910.1000)
ACGIH TLVs
NIOSH REL
是否有暴露限值規範
否
專業知識及客觀資料
是
29CRF1910.1001~1910.1052
條文規範應執行環測之物質
執行作業環境測定
確保勞工暴露低於
暴露限值

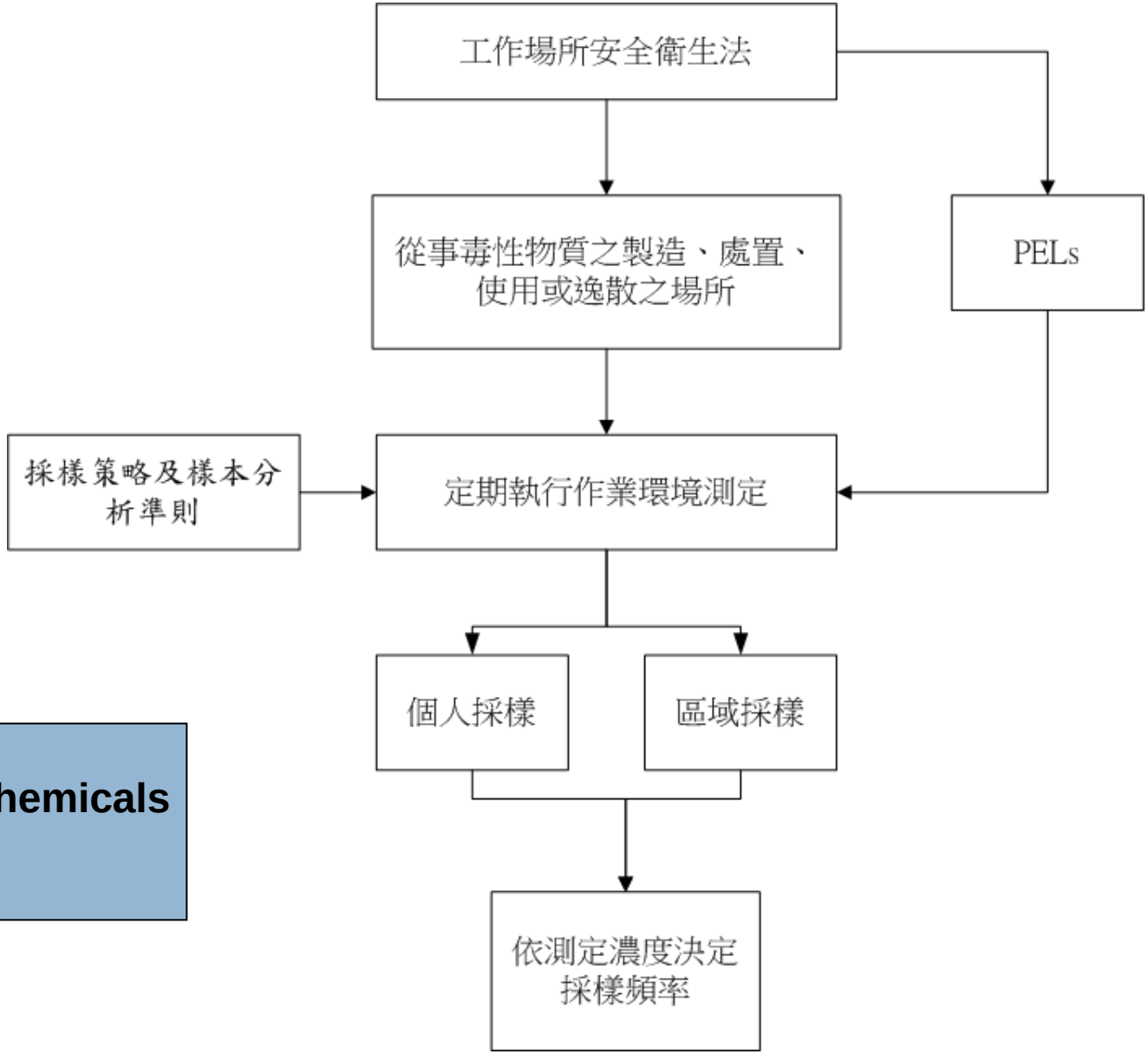
美國環測制度

- Chemicals?
- Frequency?

國外作法—新加坡

- 相關法規
  - 工作場所安全衛生法 (Workplace Safety and Health (General Provisions) Regulations)
  - 採樣策略及樣本分析報告繳交準則 (Guidelines on sampling strategy and submission of toxic substances monitoring/sample analysis report)

新加坡環測制度架構



Suiting for all chemicals With PELs

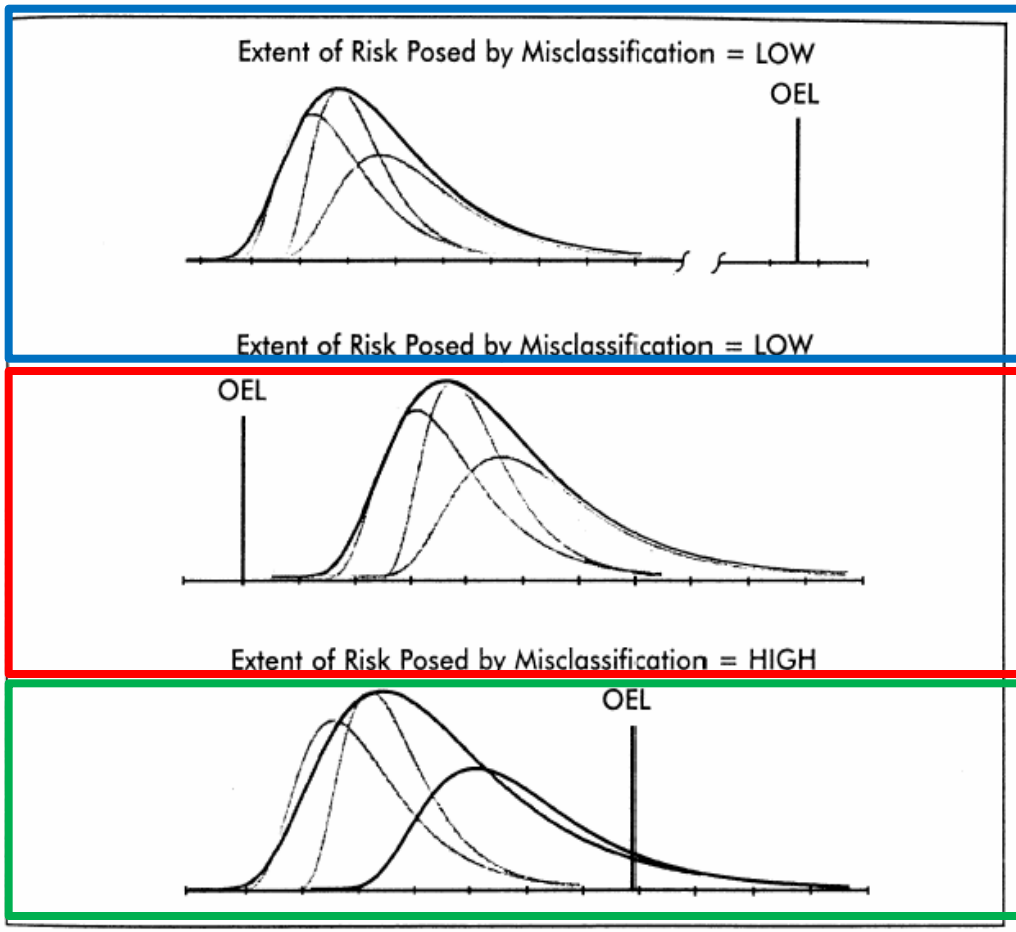
國外作法—新加坡

- 環測頻率

Concentration	Frequency
< 10% of the PEL	* No air monitoring is required
10 - 50% of the PEL	At least once a year
> 50 - 100% of the PEL	At least once every six months
> PEL	At least once every three months, until the exposure is reduced to below the PEL by appropriate control measures

*A re-assessment should be carried out if there is any change in the process.

暴露評估基本概念



- 可接受之風險
- 不須改善
- 不須環測/放寬測定頻率?

- 不可接受之風險
- 直接改善
- 改善後測定?

- 須正確執行測定

Figure 7.8 — Risk posed by misclassification of an individual worker's exposure.

