輻射防護特論

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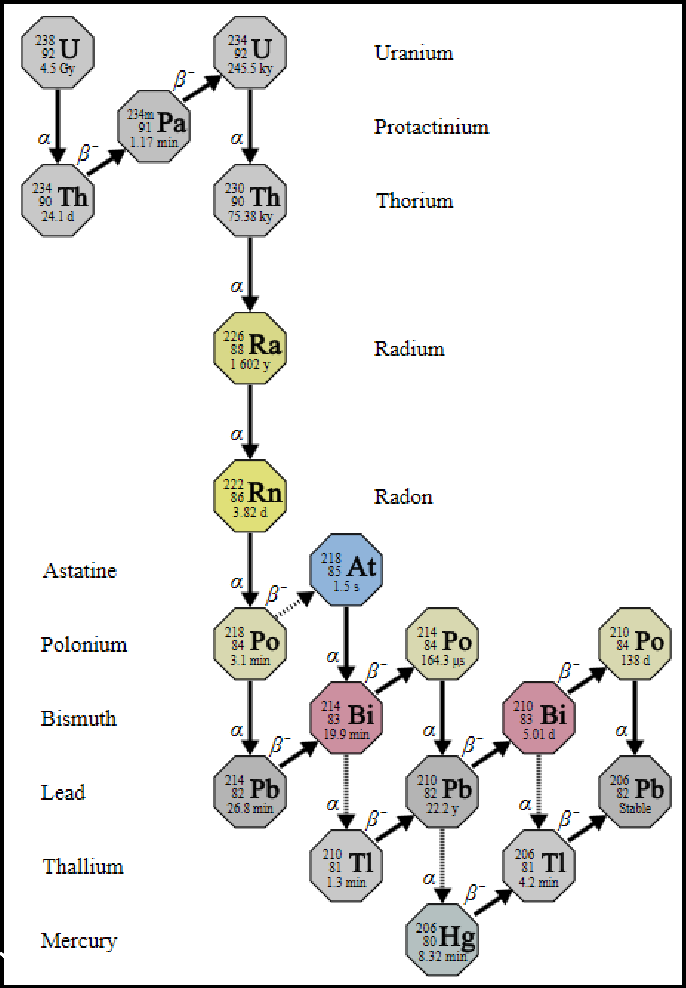
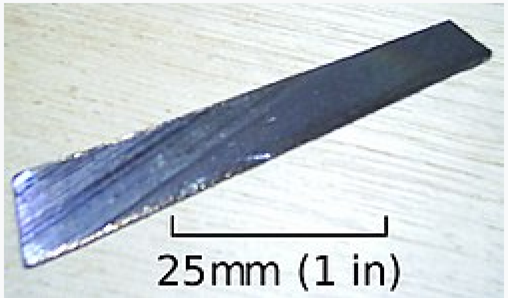
TMP Medical Physics

自然背景輻射

- 定義：環境中持續存在，可以是源自人為排放或自然存在的輻射
- 來源：
  - 太空：宇宙射線
  - 大氣層：氡(^{222}Rn)及其衰變產物 、高能宇宙射線活化的原子(^{14}C-碳)
  - 地球：生物體(^{40}K-鉀)、水、建築材料(^{60}Co-鈷)、土壤(^{238}U-鈾、^{226}Ra-鐳)
  - 人造：自發光羅盤(^{3}H-氚、^{147}Pm-鉅)、煙霧偵測器(^{3241}Am-鎇) 、核武試爆、核電廠及其核燃料(^{235}U-鈾)或廢料、燃燒礦物燃料、核子醫學設施及病人排放



Uranium-238	
 10 gram sample	
Complete table of nuclides	
General	
Name, symbol	Uranium-238, ^{238}U
Neutrons	146
Protons	92
Nuclide data	
Natural abundance	99.2745%
Half-life	4.468 billion years
Parent isotopes	^{242}Pu (α) ^{238}Pa (β^-)
Decay products	^{234}Th
Isotope mass	238.05078826 u
Spin	0
Decay mode	**Decay energy**
Alpha decay	4.267 MeV

→ ^{206}Pb

Uranium-235	
 Uranium metal highly enriched in uranium-235	
Complete table of nuclides	
General	
Name, symbol	Uranium-235, ^{235}U
Neutrons	143
Protons	92
Nuclide data	
Natural abundance	0.72%
Half-life	703,800,000 years
Parent isotopes	^{235}Pa ^{235}Np ^{239}Pu
Decay products	^{231}Th
Isotope mass	235.0439299 u
Spin	7/2−
Excess energy	40914.062 ± 1.970 keV
Binding energy	1783870.285 ± 1.996 keV
Decay mode	**Decay energy**
Alpha	4.679 MeV

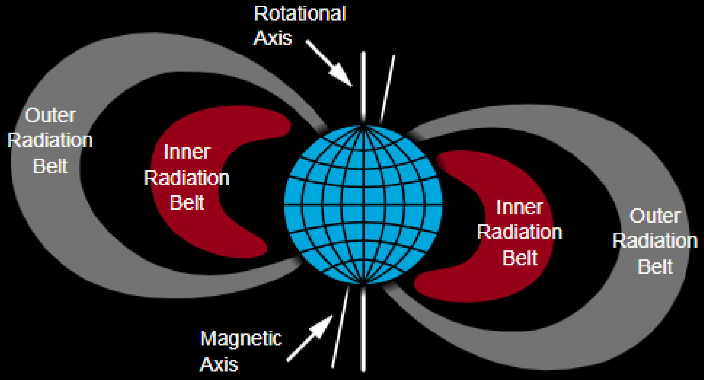
→ ^{207}Pb

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$$

$$E = 202.5 \text{ Mev} = 3.24 \times 10^{-11} \text{ J}$$

宇宙射線

- 是來自外太空的帶電高能次原子粒子。
- 成分：
  - 大約89%的宇宙線是單純的質子，10%是氦原子核（即α粒子），還有1%是重元素。孤獨的電子（像是β粒子，雖然來源仍不清楚），構成其餘1%的絕大部分；γ射線和超高能微中子只佔極小的一部分。
- 強度：(每人每年)
  - 地球表面，約 0.3-0.4 mSv (台灣海平面約 20 nSv/h)
  - 太陽系內的太空中，約 250 mSv
  - 月球表面，約 70-120 mSv
  - 近地軌道，約 100 mSv
  - 范艾倫輻射帶，約 15 Sv



https://zh.wikipedia.org/wiki/宇宙線

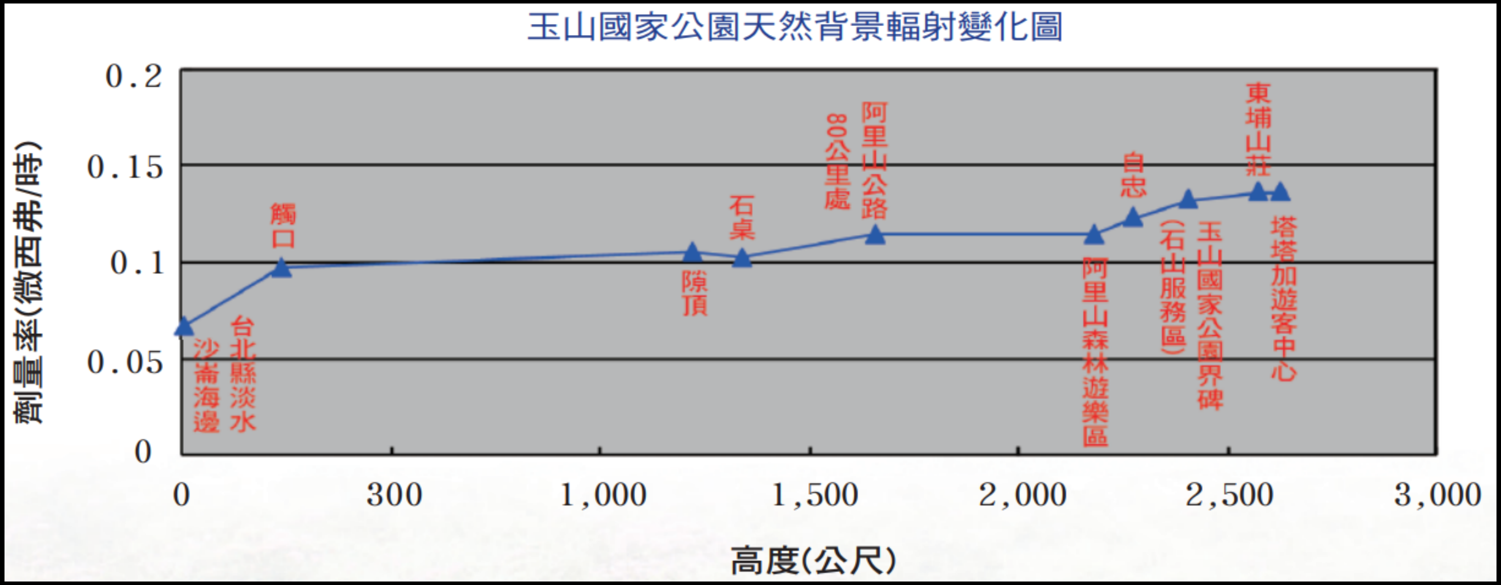
自然背景輻射

輻射來源	全世界[12]	美國[13]	日本[14]	Remark
空氣	1.26	2.28	0.40	主要來自空氣中的氡
食物與飲水	0.29	0.28	0.40	K-40, C-14等
來自地面	0.48	0.21	0.40	與土壤或建材相關
宇宙輻射	0.39	0.33	0.30	與海拔高度相關
小計（自然來源）	2.40	3.10	1.50	
醫療	0.60	3.00	2.30	全世界的統計中排除放射線療法 美國統計中多為電腦斷層與核子醫學
消費	-	0.13		自抽菸、航空飛行、建築物等
核子試爆	0.005	-	0.01	1963年極值為0.01msv，隨時間下降至今，越接近試爆點越高
職業暴露	0.005	0.005	0.01	全世界工人平均為0.7 mSv, 多為礦坑中的氡[12] 美國多為醫療與航空從業者[13]
車諾比核災	0.002	-	0.01	1986年極值為0.04，隨時間下降至今，越接近事故地點越高
核電廠的核燃料循環	0.0002		0.001	接近發生源時可高至0.02 mSv
其他	-	0.003		
小計（人工來源）	0.61	3.14	2.33	
總計	3.01	6.24	3.83	**millisievert per year**

https://zh.wikipedia.org/wiki/背景輻射

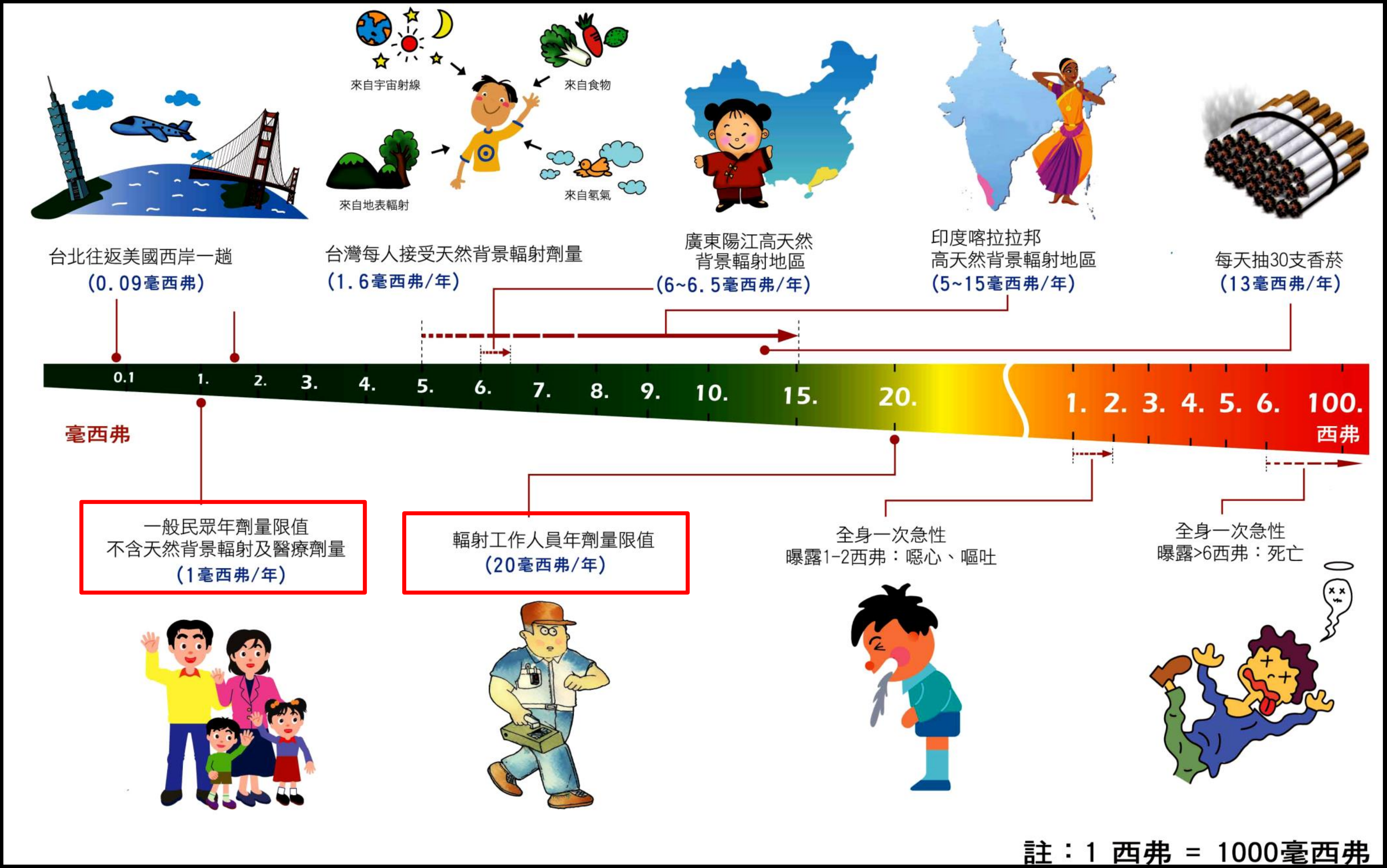
自然背景輻射

- 全球平均值 2.4 mSv/y
- 台灣 1.62 mSv/y
- 高度：
  - 台灣海平面 0.04-0.08 μSv/h
  - 阿里山森林遊樂區(海拔2182公尺) 0.117 μSv/h
  - 每升高1500-2000公尺，宇宙射線會增加1倍