職業安全衛生法與化學品健康危害管理相關規定

- 第11條

雇主對於前條之化學品，應依其健康危害、散布狀況及使用量等情形，評估風險等級，並採取分級管理措施。

前項之評估方法、分級管理程序與採行措施及其他應遵行事項之辦法，由 中央主管機關定之。

職業安全衛生法與化學健康危害管理相關規定

- 第12條

雇主對於中央主管機關定有容許暴露標準之作業場所，應確保勞工之危害 暴露低於標準值。

前項之容許暴露標準，由中央主管機關定之。

雇主對於經中央主管機關指定之作業場所，應訂定作業環境監測計畫，並 設置或委託由中央主管機關認可之作業環境監測機構實施監測。但中央主 管機關指定免經監測機構分析之監測項目，得僱用合格監測人員辦理之。

雇主對於前項監測計畫及監測結果，應公開揭示，並通報中央主管機關。 中央主管機關或勞動檢查機構得實施查核。 前二項之作業場所指定、監測計畫與監測結果揭示、通報、監測機構與監 測人員資格條件、認可、撤銷與廢止、查核方式及其他應遵行事項之辦法 ，由中央主管機關定之。

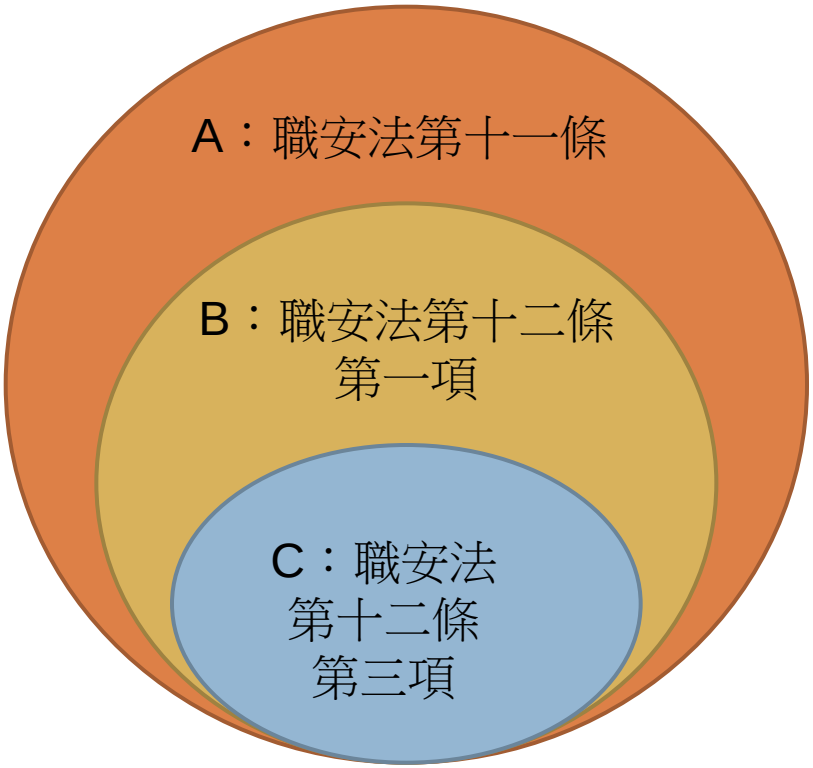
化學暴露危害管理之概念

- 結合：
  - 定性暴露危害評估-Control Banding
  - 半定量暴露危害評估-Control Banding
  - 定量暴露危害評估-Modeling
  - 定量暴露危害評估-Environmental monitoring

強度

特徵

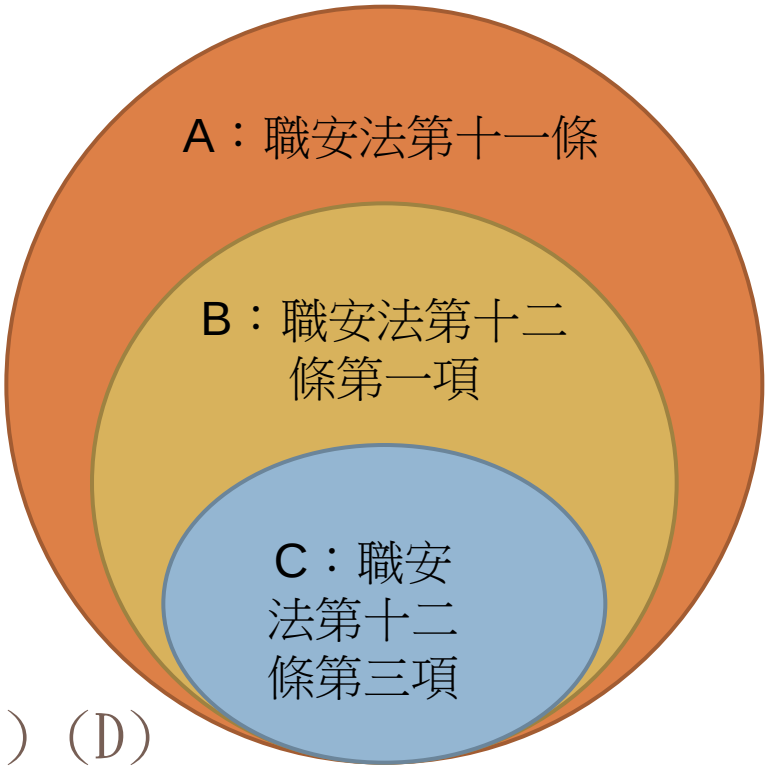
- 全面掌握
- 分層管理
- 多元評估
- 控制區分
- 基於科學



職安法化學暴露危害管理架構

A區

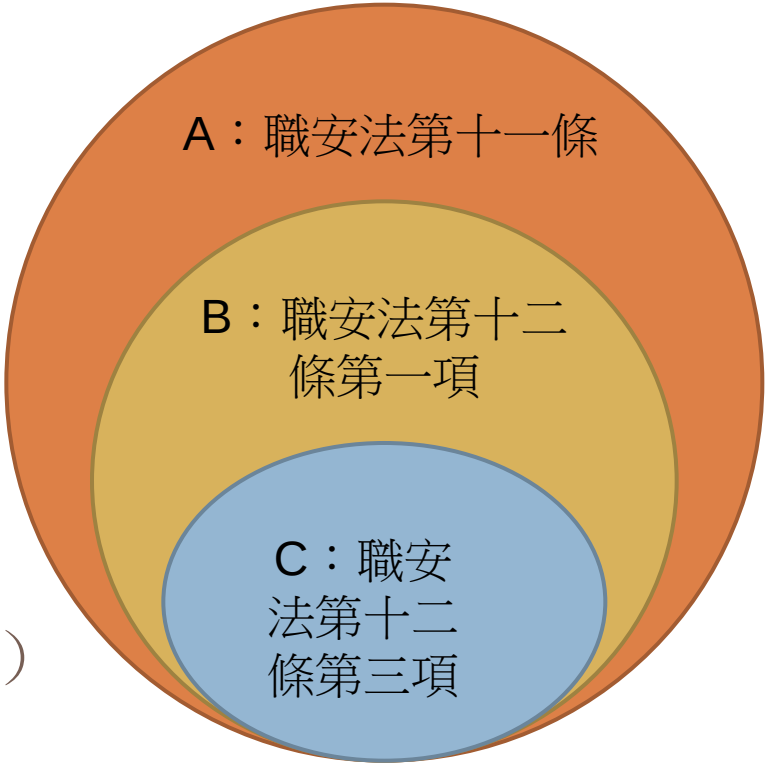
- 適用法令
  - 職安法第十一條
- 適用化學物質
  - 具工作場所GHS危害之物質(約19000種)
- 適用評估方法
  - 定性暴露危害評估（A）
  - 半定量暴露危害評估(B)
  - 定量暴露危害評估(模式分析)(C)
  - 定量暴露危害評估(作業環境監測)（D）



職安法化學暴露危害管理架構

B區

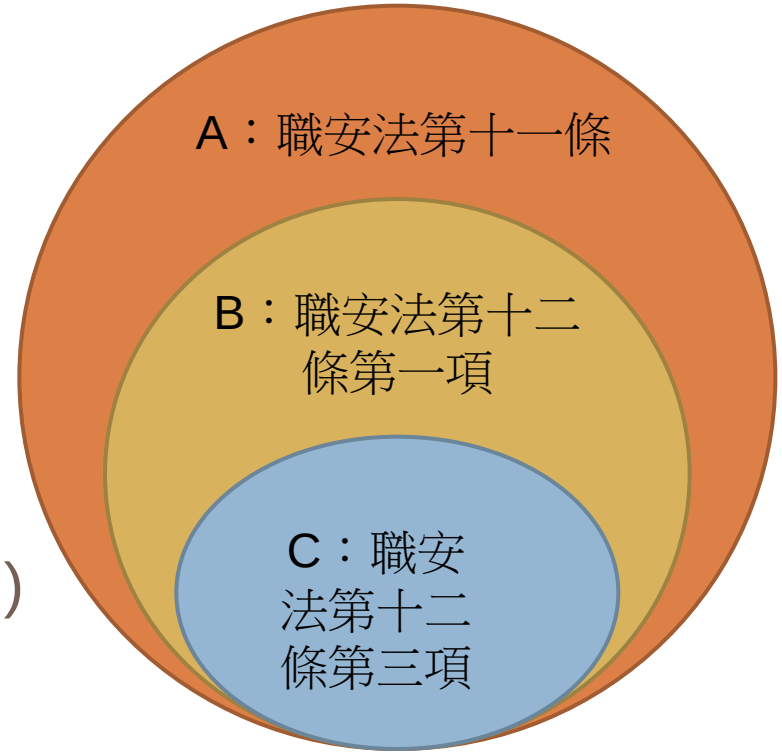
- 適用法令
  - 職安法第十二條第一項
- 適用化學物質
  - 有容許濃度標準者(491種)
- 適用評估方法
  - 定量暴露危害評估(模式分析)
  - 定量暴露危害評估(作業環境監測)



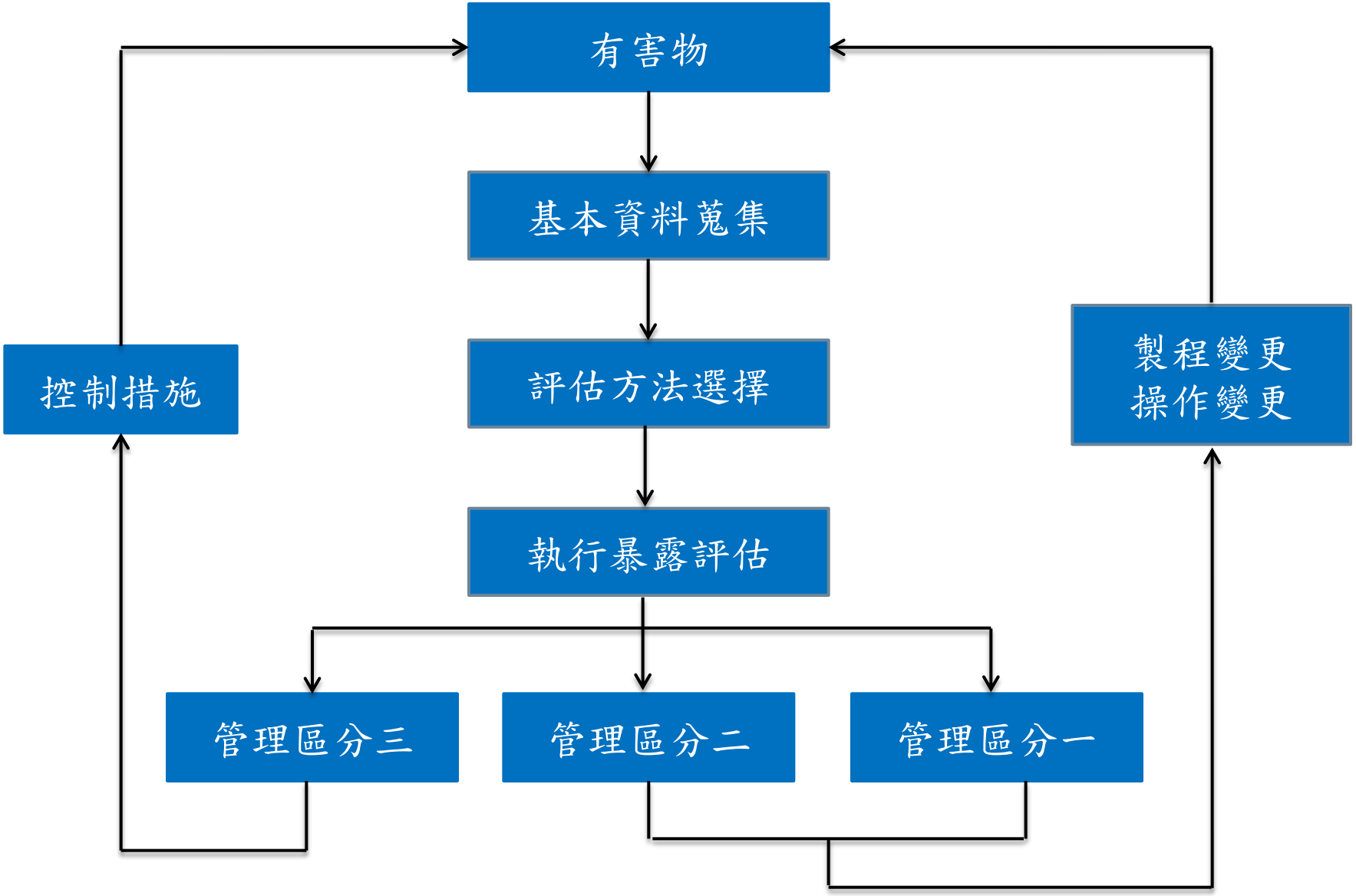
職安法化學暴露危害管理架構

C區

- 適用法令
  - 職安法第十二條第三項
- 適用化學物質
  - 公告需實施環測者(108種)
- 適用評估方法
  - 定量暴露危害評估(作業環境監測)



職安法化學暴露危害管理架構



暴露危害評估架構

管理區分

- **Exposure hazard rankings**
- **Exposure hazard ratings**
- **Exposure hazard zones**
- **Exposure hazard classifications**
- **Exposure control categories**

AIHA exposure control category

	Exposure Control Category*	Recommended Control	Uncertainty Rating
	0 (<1% of OEL)	No action	High Medium Low
	1 (<10% of OEL)	general HazCom	
	2 (10-50% of OEL)	+ chemical specific HazCom	
	3 (50-100% of OEL)	+ exposure surveillance, medical surveillance, work practices	
	4 (>100% of OEL)	+ respirators & engineering controls, work practice controls	
	5 (Multiples of OEL; e.g., based on respirator APFs)	+ immediate engineering controls or process shutdown, validate respirator selection	

* - Decision statistic = 95th percentile

管理區分 (Japan)

- 管理區分一（可接受之低度風險）
- 管理區分二(可接受之風險)
- 管理區分三(不可接受之風險)

管理區分與措施

- 管理區分一
  - 繼續維持
- 管理區分二
  - 鼓勵改善
- 管理區分三
  - 採取控制措施
    - 工程控制(如：取代、密閉、隔離、通風換氣)
    - 行政管理(如：PPE、縮短工時)
    - 健康管理

暴露危害評估技術介紹

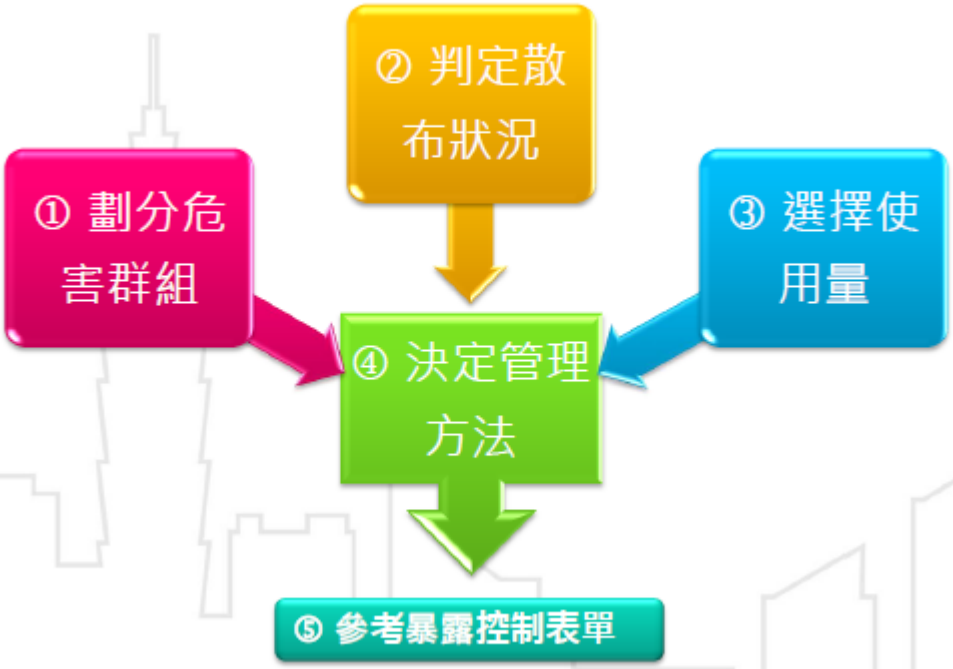
定性暴露評估:

化學品分級管理
（Chemical Control Banding; CCB）

健康風險 vs. 安全風險

- 健康風險：物質毒性　x　暴露濃度
- 安全風險：嚴重度　　x　　可能性

我國化學品分級管理 (CCB)



其他化學品分級管理 (CCB)技術

- Ministry of Manpower (Singapore): Guidelines on risk assessment for occupational exposure to harmful chemical
- International Labor Organization: International Chemical Control Toolkit, CCTK ）
- Health and Safety Executive: Control of Substances Hazardous to Health Essentials，COSHH Essentials ）
- The Minister of Health, Labor and Welfare (Japan) : Guidelines for Risk Assessment on Chemicals

半定量暴露危害評估方法:

（ Semi-Quantitative Occupational Risk Prediction Model for Chemical Exposures ）

A Semi-Quantitative Occupational Risk Prediction Model for Chemical Exposures

- The Exposure Hazard Index (EHI)

$$EHI = (TI) \times (EI) \times (PDI)$$

TI : Toxicity index → $TI = 2^{[4.16 - \log(OEL - TWA)]}$

EI : Exposure index → $EI = 0.0023(\mathrm{T}) - 0.0037$ (T：min)

PDI : Protection deficiency index

$$PDI = (1 - MI \times PI)$$ →

$MI = 0.21N + 0.18$ N：number of management measures

PI= Types of eng. control +PPE → 0~1

Source: Wang et al., *Int. J. Environ. Res. Public Health*, 2013, 10:3157-3171.

半定量暴露危害評估方法

- Example

Control priority	Recommended industries	EHI
First priority industries (EHI ranking≧90th percentile; EHI≧32.43)		
	Plastic products manufacturing (n=37)	43.47
	Petroleum products manufacturing (n=7)	35.54
	Metal products manufacturing (n=137)	33.17
Second priority industries (90th percentile >EHI ranking≧70th percentile; 32.43>EHI≧20.61)		
	Transportation manufacturing (n=17)	31.32
	Electrical equipment manufacturing (n=22)	27.23
	Electronic components manufacturing (n=34)	23.46
	Chemical materials manufacturing (n=94)	21.66
	Paper products manufacturing (n=17)	21.44
Third priority industries (70th percentile >EHI ranking≧50th percentile; 20.61>EHI≧10.41)		
	Metalworking manufacturing (n=49)	17.29
	Chemical products manufacturing (n=16)	14.06
	Non-metallic mineral products manufacturing (n=15)	12.58
	Leather products manufacturing (n=9)	12.03

模式定量風險推估模式:

（ Quantitative Models for Occupational Chemical Exposures ）

現有模式定量風險推估模式

- Completely mixing model
- Two-zone model
- Three-zone model

Example:

Completely mixing model

Example: Exposure Estimate

Agent "X"

G= steady generation rate (mg/hour)

35 to 65 mg/hour

Q= steady ventilation rate (m^3/hour)

3.6 to 540 m^3/hour

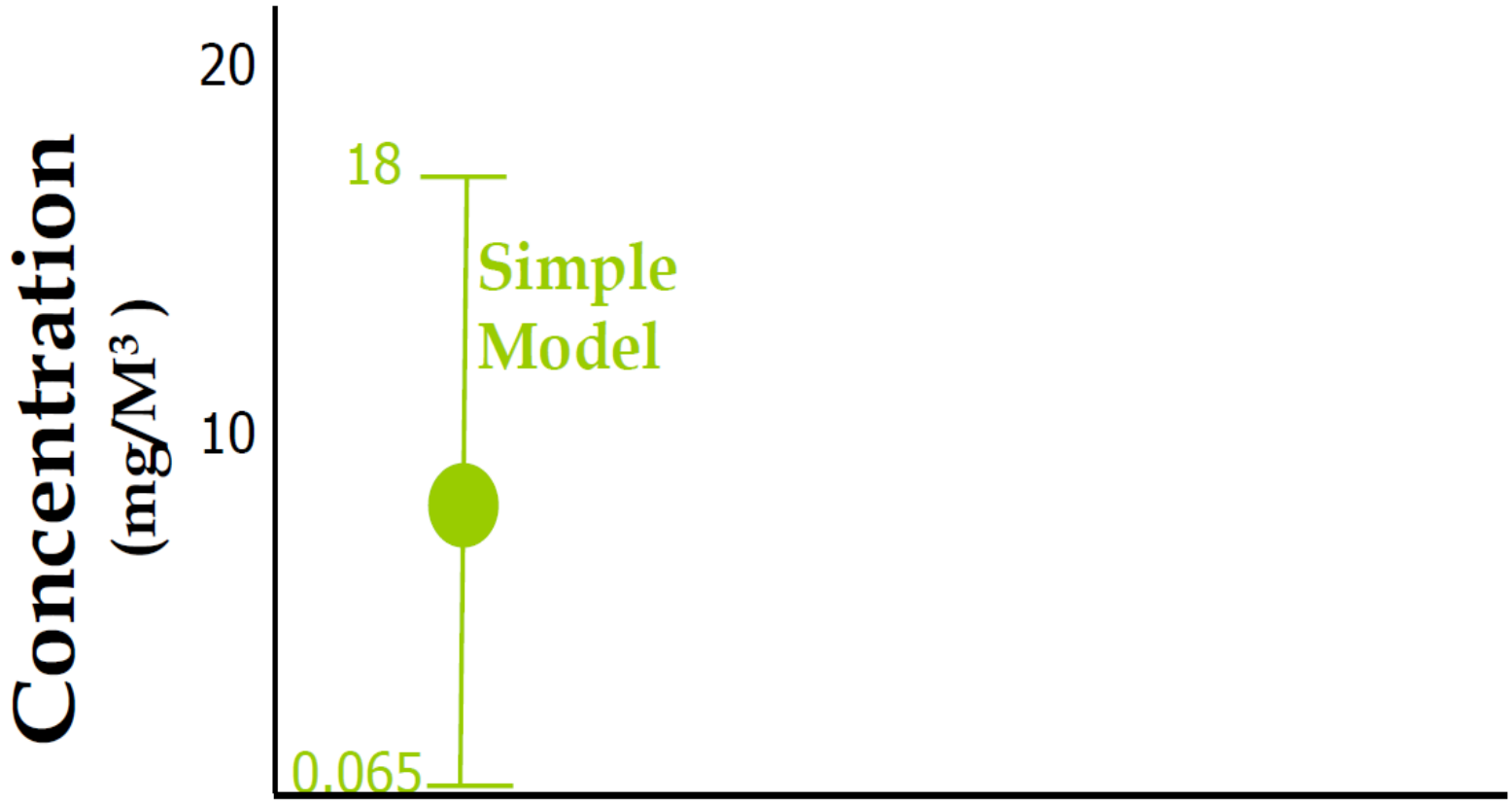
Simple Model:

$$C = \frac{G}{Q}$$

Worst Case $C = \frac{65 \text{ mg/hour}}{3.6 \text{ m}^3\text{/hour}} = 18 \text{ mg/m}^3$

Best Case $C = \frac{35 \text{ mg/hour}}{540 \text{ m}^3\text{/hour}} = 0.065 \text{ mg/m}^3$

Uncertainty and Acceptability

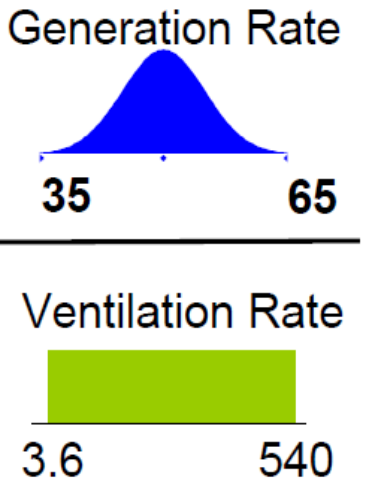


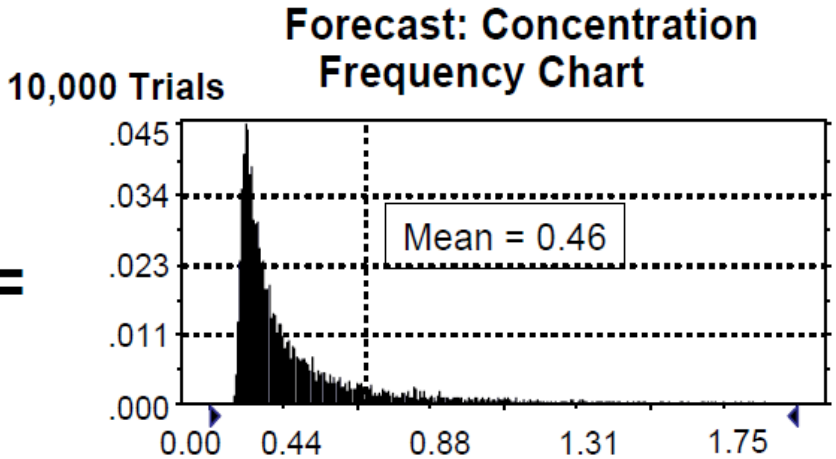
Example: Exposure Estimate

Statistical Modeling:
Monte Carlo
Uncertainty Analysis

Agent "X"
G= steady generation rate (mg/hour)
35 to 65 mg/hour
Q= steady ventilation rate (m^3/hour)
3.6 to 540 m^3/hour