https://www.aec.gov.tw/webpage/UploadFiles/headline_file/2010250120646.pdf

https://www.aec.gov.tw/webpage/UploadFiles/headline_file/2010250120646.pdf



資料來源：行政院原子能委員會網站

隨堂測驗

1.在天然的輻射源中，兼具有母核種與子核種者為何？
A. K-40　　B. U-235　　C. Ra-226　　D. Th-232

2.宇宙射線所產生核種中，何者對人造成最大之體內劑量?
A. H-3　　B. Be-7　　C. C-14　　D. Na-22

3.大氣中存在的核種，對肺部劑量貢獻最大者為何?
A. C-14　　B. Kr-85　　C. Rn-222　　D. H-3

4.全球平均每人每年接受的天然背景輻射，下列何者造成的有效等效劑量最大？
A.氡及其子核　　B. 地表輻射　　C. 宇宙射線　　D. 食物及飲水

5.台灣平地一般人的自然年平均輻射劑量約為若干毫西弗 (mSv)？
A. 0.16　　B. 1.6　　C. 16　　D. 160

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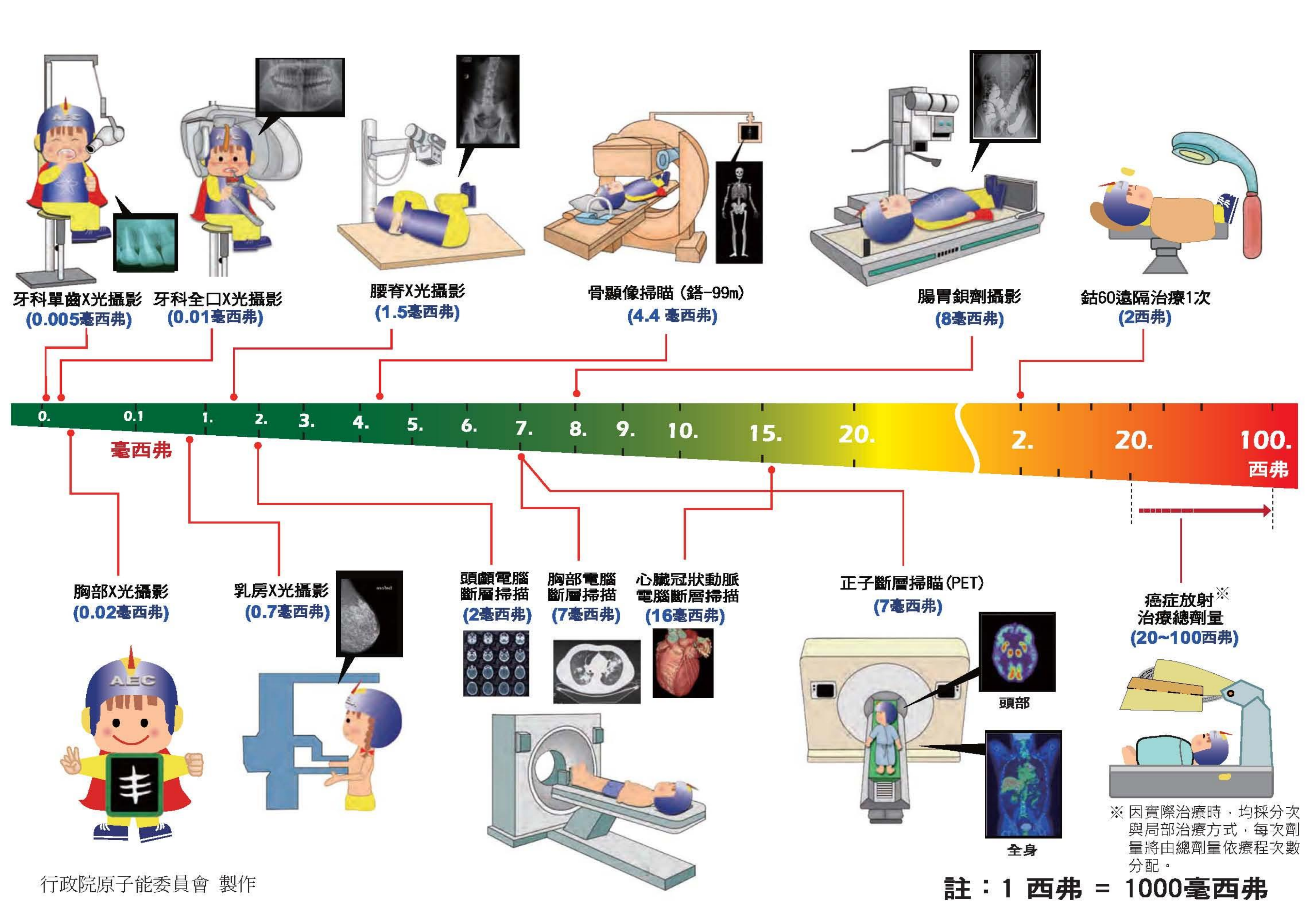
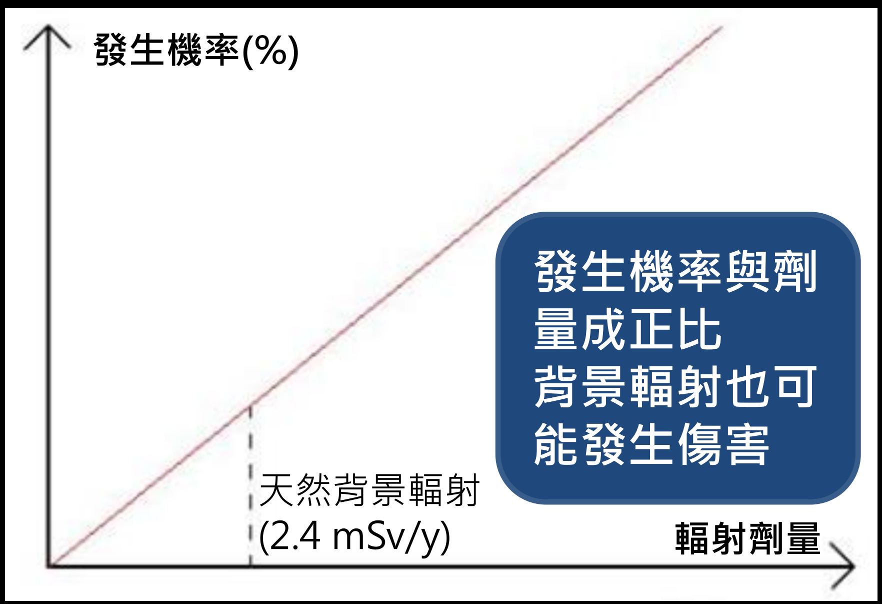


資料來源：行政院原子能委員會網站

輻射曝露傷害

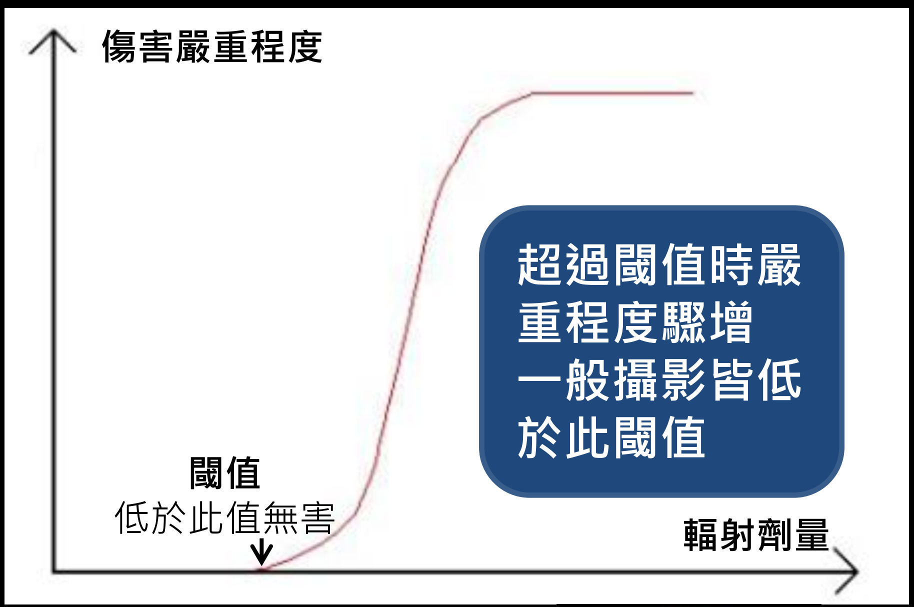
機率效應 Stochastic Effect



輻射傷害類型：

DNA破壞引發之癌症或遺傳疾病

確定效應 Deterministic Effect



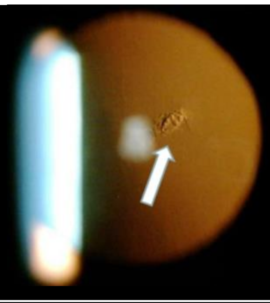
輻射傷害類型：

紅斑

噁心

脫毛

白內障

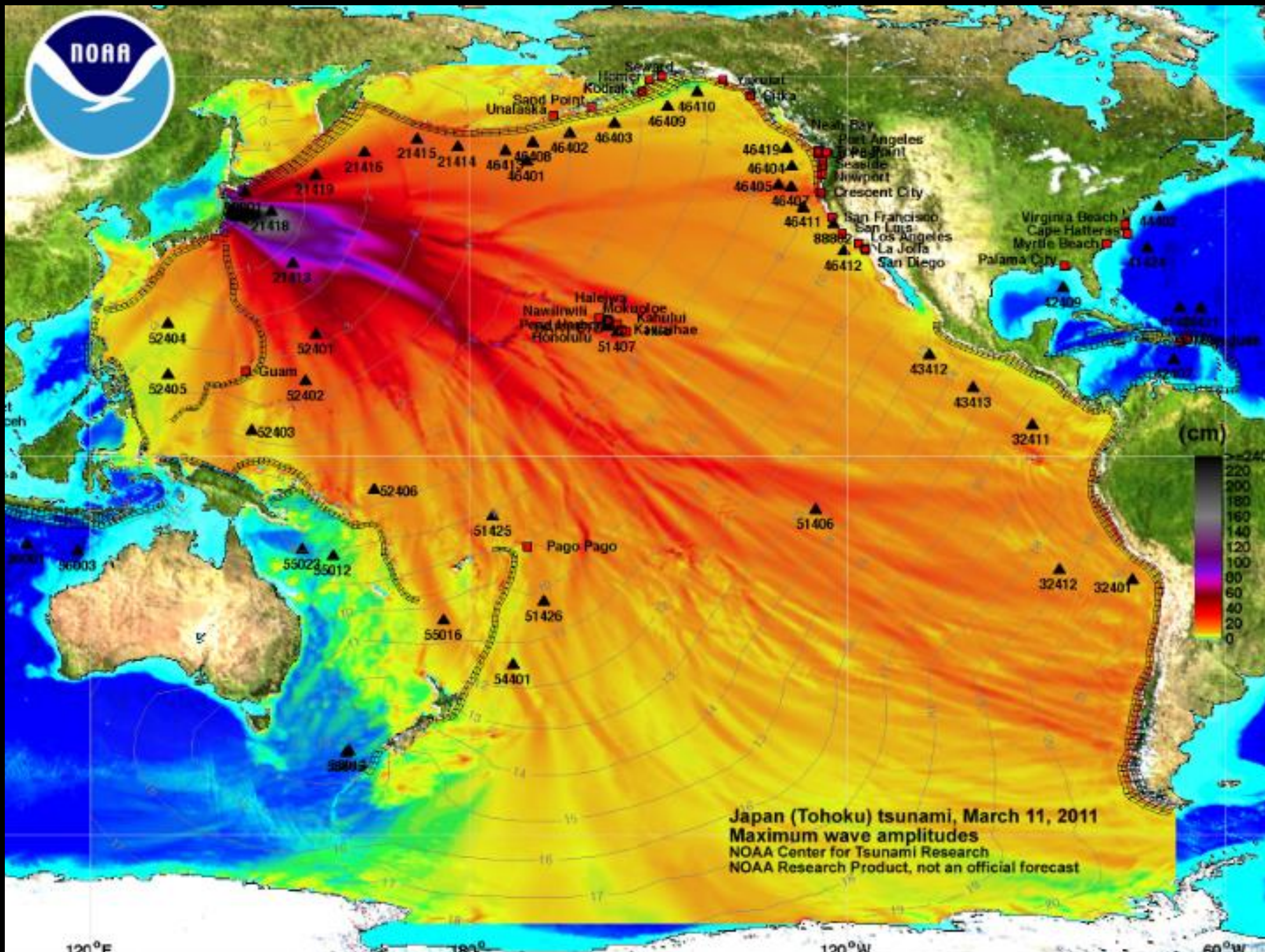


受曝露者個體因素(細胞/DNA修復能力、年齡、性別、體型、循環系統等)的差異，會使發生機率或閾值改變

確定效應：急性大劑量輻射傷害症狀
Acute Radiation Syndrome (ARS)