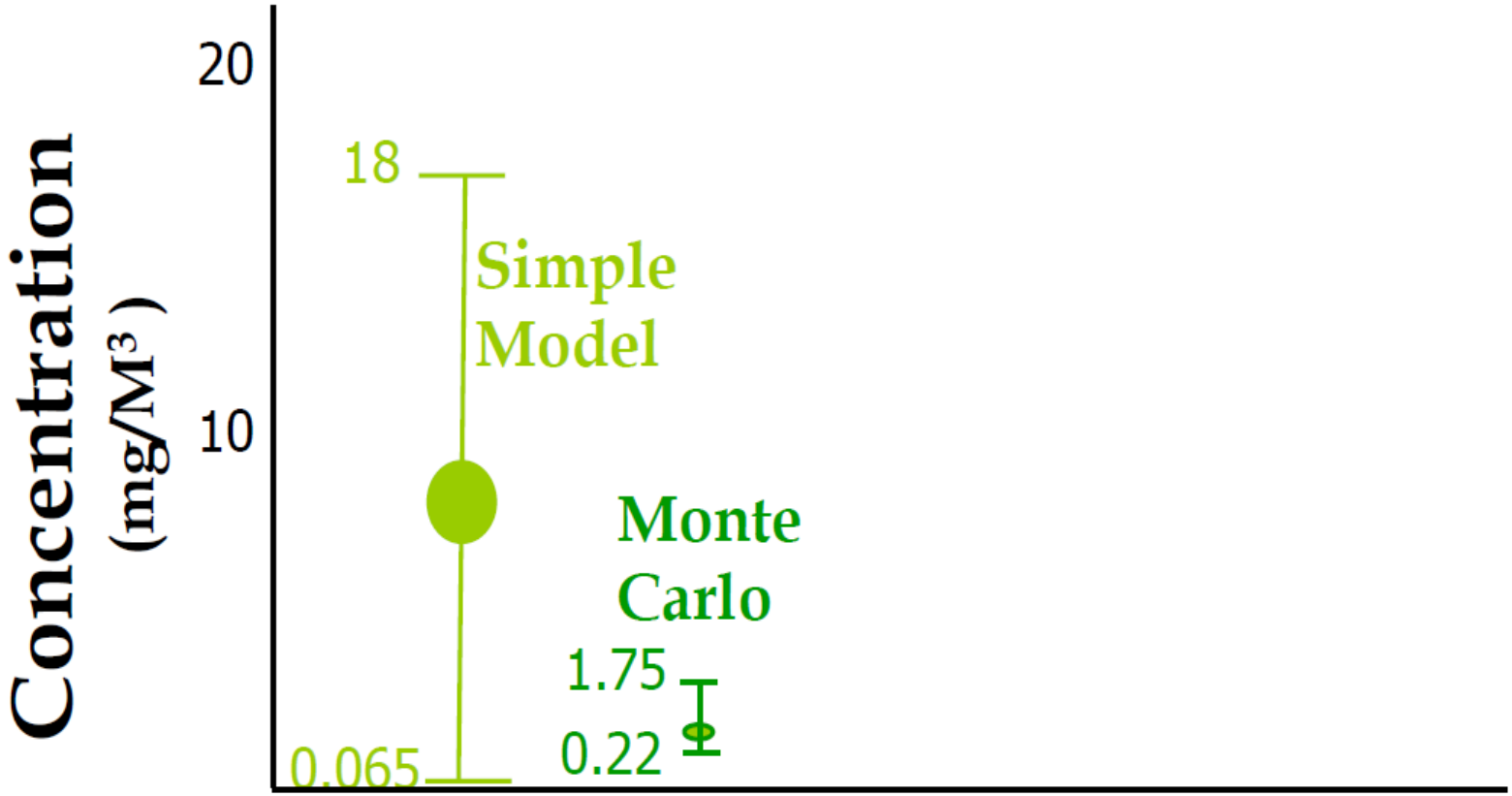
$$C = \frac{\text{Generation Rate}}{\text{Ventilation Rate}} =$$



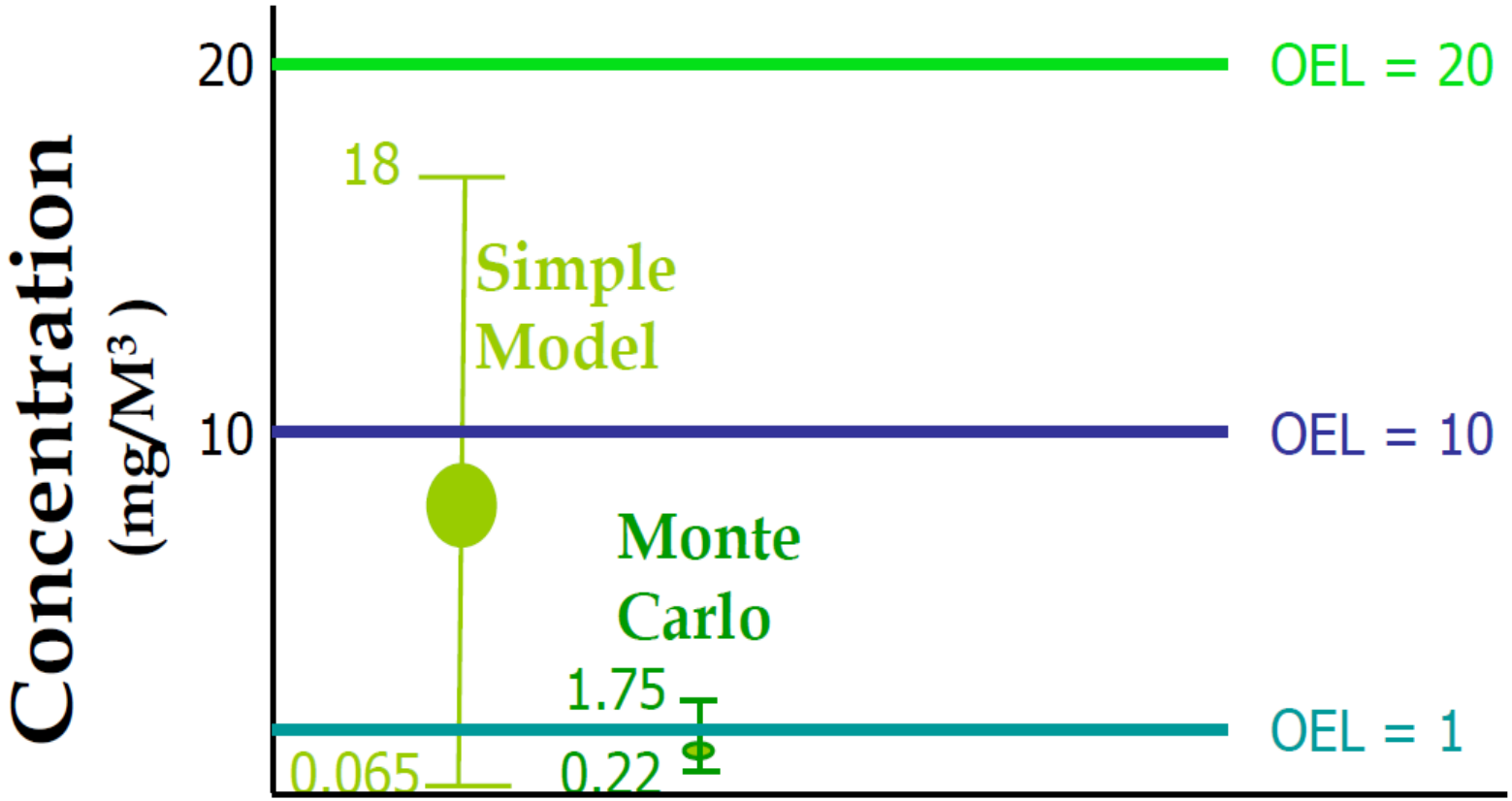


Certainty is 95.30% from 0.00 to 1.75 mg/m3

Uncertainty and Acceptability

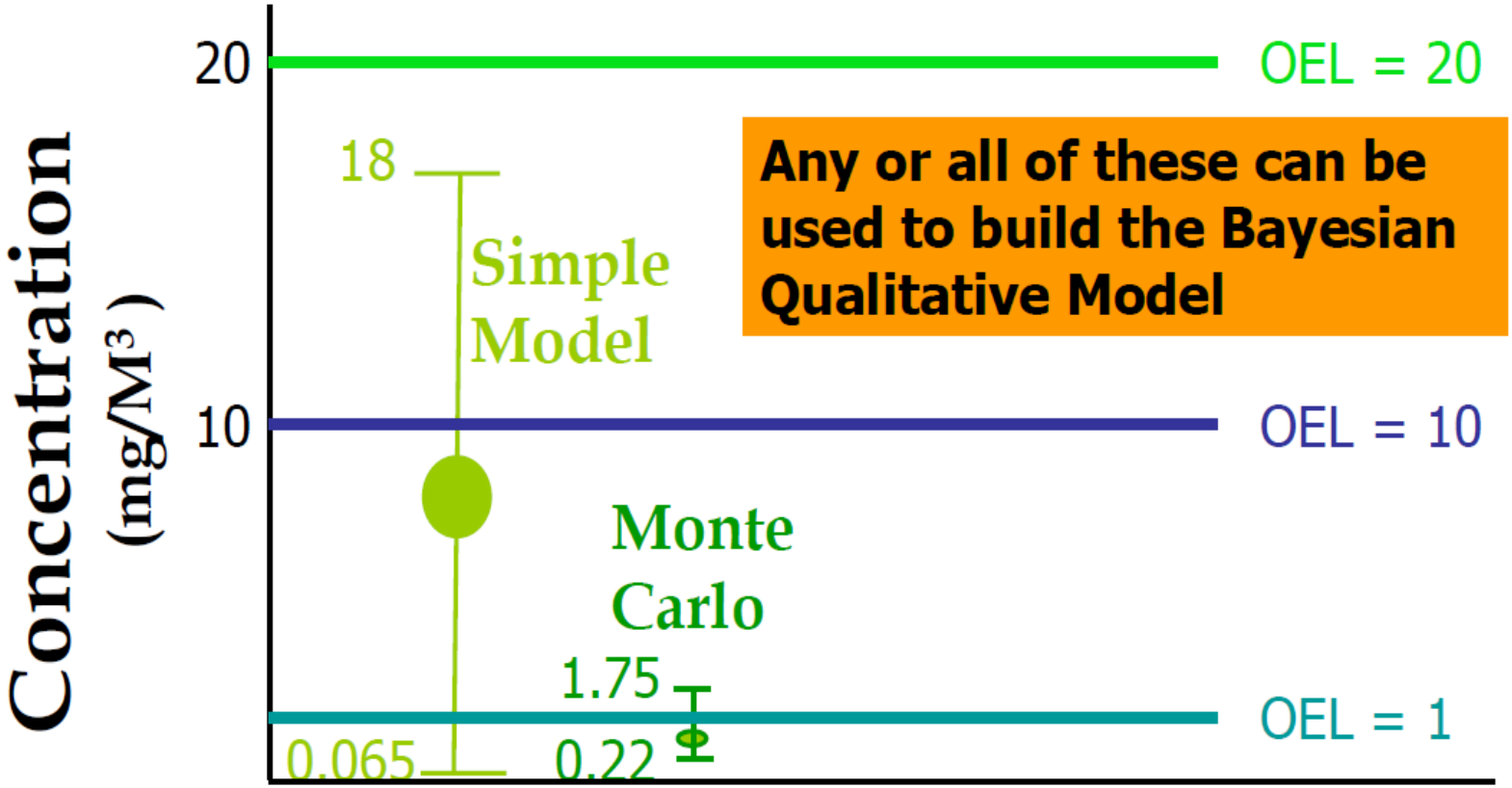


Uncertainty and Acceptability



Which To Choose? **Acceptable?**

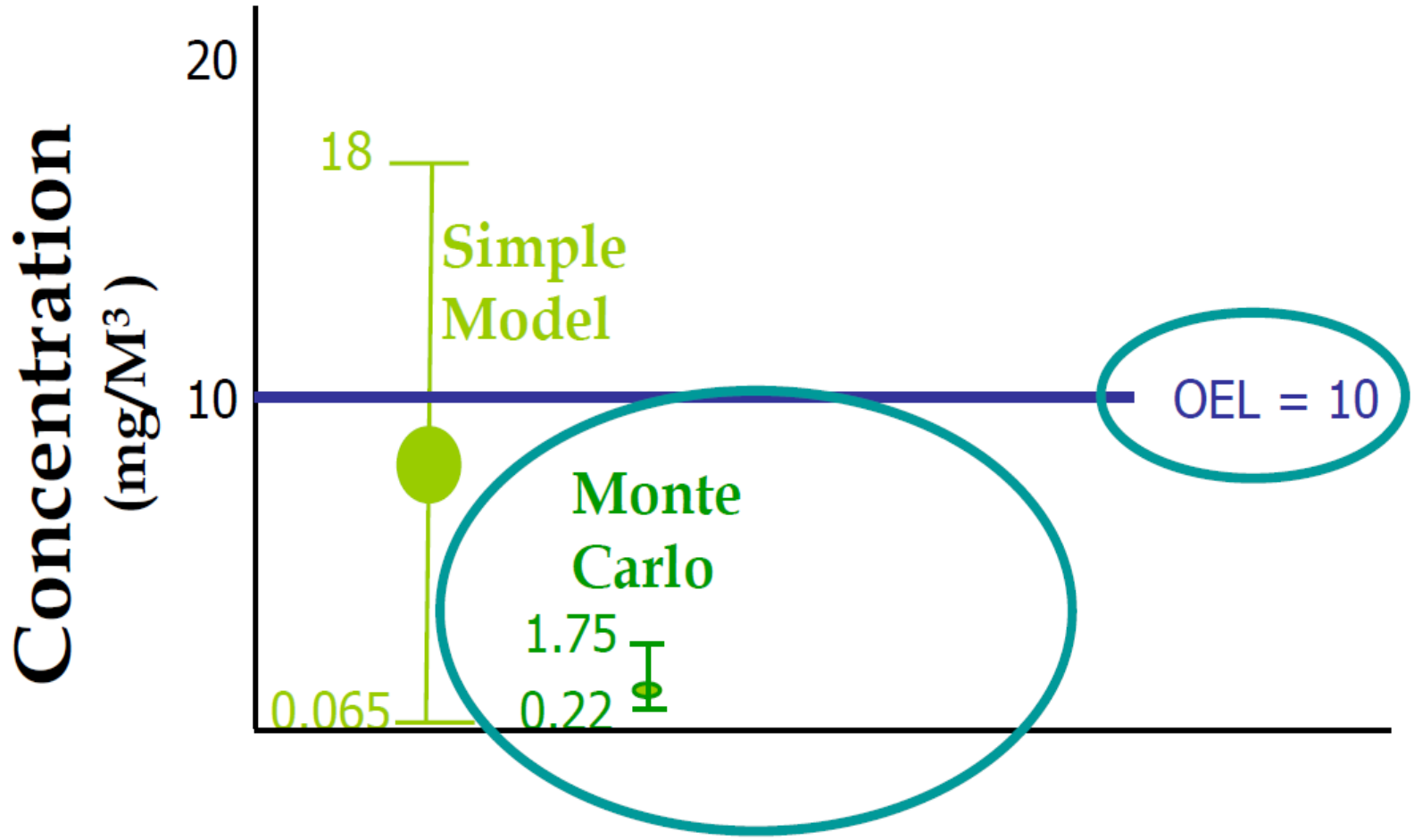
Uncertainty and Acceptability

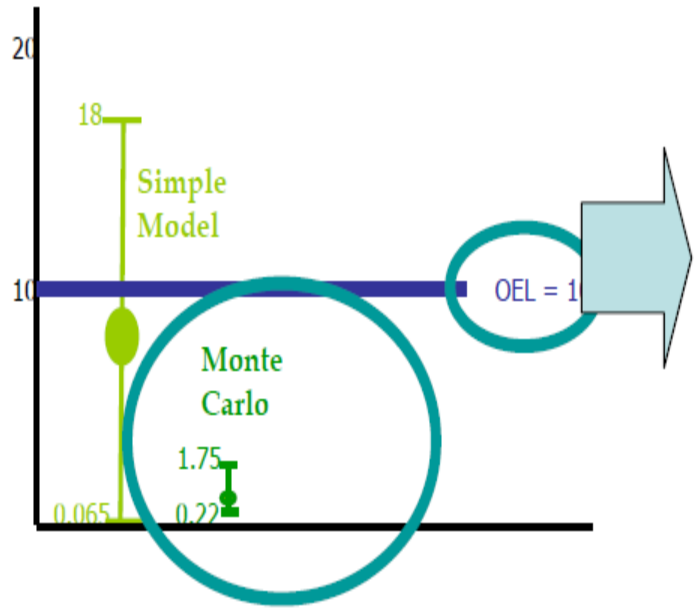


Any or all of these can be used to build the Bayesian Qualitative Model

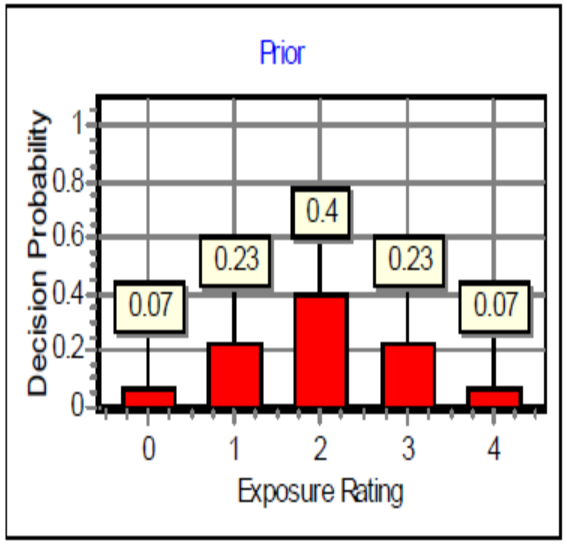
Which To Choose? **Acceptable?**

Uncertainty and Acceptability





Qualitative Assessment or Validated Model



	Exposure Control Category**	Recommended Control
	0 (<1% of OEL)	No action
	1 (<10% of OEL)	general HazCom
	2 (10-50% of OEL)	+ chemical specific HazCom
	3 (50-100% of OEL)	+ exposure surveillance, medical surveillance, work practices
	4 (>100% of OEL)	+ respirators & engineering controls, work practice controls

定量暴露評估:

（ Quantitative Monitorings for Occupational Chemical Exposures ）

現有環境監測技術 (having long-term data)

- 定量暴露危害評估-EM
  - 最大暴露危險群測定
  - 相似暴露危險群測定