- ARS (單次大量[>1.5 Gy]輻射曝露)引發症狀
  - 造血系統症狀 – Hematopoietic syndrome [幾乎]
  - 消化系統症狀 – Gastrointestinal syndrome [常見]
  - 中樞神經症狀 – Central Nervous system [罕見]
- 臨床表現
  - 噁心、嘔吐、倦怠、喪失食慾

輻射劑量 (Gy)	影響
1	噁心、嘔吐、腹瀉、倦怠等
3 – 5	貧血、出血 50%的人在60天內死亡
7 – 10	小腸損傷、低血壓、潰瘍以及循環系統崩潰 在1 – 2 周內死亡
> 25	昏迷、震顫、共濟失調(ataxia)、抽搐、譫妄(delirium) 在1 – 2 天內死亡


NOAA
Japan (Tohoku) tsunami, March 11, 2011
Maximum wave amplitudes
NOAA Center for Tsunami Research
NOAA Research Product, not an official forecast
(cm)
>=240
220
200
180
160
140
120
100
80
60
40
20
0
120°E
180°
120°W
60°W
Seward
Homer
Kodiak
Yakutat
Sitka
Sand Point
Unalaska
46410
46409
46403
46402
46408
46401
21415
21414
21416
21419
21418
21413
Neah Bay
Port Angeles
Seaside
Newport
Crescent City
46419
46404
46405
46407
46411
San Francisco
Port San Luis
Los Angeles
La Jolla
San Diego
46412
Virginia Beach
Cape Hatteras
Myrtle Beach
Panama City
44402
42409
Haleiwa
Nawiliwili
Mokuoloe
Kahului
Kawaihae
Honolulu
51407
52404
52405
52401
52402
52403
Guam
52406
51425
Pago Pago
51406
51426
55016
54401
55023
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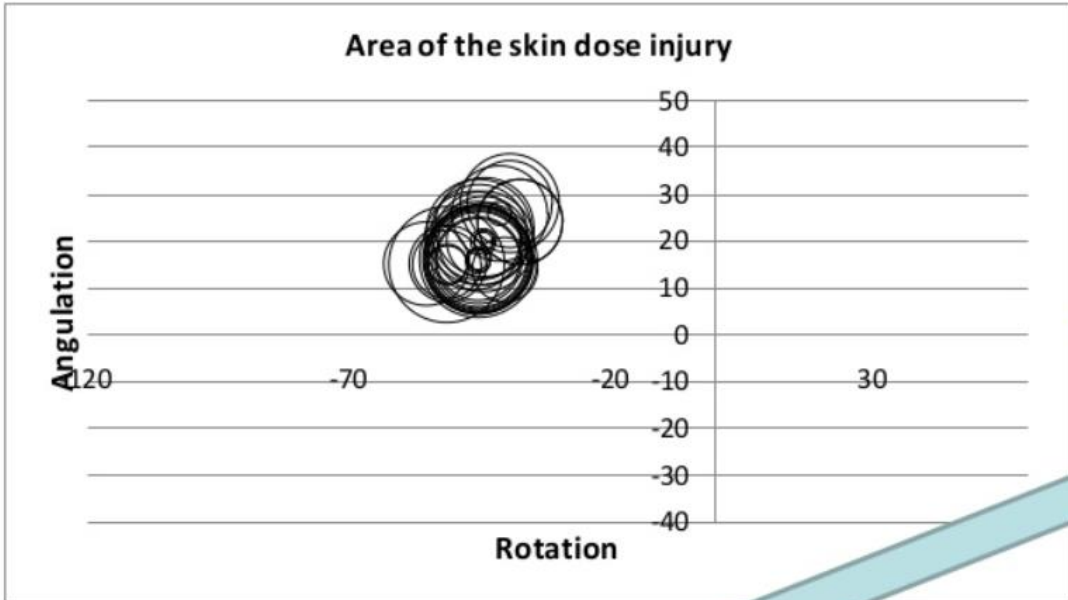
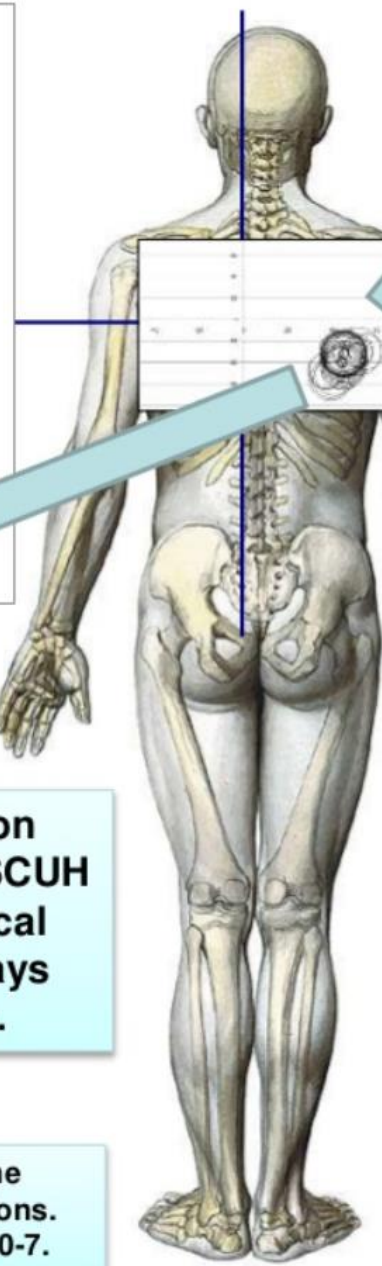
43413
32411
32412
32401





13.0 Gy

Chronic total occlusion procedure made at the SCUH on October 2010. Cinical follow-up. Image 45 days after the procedure.

Importance of a patient dosimetry and clinical follow-up program in the detection of radiodermatitis after long percutaneous coronary interventions. Vano E, Escaned J, et al. Cardiovasc Intervent Radiol. 2013 Apr;36(2):330-7.

Table 2.2. Thresholds for tissue reactions (ICRP, 2007).

Tissue and effect	Threshold	
	Total dose in a single exposure (Gy)	Annual dose in the case of fractionated exposure (Gy/year)
Testes		
Temporal sterility	0.1	0.4
Permanent sterility	6.0	2.0
Ovaries		
Sterility	3.0	>0.2
Lens		
Cataract (visual impairment)	0.5	0.5 divided by years of duration
Bone marrow		
Depression of haematopoiesis	0.5	>0.4
Heart or brain		
Circulatory disease	0.5	0.5 (total dose for fractionated exposure)

機率效應

- 低劑量率時的風險因數 (detriment-adjusted nominal risk coefficient)
  - 癌症發生 – 每 1 Sv 會增加 5.5%
  - 基因病變 – 每 1 Sv 會增加 0.2% (動物實驗數據)
- 致癌風險是由機率決定的
  - 單一器官劑量 > 100 mGy 時 → 引發癌化效應

1 chest CT scan ~ 8 mSv → 20 mGy to breast
5 ~ 15 CT scans → carcinogenic effects

機率效應是沒有閾值的

機率效應

Hiroshima and Nagasaki

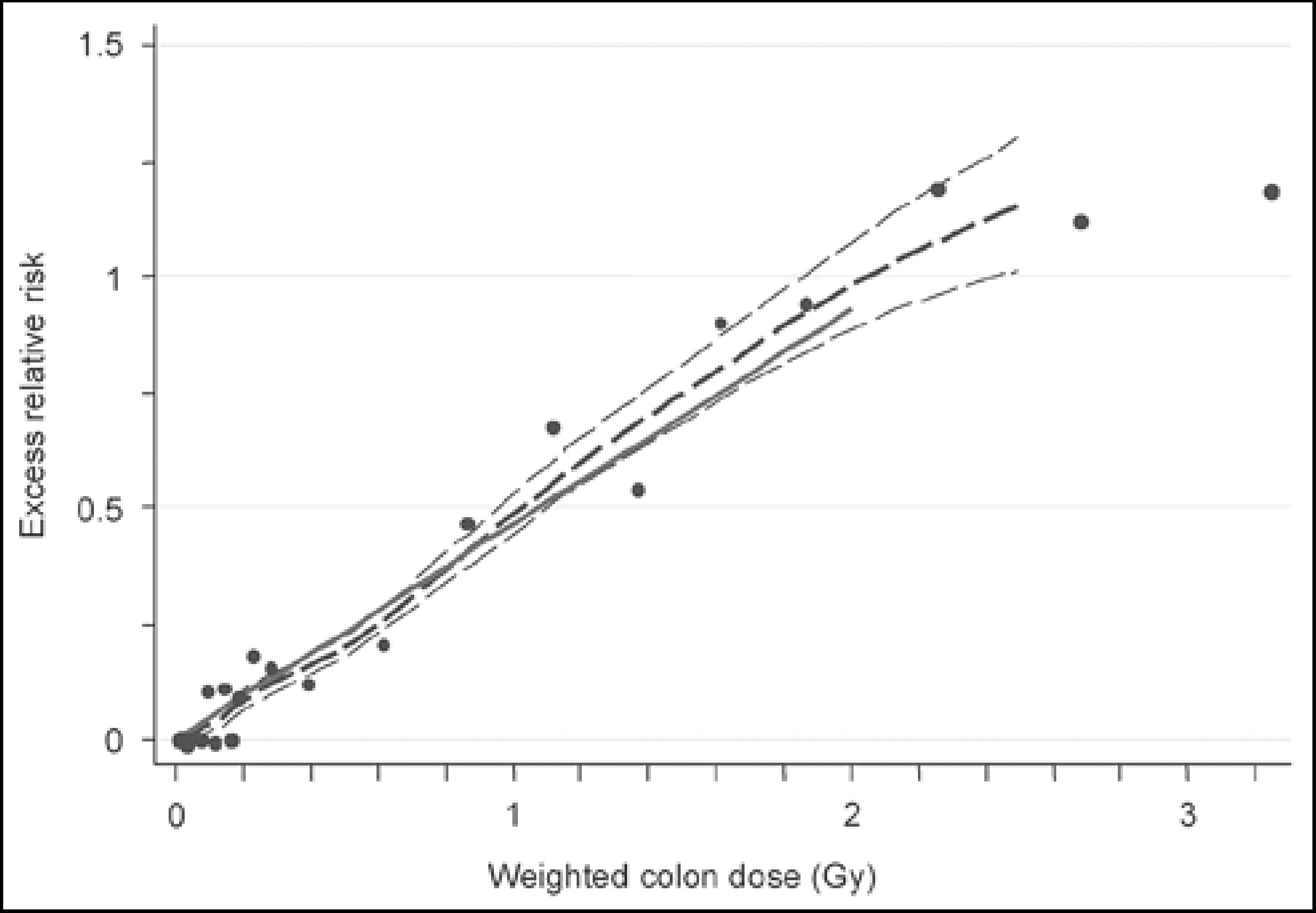
For the average radiation exposure of survivors within 2,500 meters (about 0.2 Gy), the increase is about 10% above normal age-specific rates. For a dose of 1.0 Gy, the corresponding cancer excess is about 50% (relative risk = 1.5)

The excess number of solid cancers is estimated as 848 (10.7%)

Table. Excess risk of developing solid cancers in LSS, 1958-1998

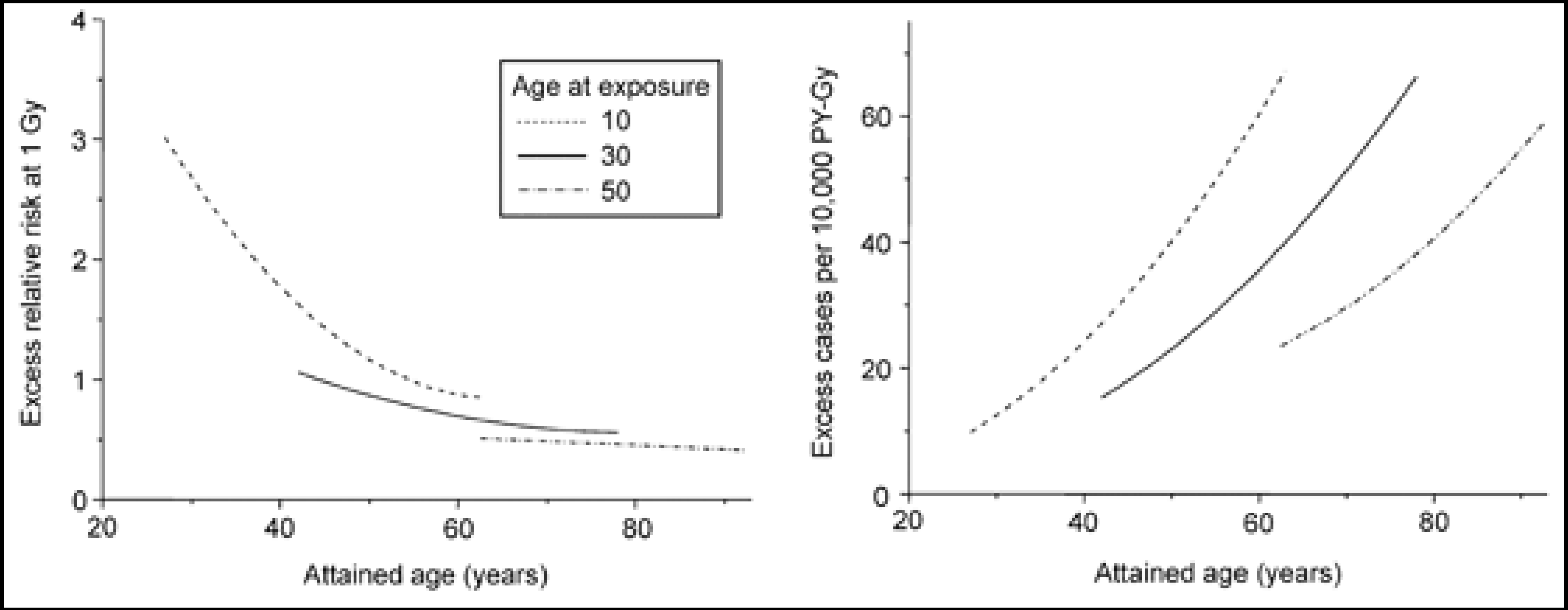
Weighted colon dose (Gy)	LSS subjects	Cancers		Attributable risk
		Observed	Estimated excess	
0.005 - 0.1	27,789	4,406	81	1.8%
0.1 - 0.2	5,527	968	75	7.6%
0.2 - 0.5	5,935	1,144	179	15.7%
0.5 - 1.0	3,173	688	206	29.5%
1.0 - 2.0	1,647	460	196	44.2%
>2.0	564	185	111	61.0%
Total	44,635	7,851	848	10.7%

The dose-response relationship appears to be linear, without any apparent threshold below which effects may not occur



The probability that an A-bomb survivor will have a cancer caused by A-bomb radiation (excess lifetime risk) depends on the (1)dose received, (2)age at exposure, and (3)sex.