  - 區域採樣

貝氏統計決策技術

暴露危害評估

現有環境監測技術 (Lacking long-term data)

- 替代測定數據 (surrogate data)
  - 定性暴露危害評估
  - 半定量暴露危害評估
  - 定量暴露危害評估-Modeling

Prior distribution

+

- 定量暴露危害評估-EM
  - 最大暴露危險群測定
  - 相似暴露危險群測定
  - 區域採樣

Likelihood distribution

貝氏統計決策技術

暴露危害評估

Posterior distribution

Example:

Model + EM + Bayesian Decision Analysis

Why do we need Bayesian decision analysis?

Agent "X"

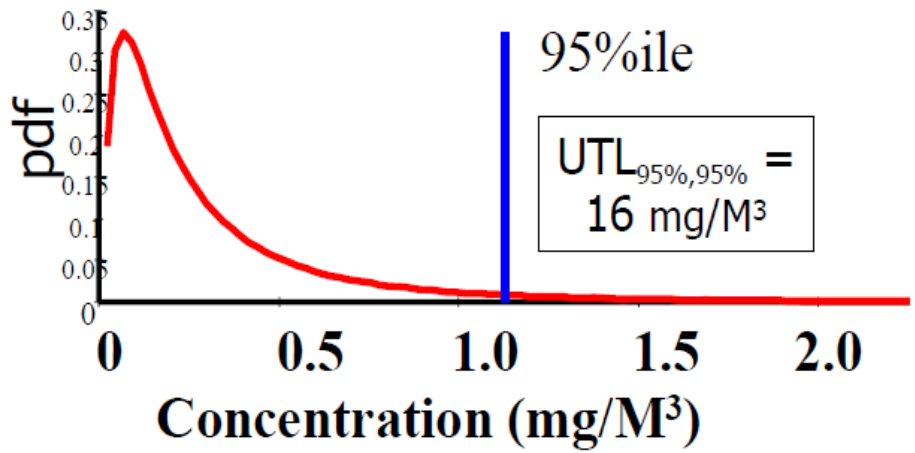
G= steady generation rate (mg/hour)
35 to 65 mg/hour

Q= steady ventilation rate (m^3/hour)
3.6 to 540 m^3/hour

OEL=10 mg/m3

Monitoring Results:

0.05 mg/M^3
0.14 mg/M^3
0.21 mg/M^3
0.37 mg/M^3
0.78 mg/M^3



Exceeding OEL?

Bayesian decision analysis result

Agent "X"

G= steady generation rate (mg/hour)
35 to 65 mg/hour

Q= steady ventilation rate (m^3/hour)
3.6 to 540 m^3/hour

Monitoring Results:

0.05 mg/M^3
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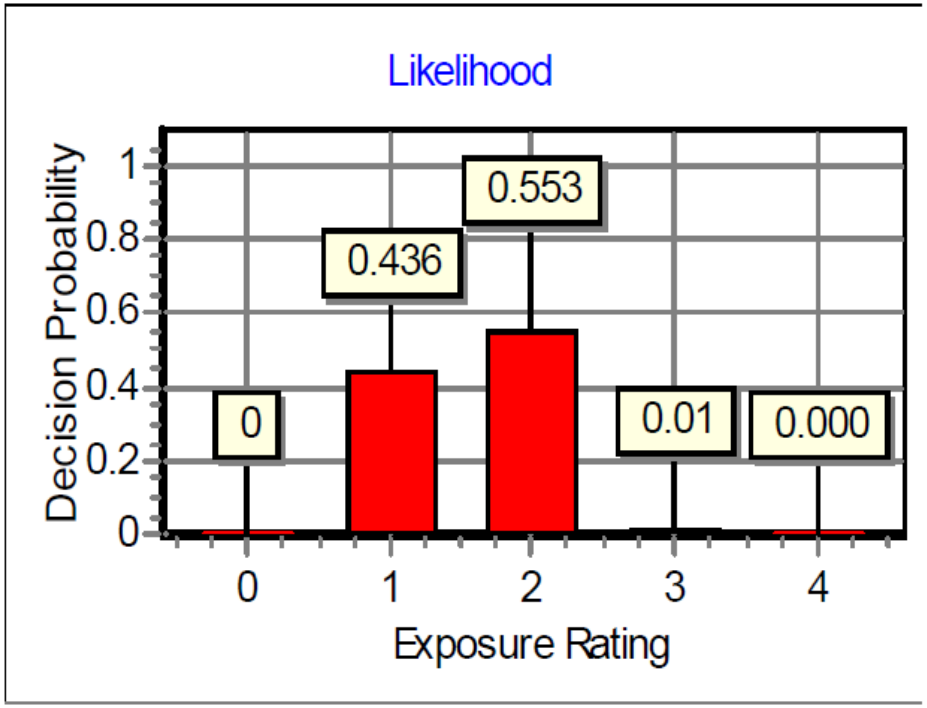
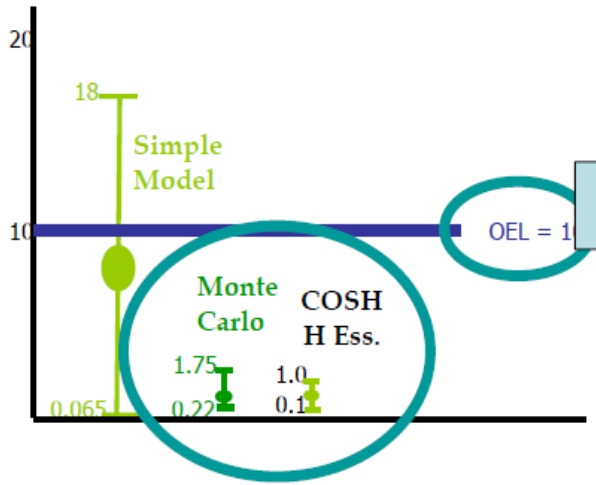
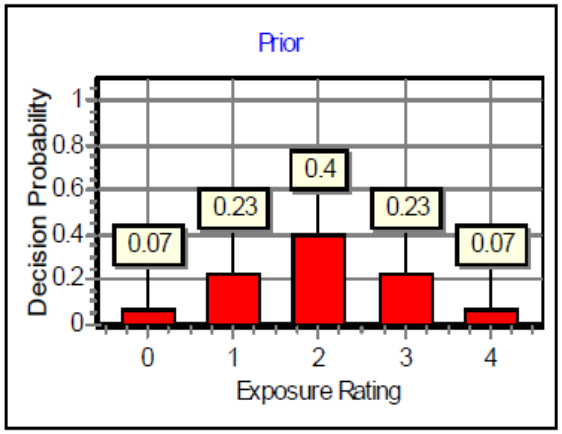
0.78 mg/M^3