Other analyses (not shown) indicate that females have somewhat higher risks of cancer from radiation exposure than males do.



一般X光攝影之胎兒輻射劑量

Estimated Fetal Radiation Dose Based on "Typical" Exposure Values

Study	Fetal Dose mrem, (mSv)			
	Early Pregnancy	3-Month	6-Month	9-Month
AP Pelvis	144 (1.44)	131 (1.31)	127 (1.27)	157 (1.57)
PA Pelvis	40 (0.40)	16 (0.16)	232 (2.32)	100 (1.00)
Lateral Pelvis	53 (0.53)	32 (0.32)	48 (0.48)	52 (0.52)
AP T-Spine (wide FOV)	1.8 (0.018)	1.1 (0.011)	6.9 (0.069)	13 (0.13)
AP T-Spine (narrow)	1.2 (0.012)	0.8 (0.008)	4.6 (0.046)	8.9 (0.089)
Lateral T-Spine	0.6 (0.006)	0.6 (0.006)	1.7 (0.017)	3.2 (0.032)
AP Lumbar Spine	225 (2.25)	197 (1.97)	394 (3.94)	926 (9.26)
Lat Lumbar Spine	113 (1.13)	62 (0.62)	84 (0.84)	85 (0.85)

一般而言，胎兒劑量 <5000 mrem (0.05 Gy, 50 mGy)的曝露對胎兒是安全的。

https://radpage.wordpress.com/radiation-dose-tidbits/

IMAGING of MOTHER	MREM DOSE TO FETUS
Abdomen CR	220
Chest CR	0.5
Extremities CR	<0.50
Femur (distal) CR	1
Hip & Femur (proximal) CR	120
Lumbar Spine CR	720
Pelvis CR	210
Thoracic Spine CR	11
Intravenous Pyel (IVP)	590
Mammography	<10
Abdomen CT	200-400
Abdomen Pelvis CT	2000
Chest CT for PE	5-10
V/Q	72

1 mrem = 0.01 mSv

1 Gy (gray) = 1 Sv (Sievert)

在受孕的前2周，若胎兒劑量 > 0.1 Gy，可能會導致胚胎死亡。

胎兒受到輻射可能產生的影響(癌症除外)

Acute Radiation Dose* to the Embryo/Fetus	Time Post Conception				
	Blastogenesis (up to 2 wks)	Organogenesis (2–7 wks)	Fetogenesis		
			(8–15 wks)	(16–25 wks)	(26–38 wks)
< 0.05 Gy (5 rads)†	**Noncancer health effects NOT detectable**				
0.05–0.50 Gy (5–50 rads)	Incidence of failure to implant may increase slightly, but surviving embryos will probably have no significant (noncancer) health effects	• Incidence of major malformations may increase slightly • Growth retardation possible	• Growth retardation possible • Reduction in IQ possible (up to 15 points, depending on dose) • Incidence of severe mental retardation up to 20%, depending on dose	**Noncancer health effects unlikely**	
> 0.50 Gy (50 rads) *The expectant mother may be experiencing acute radiation syndrome in this range, depending on her whole-body dose.*	Incidence of failure to implant will likely be large‡, depending on dose, but surviving embryos will probably have no significant (noncancer) health effects	• Incidence of miscarriage may increase, depending on dose • Substantial risk of major malformations such as neurological and motor deficiencies • Growth retardation likely	• Incidence of miscarriage probably will increase, depending on dose • Growth retardation likely • Reduction in IQ possible (> 15 points, depending on dose) • Incidence of severe mental retardation > 20%, depending on dose • Incidence of major malformations will probably increase	• Incidence of miscarriage may increase, depending on dose • Growth retardation possible, depending on dose • Reduction in IQ possible, depending on dose • Severe mental retardation possible, depending on dose • Incidence of major malformations may increase	Incidence of miscarriage and neonatal death will probably increase depending on dose§

*Acute dose: dose delivered in a short time (usually minutes). Fractionated or chronic doses: doses delivered over time. For fractionated or chronic doses the health effects to the fetus may differ from what is depicted here.

†Both the gray (Gy) and the rad are units of absorbed dose and reflect the amount of energy deposited into a mass of tissue (1 Gy = 100 rads). In this document, the absorbed dose is that dose received by the entire fetus (whole-body fetal dose). The referenced absorbed dose levels in this document are assumed to be from beta, gamma, or x-radiation. Neutron or proton radiation produces many of the health effects described herein at lower absorbed dose levels.

‡A fetal dose of 1 Gy (100 rads) will likely kill 50% of the embryos. The dose necessary to kill 100% of human embryos or fetuses before 18 weeks' gestation is about 5 Gy (500 rads). § For adults, the LD50/60 (the dose necessary to kill 50% of the exposed population in 60 days) is about 3-5 Gy (300-500 rads) and the LD100 (the dose necessary to kill 100% of the exposed population) is around 10 Gy (1000 rads).

https://radpage.files.wordpress.com/2010/12/cdcprenatalradiation.pdf

胎兒受到輻射可能產生的影響(癌症除外)

緊急曝露時胚胎/胎兒的劑量	卵子受精後的時間				
	胚胎成形 (2 周內)	器官生成 (2-7 周)	胚胎發育		
			(8-15 周)	(16-25 周)	(26-38 周)
< 0.05 Gy	**沒有發現任何非癌症病變**				
0.05-0.50 Gy	可能稍微提高著床失敗率，存活的胚胎不會有明顯的病變	• 嚴重畸形的發生率會稍微提高 • 可能會有生長遲緩	• 可能會有生長遲緩 • 可能會有智力下降(與劑量有關) • 最高有 20%機率會發生心智發展遲緩(與劑量有關)	**應與非癌症病變無關**	
> 0.50 Gy	著床失敗率會很高，存活的胚胎不會有明顯的病變	• 流產的發生率會提高(與劑量有關) • 有極高機率發生嚴重畸形，例如神經或運動缺陷 • 應會生長遲緩	• 流產的發生率會提高(與劑量有關) • 應會生長遲緩 • 智力下降(與劑量有關) • 最高有 20%機率會發生心智發展遲緩(與劑量有關) • 可能增加發生嚴重畸形的機率	• 流產的發生率會提高(與劑量有關) • 會生長遲緩 • 智力下降(與劑量有關) • 可能會發生嚴重心智發展遲緩(與劑量有關) • 可能增加發生嚴重畸形的機率	流產與胎兒早期死亡的發生率會提高(與劑量有關)

1 Gy 的胎兒劑量大約會殺死50%的胚胎；
要100%殺死胚胎或胎兒，大約需要5 Gy。
在成人，LD50/60的劑量大約3-5 Gy，LD100大約是10 Gy。

隨堂測驗

1. 在受孕的前2周，可能會導致胚胎死亡之胎兒劑量的閾值為何？
   A. 0.1 Gy　B. 0.1 rem　C. 10 mGy　D. 10 mrem

2. 在受孕後8-15周期間，若推定胎兒劑量為 0.2 Gy，下列何者不會發生在胎兒身上?
   A. 生長遲緩　B. 智力降低　C. 流產　D. 心智發展遲緩

3. 在受孕的前2周，接受輻射曝露後胚胎最可能發生的病變為下列何者？
   A. 生長遲緩　B. 智力降低　C. 流產　D. 心智發展遲緩

4. 在懷孕期間接受下列何種檢查，會使胚胎/胎兒接受到最高的輻射劑量？
   A. 乳房攝影　B. 胸部X光攝影　C. 上肢X光攝影　D. 胸椎X光攝影

5. 下列何種 X光檢查受檢者接受到的輻射劑量最大？
   A. 胸部PA攝影　B. 乳房X光攝影　C. 腰椎X光攝影　D. 牙科全口攝影

隨堂測驗

1. 在受孕的前2周，可能會導致胚胎死亡之胎兒劑量的閾值為何？
   A. 0.1 Gy　B. 0.1 rem　C. 10 mGy　D. 10 mrem

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核能電廠外的輻射劑量

熱發光劑量計計讀結果

單位：毫西弗/年

熱發光劑量計 廠別	台電測站平均值 99年	台電測站平均值 100年	台電測站平均值 運轉前背景值	原能會輻射偵測中心測值 100年
核一廠	0.544	0.526	0.645	0.359～0.666
核二廠	0.549	0.560	0.534	0.333～0.666
核三廠	0.500	0.526	0.524	0.368～0.578
龍門電廠	0.535	0.584	正執行背景調查	正執行背景調查
蘭嶼貯存場	0.307	0.324	0.339	0.270～0.368

高壓游離腔監測結果

單位：微西弗/時

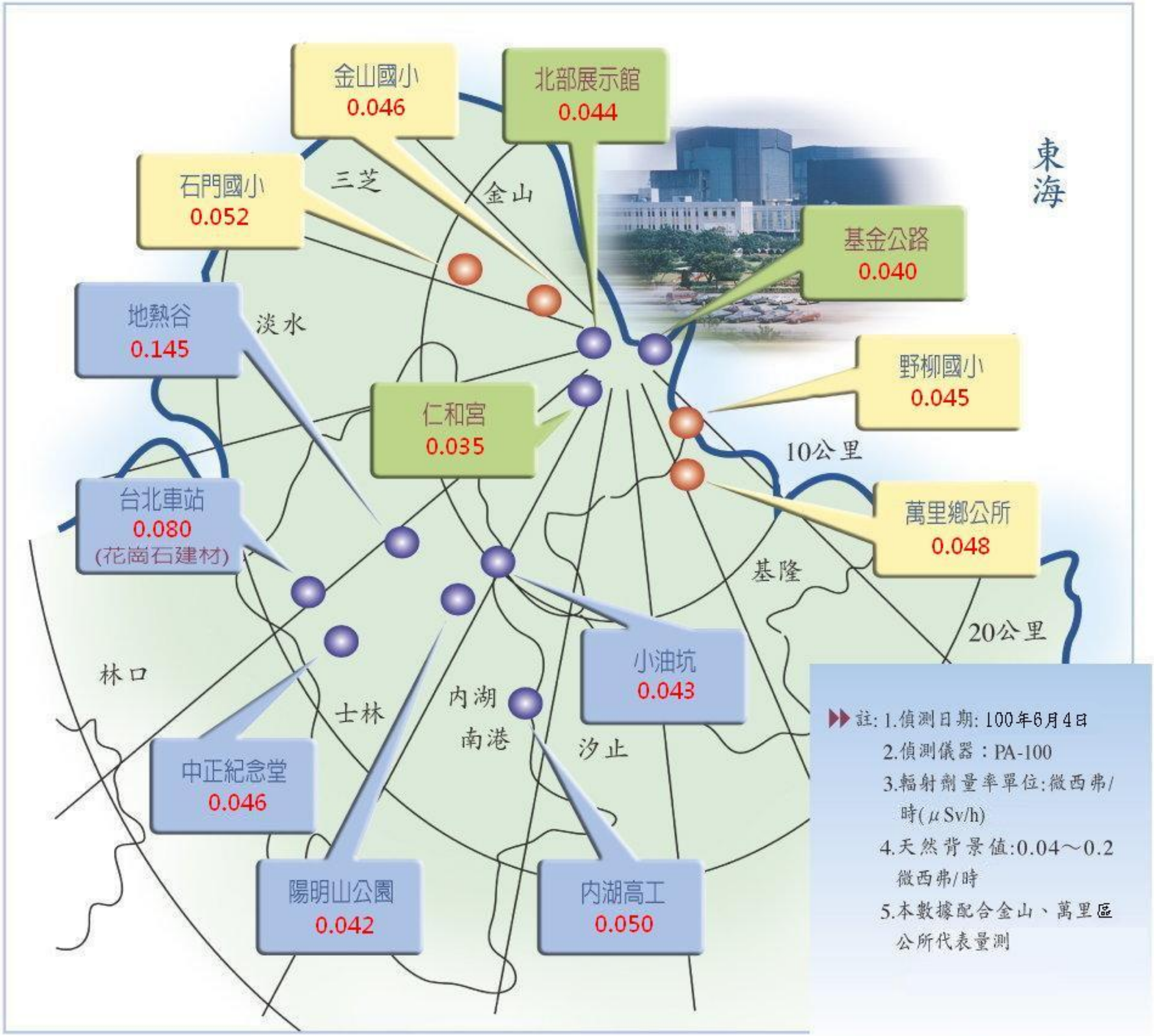
高壓游離腔 廠別	台電測站平均值 99年	台電測站平均值 100年	台電測站平均值 運轉前背景值	原能會輻射偵測中心測值 100年
核一廠	0.0667	0.0670	0.0648	0.045～0.144
核二廠	0.0638	0.0663	0.0571	0.053～0.139
核三廠	0.0642	0.0631	0.0600	0.043～0.101
龍門電廠	0.0684	0.0681	正執行背景調查	正執行背景調查
蘭嶼貯存場	0.0673	0.0586	—	0.038～0.086

一般人每年輻射的有效等效劑量法定限值為 1 西弗。(不含背景輻射或醫療曝露)

1 年 = 8760 小時

http://wapp4.taipower.com.tw/nsis/web/006.html

核能電廠旁輻射劑量率與背景值無異



註：依據原能會環境輻測監測網站資料(95.08.09)顯示之背景輻射劑量率——台中地區：0.064微西弗/時、高雄地區：0.060微西弗/時

在符合管制規定之運轉下，核能電廠附近為天然輻射背景值，足見輻射安全無慮。

http://wapp4.taipower.com.tw/nsis/web/006.html

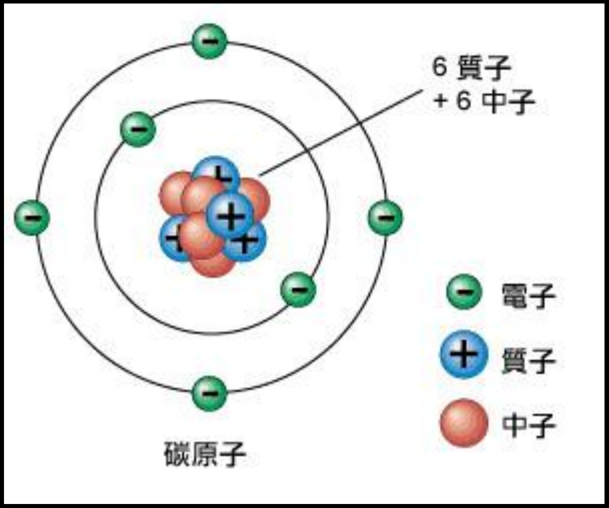
核能燃料廢料

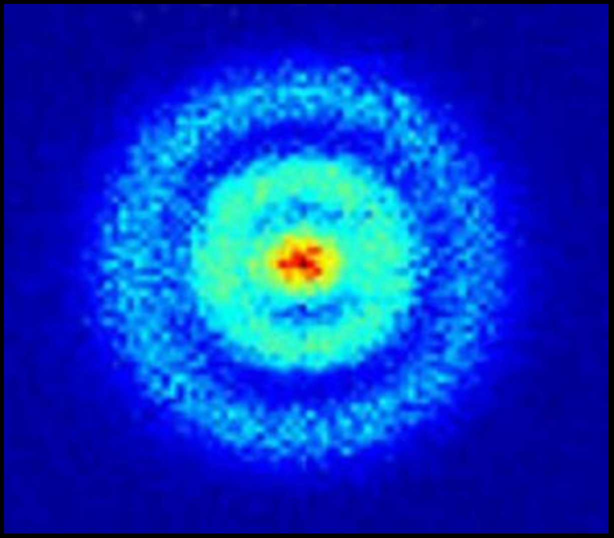
Long-lived fission products				
Prop:	$t_{1/2}$	Yield	Q *	βγ
Unit:	(Ma)	(%)	(keV)	*
^{99}Tc	0.211	6.1385	294	β
^{126}Sn	0.230	0.1084	4050	βγ
^{79}Se	0.327	0.0447	151	β
^{93}Zr	1.53	5.4575	91	βγ
^{135}Cs	2.3	6.9110	269	β
^{107}Pd	6.5	1.2499	33	β
^{129}I	15.7	0.8410	194	βγ

Medium-lived fission products				
Prop:	$t_{1/2}$	Yield	Q *	βγ *
Unit:	(a)	(%)	(keV)	
^{155}Eu	4.76	0.0803	252	βγ
^{85}Kr	10.76	0.2180	687	βγ
^{113m}Cd	14.1	0.0008	316	β
^{90}Sr	28.9	4.505	2826	β
^{137}Cs	30.23	6.337	1176	βγ
^{121m}Sn	43.9	0.00005	390	βγ
^{151}Sm	96.6	0.5314	77	β

Ma = megaannus = 百萬年

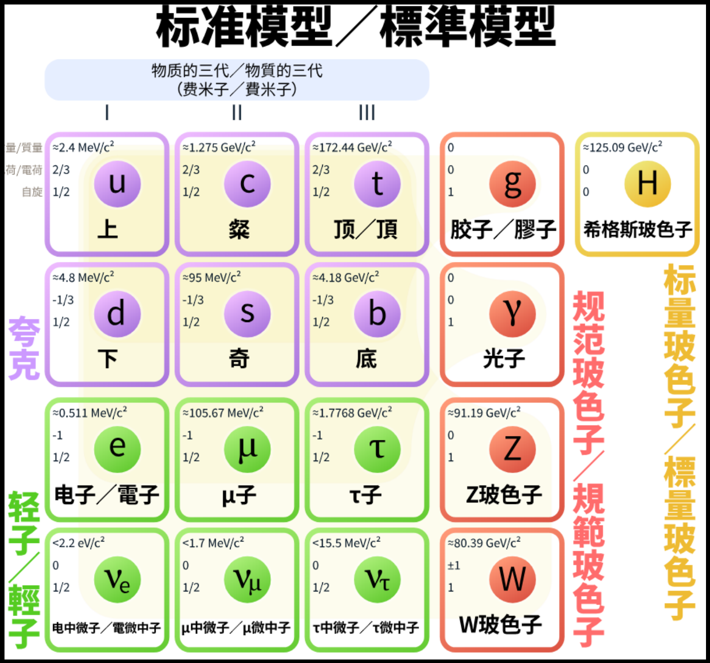
原子物理





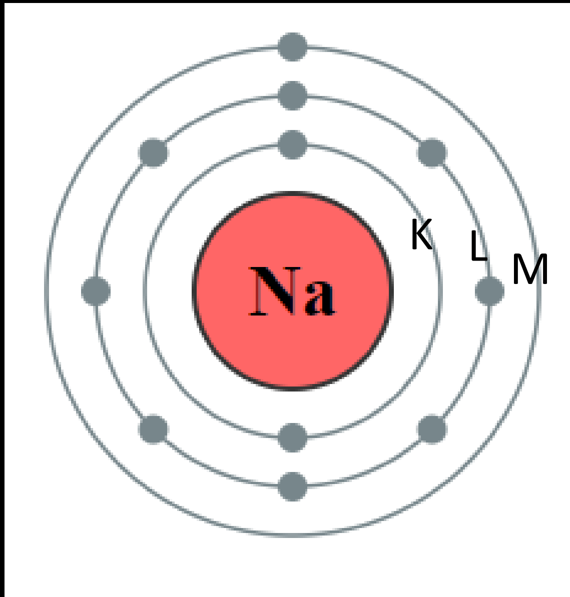
原子

- 組成：
  - 質子 (proton)
  - 中子 (neutron)
  - 電子 (electron)
- 原子序：原子中質子的數量
- 質量數：原子中質子+中子的質量



名稱	組成	符號	質量(kg)	能量 (MeV)	電荷	平均壽命
質子	上夸克 x 2 下夸克 x 1	p^+	$1.673\text{x}10^{-27}$	938.3	+1 e	>$2.1\text{x}10^{29}$年
中子	上夸克 x 1 下夸克 x 2	n	$1.675\text{x}10^{-27}$	939.6	0	881.5 秒 (自由中子)
電子	基本粒子	e^-	$9.109\text{x}10^{-31}$	0.511	-1 e	穩定

1 e = 1.6×10^{-19} C (每個電子的帶電量)



11:Sodium
K：2
L：8
M：1

亞層符號	ℓ	極限電子數	主層	命名來源
s	0	2	每個主層	sharp
p	1	6	第二層及以上	principal
d	2	10	第三層及以上	diffuse
f	3	14	第四層及以上	fundamental
g	4	18	第五層及以上	f的後一個字母

Shell name	Subshell name	Subshell max electrons	Shell max electrons
K	1s	2	**2**
L	2s	2	2 + 6 = **8**
	2p	6	
M	3s	2	2 + 6 + 10 = **18**
	3p	6	
	3d	10	
N	4s	2	2 + 6 + 10 + 14 = **32**
	4p	6	
	4d	10	
	4f	14	
O	5s	2	2 + 6 + 10 + 14 + 18 = **50**
	5p	6	
	5d	10	
	5f	14	
	5g	18	

1	1 氫 Hydrogen 1.008	原子序 Sym 名字 原子量
2	3 鋰 Lithium 6.94	4 鈹 Beryllium 9.0122
3	11 鈉 Sodium 22.990	12 鎂 Magnesium 24.305
4	19 鉀 Potassium 39.098	20 鈣 Calcium 40.078

^{2}He：2

^{10}Ne：2, 8

^{18}Ar：Ne $3s^2$ $3p^6$
2, 8, 8

^{19}K：Ar $4s^1$
2, 8, 8, 1

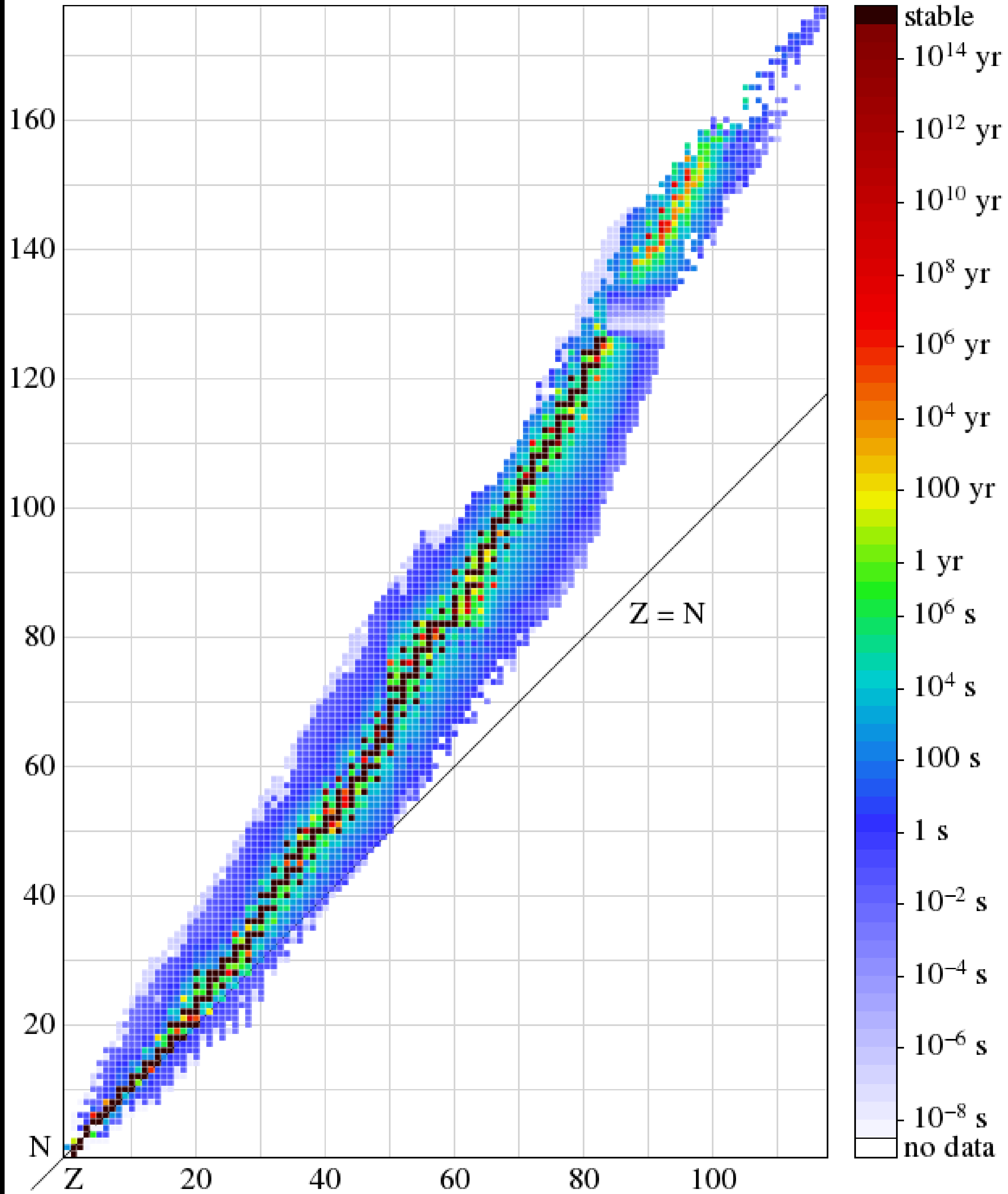
^{20}Ca：Ar $4s^2$
2, 8, 8, 2

^{21}Sc：Ar $3d^1$ $4s^2$
2, 8, 9, 2

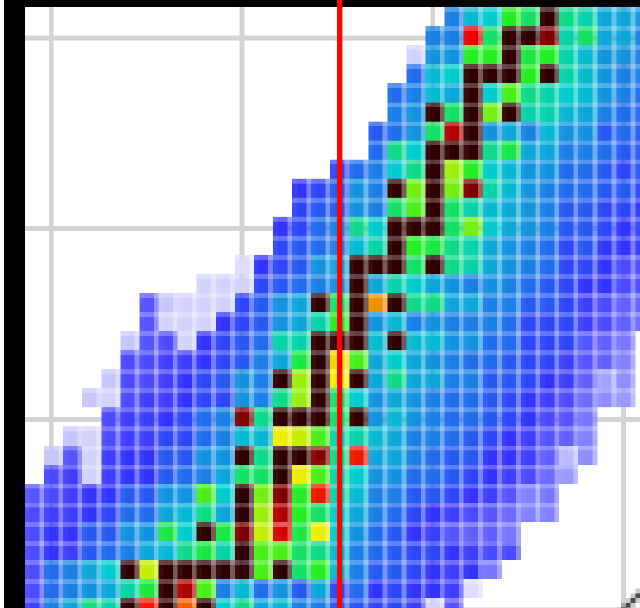
原子的性質

- 原子半徑：約 10^{-12} cm
- 莫耳：(亞佛加厥數)12g的碳所含的原子個數 = 6.02×10^{23}
- 同位素：(isotope)具有相同質子數，不同中子數 (例：^{59}Co, ^{60}Co)
- 同中素：(isotone)具有相同中子數，不同質子數 (例：^{89}Y, ^{92}Mo)
- 同重(量)素：(isobar)具有相同質量數 (例：^{40}Cl, ^{40}K)
- 電量：
  - 1 安培 (A)：1秒內通過橫截面的電量為1庫侖(C)時的電流強度。
  - 1 個電子帶有 1.6×10^{-19} C的電量。
  - 1 A = $1 / (1.6 \times 10^{-19}) = 6.24 \times 10^{18}$ 個電子
- 能量：
  - 1個電子受到1伏特電場的加速，會獲得1.6×10^{-19} 焦耳的能量
  - 1焦耳 = 6.24×10^{18} 電子伏特 (eV)
  - 在空氣中產生一個離子對，需要 34 eV 的能量
- 平均原子量：所有同位素之質量數x豐度的總和
  - 例：^{35}Cl 豐度為 75%，^{37}Cl 豐度為 25%