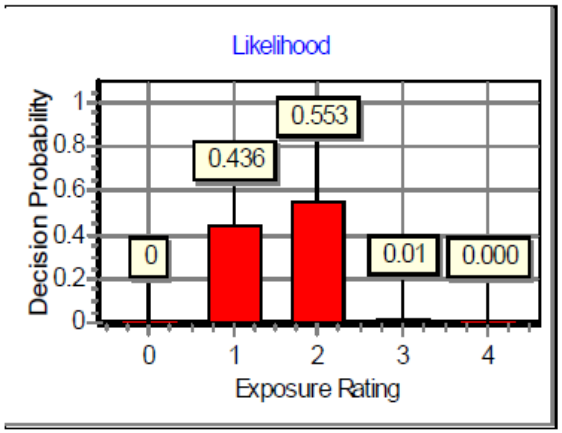


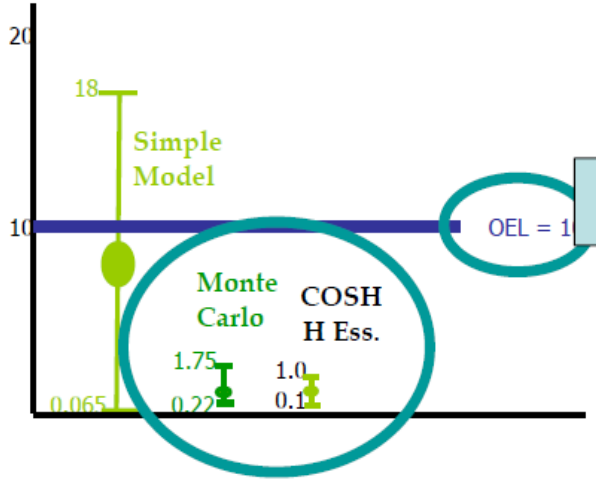
Qualitative Assessment or Validated Model



0.05 mg/M³
0.14 mg/M³
0.21 mg/M³
0.37 mg/M³
0.78 mg/M³

Monitoring Results





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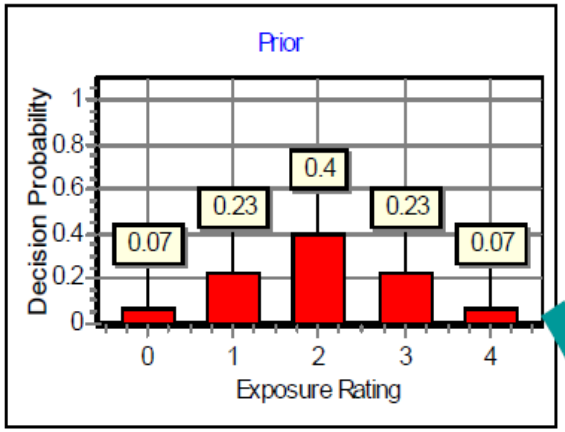
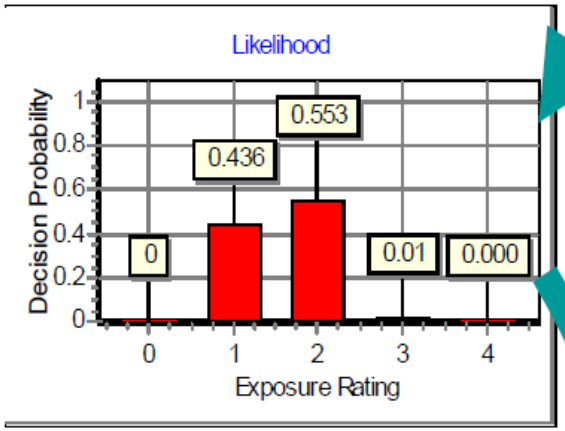
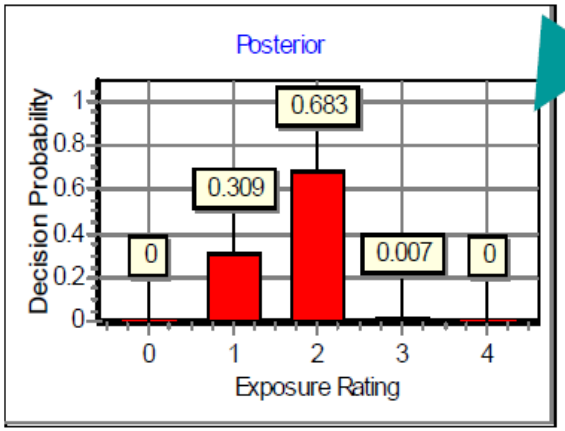
Qualitative Assessment or Validated Model



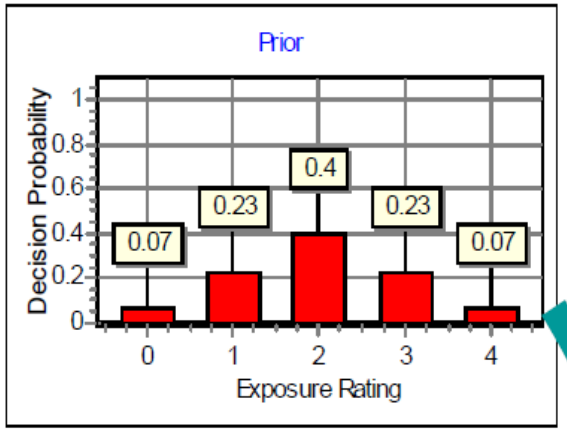
Monitoring Results

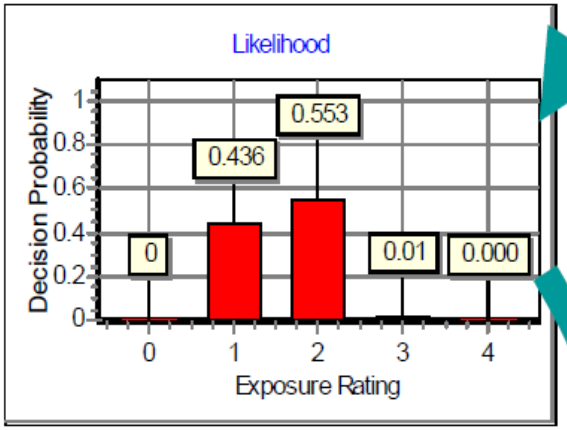


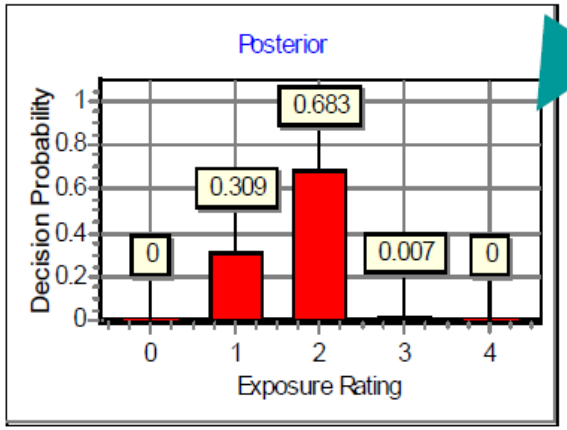
Integrated Exposure Assessment



Integrated Exposure Assessment Result Leads to Control Recommendations







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	3 (50-100% of OEL)	+ Medical surveillance, work practices
	4 (>100% of OEL)	+ Respirators & engineering controls, work practice controls
	Multiples of OEL (i.e., based on respirator APFs)	+ Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirator

Thanks and please comment.