    平均原子量 = 35 x 75% + 37 x 25% = 35.5



Isotope (同位素)
(質子數 Z 相同)



鉛(^{82}**Pb**)有四種自然的、穩定的同位素：Pb-204（1.4%）、Pb-206（24.1%）、Pb-207（22.1%）和Pb-208（52.4%）。後三種是鈾-238、鈾-235和釷-232經過一系列裂變後的最終產物。這些反應的半衰期分別是4.47×10^{9}年、7.04×10^{8}年和1.4×10^{10}年。只有Pb-204是自然存在的、非衰變產物。

Pb-208在穩定的同位素中質量最大。

原子的性質

- 動能：
  - 電子伏特(eV)：代表一個電子(所帶電量為1.6×10^{-19} C)經過1伏特的電位差加速後所獲得的動能(1.6×10^{-19} J)。

卡(卡路里)	焦耳(J)	爾格(erg)	電子伏特(eV)	百萬電子伏特(MeV)
0.239	1	10^7	$6.24\text{x}10^{18}$	$6.24\text{x}10^{12}$
1	4.18	$4.18\text{x}10^7$	$2.61\text{x}10^{19}$	$2.61\text{x}10^{13}$

$1\ \text{J} = 1\ \text{nt}\cdot\text{m} = 1\ \text{kg}\cdot\text{m/s}^2\cdot\text{m} = 10^7\ \text{g}\cdot\text{cm/s}^2\cdot\text{cm (erg)}$

$1\ \text{nt} = 10^5\ \text{dyne} = 10^5\ \text{g}\cdot\text{cm/s}^2$　　　$1\ \text{erg} = 1\ \text{dyne}\cdot 1\ \text{cm}$

- 質能轉換：$E = mc^2$ (m 為靜止質量)

$E_{electron} = 9.109\text{x}10^{-31}\ \text{x}\ (3\text{x}10^8)^2 = 8.198\ \text{x}\ 10^{-14}\ \text{J} = 0.511\ \text{MeV}$

隨堂測驗

1.下列能量單位，何者為最小?

A. MeV　B. erg　C. Joule　D. calorie

2.反質子為帶負電荷的質子，若一個質子和一個反質子發生互毀時，會放出多少能量?

A. 0.511 MeV　B. 1.022 MeV　C. 1.86 GeV　D. 3.72 GeV

3.下列有關軌道電子在K、L、M層最大電子數的數量，何者正確?

A. 2,8,8　B. 8,10,18　C. 2,8,10　D. 2,8,18

4. 原子的平均原子量與下列何者無關？

A. 同位素的原子量　B. 同位素的豐度

C. 同重素的原子量　D. 質子的質量

5.下列何者為能量單位?

A. 瓦特(watt)　B. 毫安培(mA)　C. 千伏特(kV)　D. 電子伏特(eV)

隨堂測驗

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粒子的動能

- 古典物理學：$E = \frac{1}{2}mv^2$
  - 例：某熱中子能量 0.025 eV，該中子的速度為多少?

    (中子質量為 1.67×10^{-27} kg)

    $0.025\ \text{eV}\times1.6\times10^{-19}\ \text{J eV}^{-1} = 0.5\times1.67\times10^{-27}\ \text{kg}\times v^2$

    $v^2 = 4.79\times10^{6}\ \text{m}^2\ \text{s}^{-2}$ (註：$1\ \text{J} = 1\ \text{kg m}^2\ \text{s}^{-2}$)，$v = 2189\ \text{m s}^{-1}$

- 洛倫茲因子：$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-\beta^2}} = \frac{dt}{d\tau}$
  - 近光速時：
    - 物體的質量 $m = \gamma m_0$；總能量 $E = \gamma m_0 c^2$
    - 物體的動能 $E_k = E - m_0c^2 = (m-m_0)\ c^2 = (\gamma - 1)\ m_0c^2$
  - 例：若電子的速度為 $2.70\times10^{8}\ \text{m s}^{-1}$，其動能約為？

總能量 $E = \frac{0.511}{\sqrt{1-(\frac{2.7\times10^8}{3\times10^8})^2}} = \frac{0.511}{\sqrt{1-0.81}} = 2.294\times0.511\ MeV = 1.172\ MeV$

扣除電子靜質量 (0.511 MeV)，則此時電子的動能(E_k)為1.172-0.511=0.661 MeV

隨堂測驗

1. 某熱中子能量 0.05 eV，問該中子的速度約為多少m/s? (中子質量為 1.67×10^{-27} kg)
   A. 3000　B. 3×10^{8}　C. 1.2×10^{12}　D. 4400

2. 某一質點，若其前進的速度是光速的 98%，則其質量變為靜止質量的幾倍?
   A. 2　B. 4　C. 5　D. 8

3.若一電子具有 20 MeV 之動能，則其相對質量 m 約為靜止質量 m_0 之幾倍?
   A. 10　B. 20　C. 30　D. 40

4. 在加速器加速質子能量至 0.936 MeV，質子的靜止質量為 936 MeV/c^2， 則質子的速度為每秒幾公里？
   A. 600　B. 9490　C. 13420　D. 300000

5.下列何者之質量轉為能量，可得到最大數值?
   A. 質子　B.中子　C.電子　D. 光子

隨堂測驗

1. 某熱中子能量 0.05 eV，問該中子的速度約為多少m/s? (中子質量為 1.67×10^{-27} kg)
   A. 3000　　B. 3×10^{8}　　C. 1.2×10^{12}　　D. 4400

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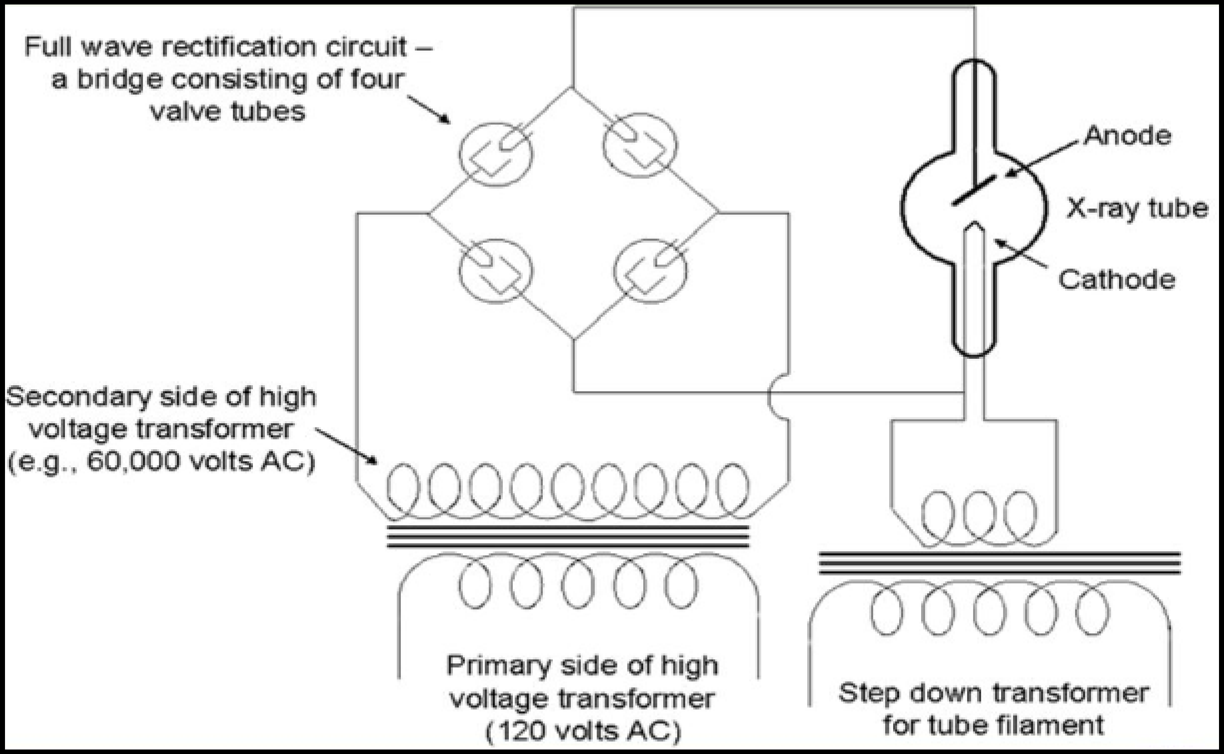
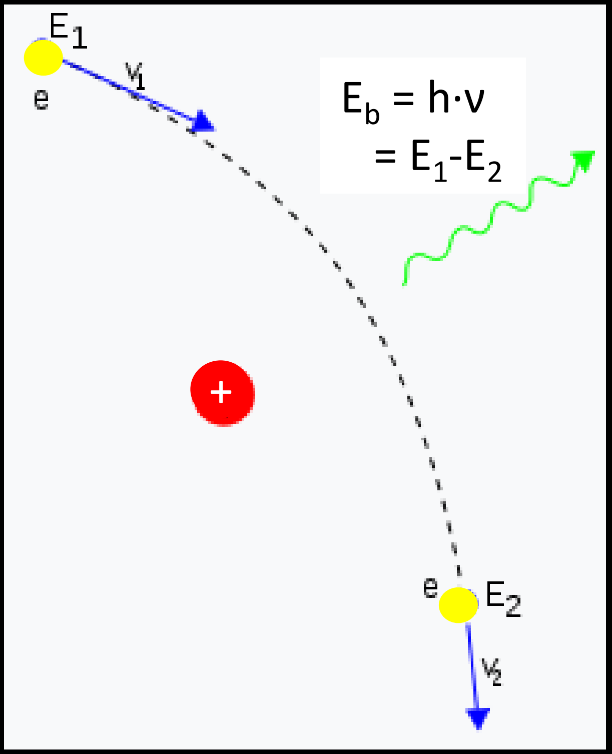
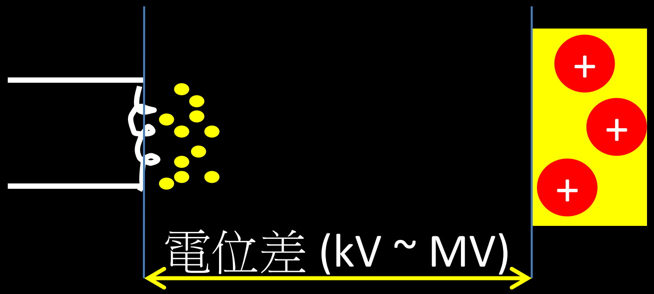
荷電粒子與物質的交互作用

- 制動輻射 Bremsstrahlung radiation





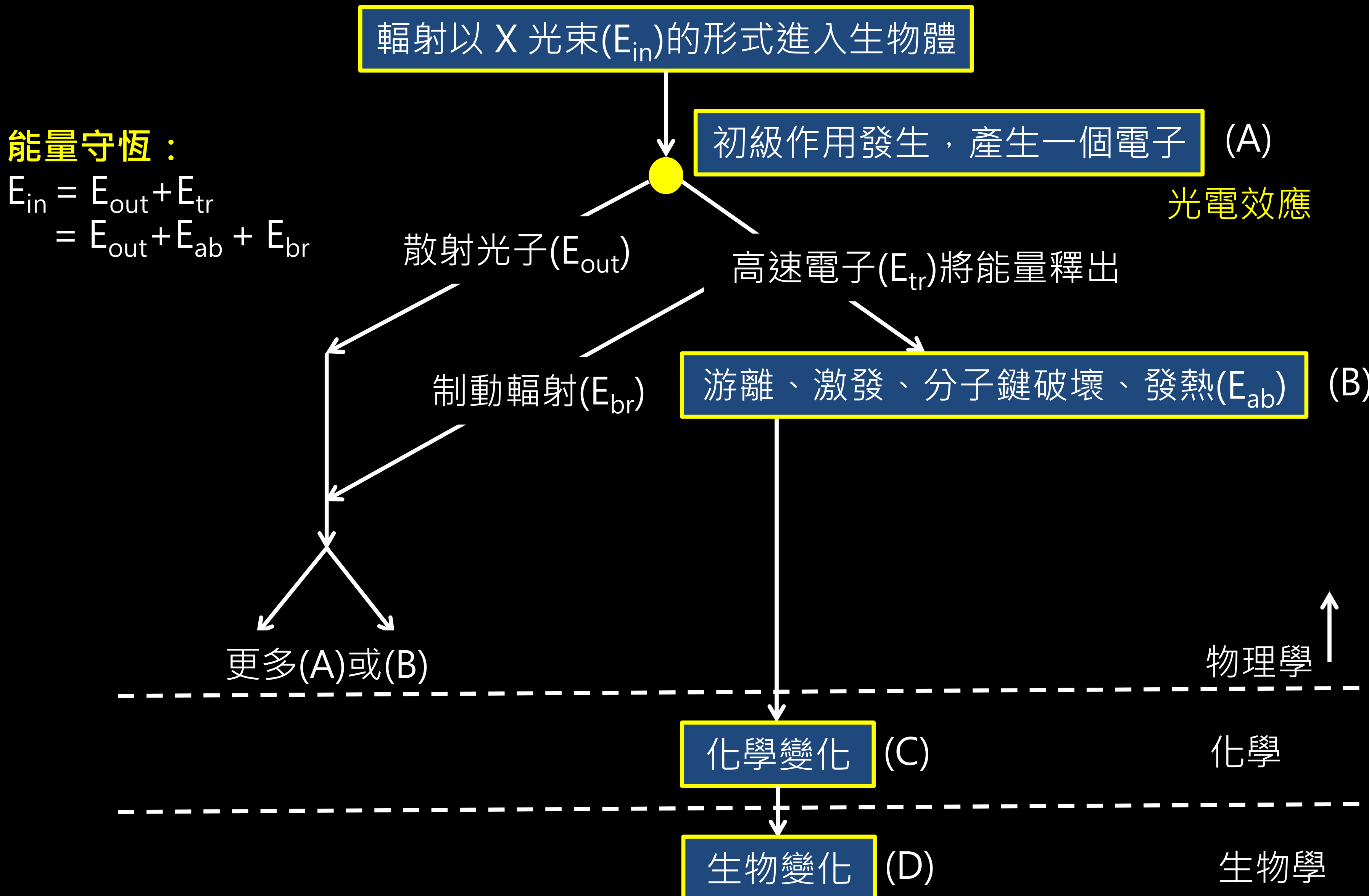
Electric field：kV ~ MV　　Tube current：mA ~ A



帶電粒子：
速度改變 ($V_1 \rightarrow V_2$)→
動量改變 (p=mv) →
能量改變 ($E_1 \rightarrow E_2$)→

制動輻射光子能量 $E_b = E_1 - E_2$

輻射與生物體的交互作用



關於交互作用的數量

初始光子數 = N_0
在物質中發生交互作用的光子數 = n
在物質中發生交互作用時的物質厚度 = Δx
交互作用常數 = μ

$$n = \mu N \Delta x$$

μ：與(1)物質的電子數
(2)物質的質子數
(3)光子的能量
有關

在極小的厚度中，光子與物質發生作用後的數量為 $N = N_0 - n$
→ $\Delta N = N - N_0 = -n$
→ $\Delta N = -\mu N_0 \Delta x$　　此時 $\mu \Delta x << 1$
→ $dN = -\mu N_0 dx$
→ $1/N_0\, dN = -\mu dx$

→ 等號兩邊同時積分
→ $\ln N_0 = -\mu x + C$　　若 x =0 時，$C = \ln N_0$
→ 帶入前式，對任何N而言
→ $\ln N = -\mu x + \ln N_0$
→ $\ln N - \ln N_0 = -\mu x$
→ $\ln(N/N_0) = -\mu x$
→ $N/N_0 = e^{-\mu x}$
→ $N = N_0 e^{-\mu x}$　光子與物質發生作用後的數量

半值層 (Half value layer)
$HVL = X_h = 0.693/\mu$

衰減係數的類型

Coefficient	Symbol	Relation between coefficients	Units of coefficients	Units in which thickness is measured
linear	μ		m-1	m
mass	$(\frac{\mu}{\rho})$	$\frac{\mu}{\rho}$	m^2/kg	kg/m^2
electronic	$_e\mu$	$\frac{\mu}{\rho}\cdot\frac{1}{1000N_e}$	m^2/el	el/m^2
atom	$_a\mu$	$\frac{\mu}{\rho}\cdot\frac{Z}{1000N_e}$	m^2/at	at/m^2

亞弗加厥數 (Avogadro' s number) = N_A = 6.022 x 10^{23}

Material	ρ-Density (kg/m^3)	Effective Atomic Number, Z	Atomic weight, A (g)	N_e (el per g)
Hydrogen	0.8988	1	1.008	5.97 x10^{23}
Carbon	2250	6	12.011	3.01 x10^{23}
Oxygen	1.429	8	15.999	3.01 x10^{23}
Aluminum	2699	13	26.982	2.90 x10^{23}
Copper	8960	29	63.546	2.75 x10^{23}
Lead	11360	82	207.2	2.38 x10^{23}
Air	1.293	7.78		3.01 x10^{23}
Water	1000	7.51		3.34 x10^{23}

#a/g=N_A/A
#el/g=N_AZ/A

例：有一X光束帶有 10^4 個 10 MeV的光子，撞擊一塊20cm厚的碳靶。請計算在10 cm深處 1 mm 厚度內，有多少個光子會與碳原子進行交互作用。
(此能量下，$\mu/\rho = 0.00196\ m^2/kg$， $\rho = 2250\ kg/m^3$)

例：有一X光束帶有 10^4 個 10 MeV的光子，撞擊一塊20cm厚的碳靶。請計算在 10 cm深處 1 mm 厚度內，有多少個光子會與碳原子進行交互作用。
(此能量下，μ/ρ = 0.00196 m^2/kg， ρ = 2250 kg/m^3)

在10cm深處(涵蓋1mm)的修正厚度為：0.1 m x 2250 kg/m^3 = 225 kg/m^2

衰減係數 x 厚度：0.00196 x 225 = 0.441

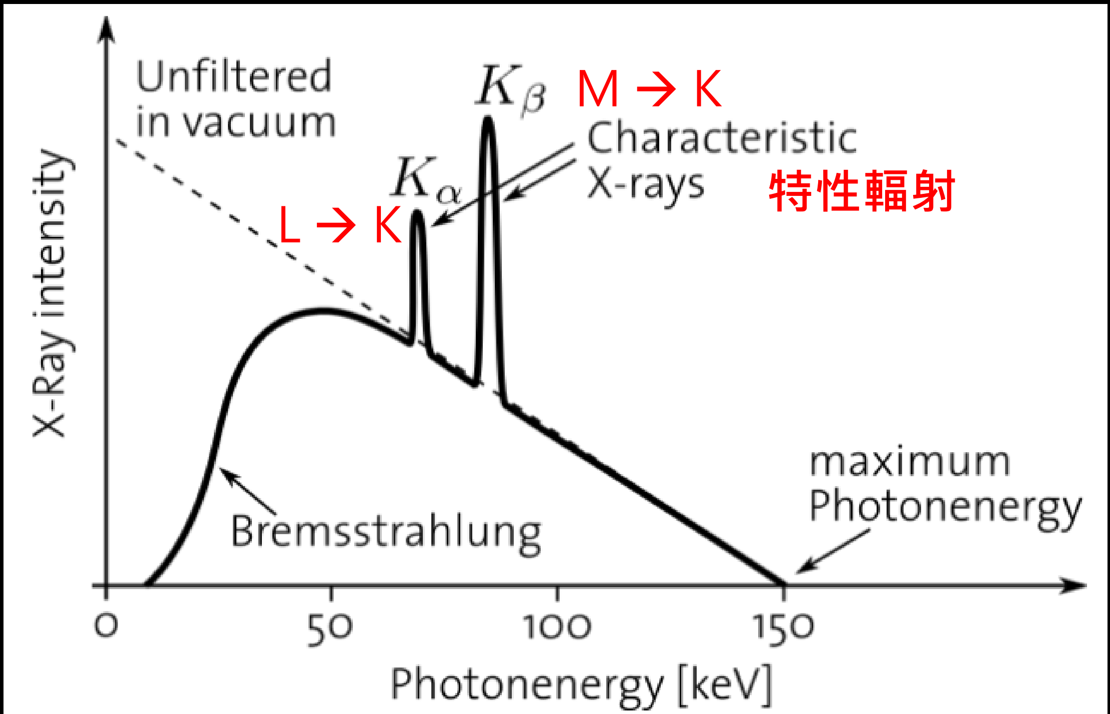
$$N = N_0 e^{-\mu x}$$

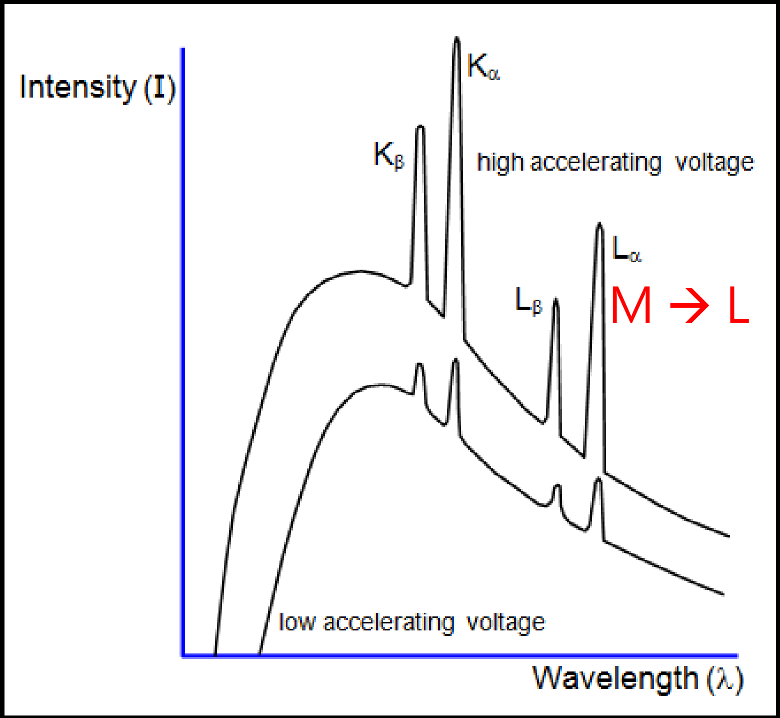
到達 10 cm 處的光子數：$10^4 \times e^{-0.441}$ = 6434

$$n = \mu N \Delta x$$

在 10 cm深處 1 mm 厚度內參與作用的光子數：6434 x 0.00196 x 2250 x 10^3 = **28.37**

X-ray spectrum

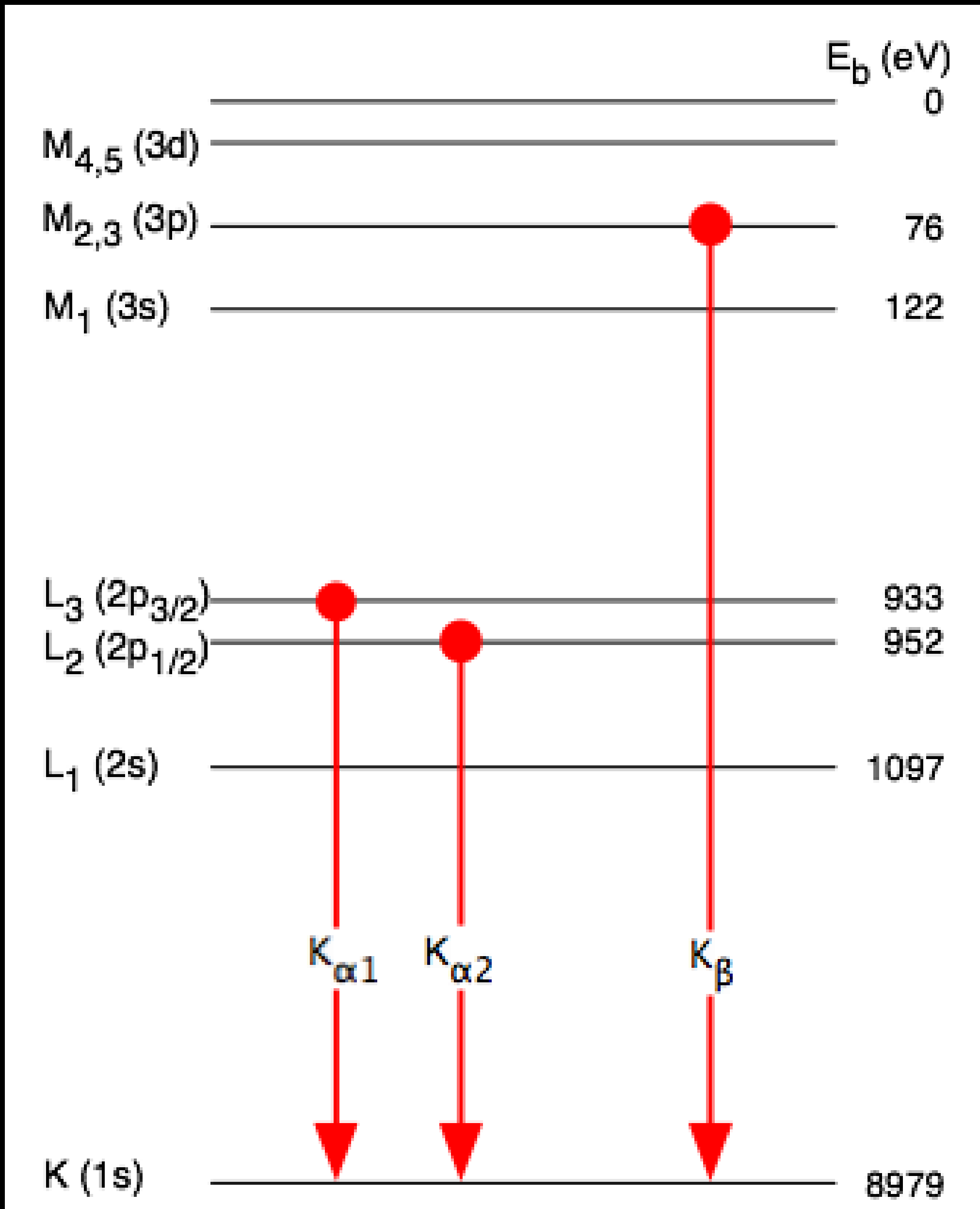


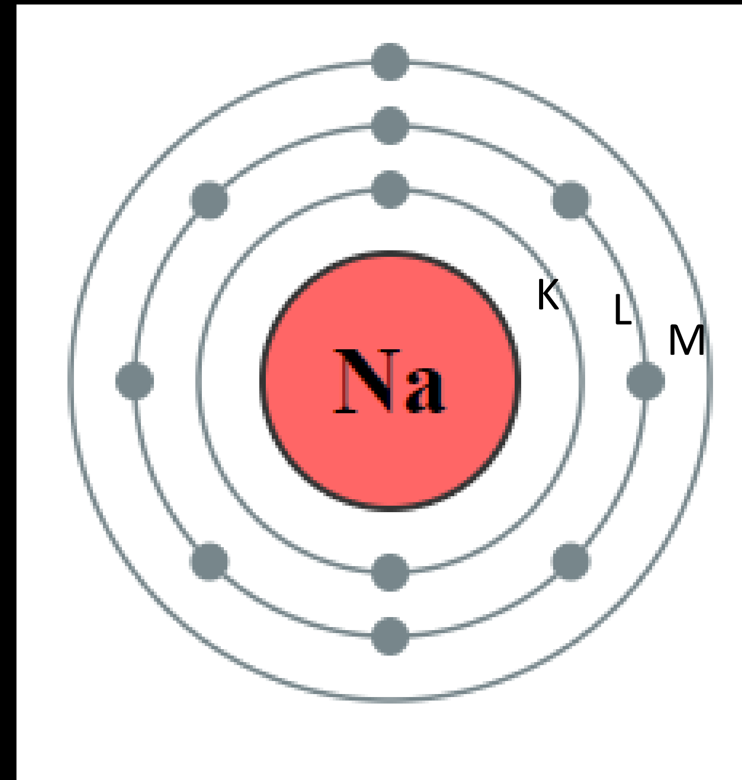


- 光子的波動性
  - 速度=波長 x 頻率 ($c = \lambda \cdot \nu$)
  - 動能 = 蒲朗克常數 x 頻率 ($E = h \cdot \nu$)

    = 蒲朗克常數 x 速度/波長 ($E = h \cdot c / \lambda$)

蒲朗克常數 $h = 6.62 \times 10^{-34}$ J s


E_b (eV)
0
$M_{4,5}$ (3d)
$M_{2,3}$ (3p)
76
M_1 (3s)
122
L_3 ($2p_{3/2}$)
933
L_2 ($2p_{1/2}$)
952
L_1 (2s)
1097
$K_{\alpha 1}$
$K_{\alpha 2}$
K_{β}
K (1s)
8979


Na
K
L
M

單位接頭詞

接頭詞名稱（記號，英文，中文）			
記號	英文	中文	因次
Y	Yota-	佑	10^{24}
Z	Zeta-	皆	10^{21}
E	Exa-	艾	10^{18}
P	Peta-	拍	10^{15}
T	Tera-	兆	10^{12}
G	Giga-	吉，十億	10^{9}
M	Mega-	百萬	10^{6}
k	kilo-	千	10^{3}
h	hector-	百	10^{2}
da	deka-	十	10^{1}

接頭詞名稱（記號，英文，中文）			
記號	英文	中文	因次
d	deci-	十	10^{-1}
c	centi-	厘	10^{-2}
m	milli-	毫	10^{-3}
μ	micro-	微	10^{-6}
n	nano-	奈	10^{-9}
p	pico-	皮	10^{-12}
f	femto-	飛	10^{-15}
a	atto-	阿	10^{-18}
z	zepto-	介	10^{-21}
y	yocto-	攸	10^{-24}

1 Å (埃) = 10^{-10} 公尺

例：某 X 光機的加速電壓為60 kV，放出最短 X 光波長為0.206 Å，試求蒲郎克常數 h (Plank constant)。

(1 Å (埃) = 10^{-10} 公尺，光速 c = 3×10^{8} 公尺/秒，電子電量為 1.602×10^{-19} 庫侖)

例：試求100 kVp 之 X 光其最短波長？

例：某 X 光機的加速電壓為60 kV，放出最短 X 光波長為0.206 Å，試求蒲郎克常數 h (Plank constant)。

(1 Å (埃) = 10^{-10} 公尺，光速 c = 3×10^{8} 公尺/秒，電子電量為 1.602×10^{-19} 庫侖)

0.206 Å = 2.06×10^{-11} 公尺,
$c = \lambda\cdot\nu \rightarrow \nu = c / \lambda$
$\nu = (3\times10^{8}$ 公尺/秒$)/2.06\times10^{-11}$ 公尺 $= 1.456\times10^{19}\ s^{-1}$,

$E = 60\ keV = 60000\times1.602\times10^{-19}\ J = 9.612\times10^{-15}\ J$,

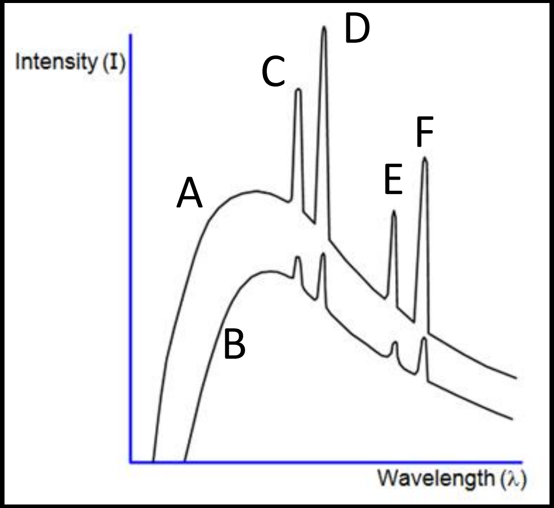
$E = h\,\nu$,
$9.612\times10^{-15}\ J = h\times1.456\times10^{19}\ s^{-1}$,
$\therefore h =$ **6.60×10^{-34} J s**

例：試求100 kVp 之 X 光其最短波長？

$E = h\,\nu = hc/\lambda$,
$\therefore \lambda = hc/E$
$= (6.625\times10^{-34}\ J\ s)\times(3\times10^{8}\ m/s)/(1.6\times10^{-14}\ J)$
$=$ **1.24×10^{-11} m**
$= 0.124$ Å

隨堂測驗

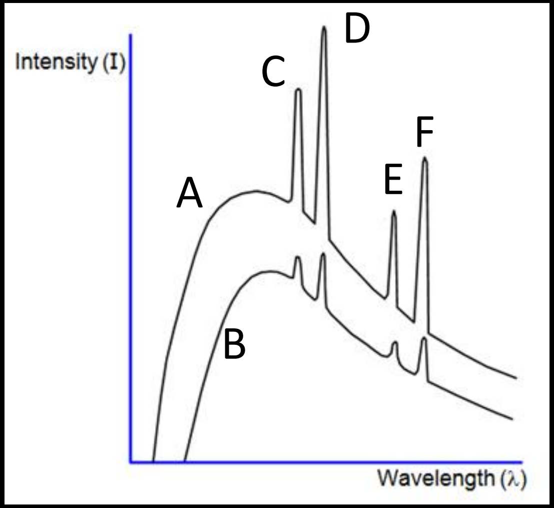
1. 如右圖所示，請回答下列問題：
   (1) A、B 兩次曝露，何者的管電壓較高?
   (2) C~F 峰有何專有名詞?
   (3) C、F 峰各為種名稱?
   (4) A、B 兩次曝露何者的輻射劑量較大?



2.已知拍攝一 X 光片之操作條件為 74 kVp 與 100 mAs，試問在其產生 X 光之過程中有若干個電子與陽極靶起作用？

隨堂測驗

1. 如右圖所示，請回答下列問題：
   (1) A、B 兩次曝露，何者的管電壓較高? **A**
   (2) C~F 峰有何專有名詞? **特性輻射**
   (3) C、F 峰各為種名稱? **K_β、L_α**
   (4) A、B 兩次曝露何者的輻射劑量較大? **A**



2.已知拍攝一 X 光片之操作條件為 74 kVp 與 100 mAs，試問在其產生 X 光之過程中有若干個電子與陽極靶起作用？

100 mAs = 0.1 C
= 0.1 C/(1.6×10^{-19} C/個電子)
= **6.25×10^{17} 個電子**

如何降低臨床檢查之病患劑量

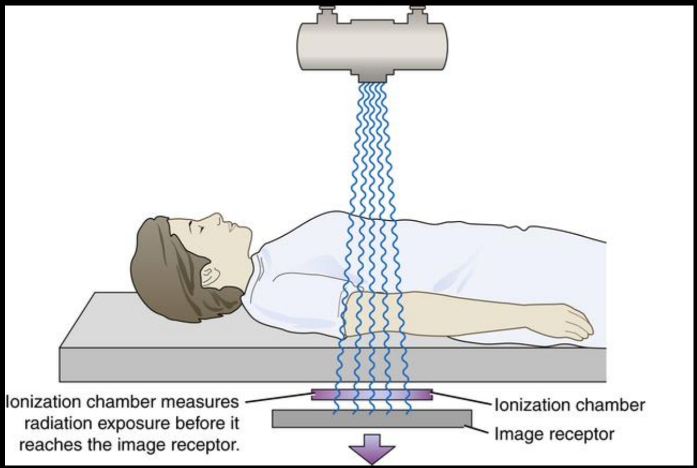
1. 執行品質保證測試 (Quality Assurance Test)
2. 使用適當造影技術與防護 (Proper techs & sheilding)
3. 建立診斷參考水平 (DRL, diagnostic reference level)

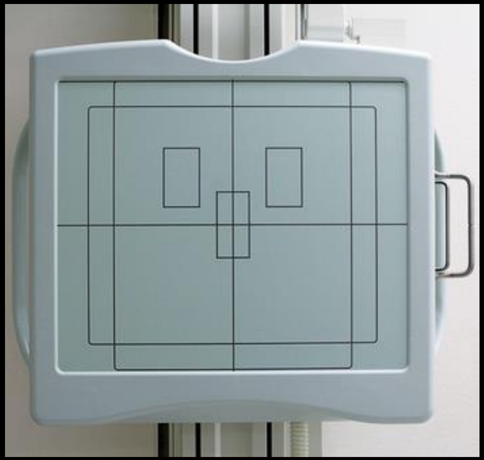
劑量指標 (Exposure Index)

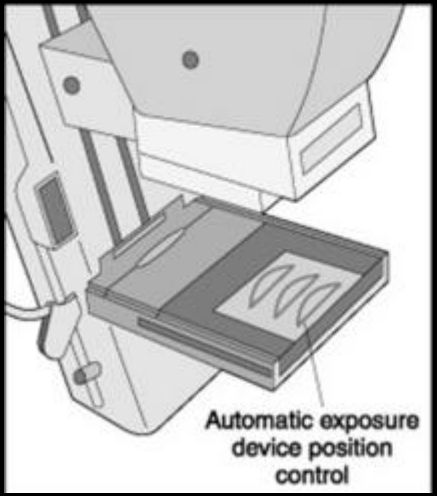
醫學影像設備之劑量指標
Exposure Index in Radiology

Exposure Indicator (CR, DR)
Dose-Area Product (RF)
Dose Index (CR, DR, RF)
Average Glandular Dose (MG)
Computed Tomography Dose Index (CT)

自動曝光工作原理


Ionization chamber measures radiation exposure before it reaches the image receptor.
Ionization chamber
Image receptor




Automatic exposure device position control

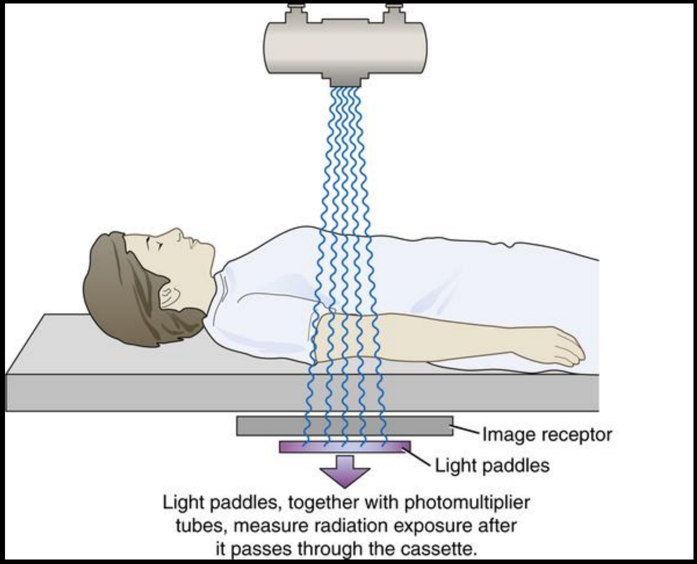
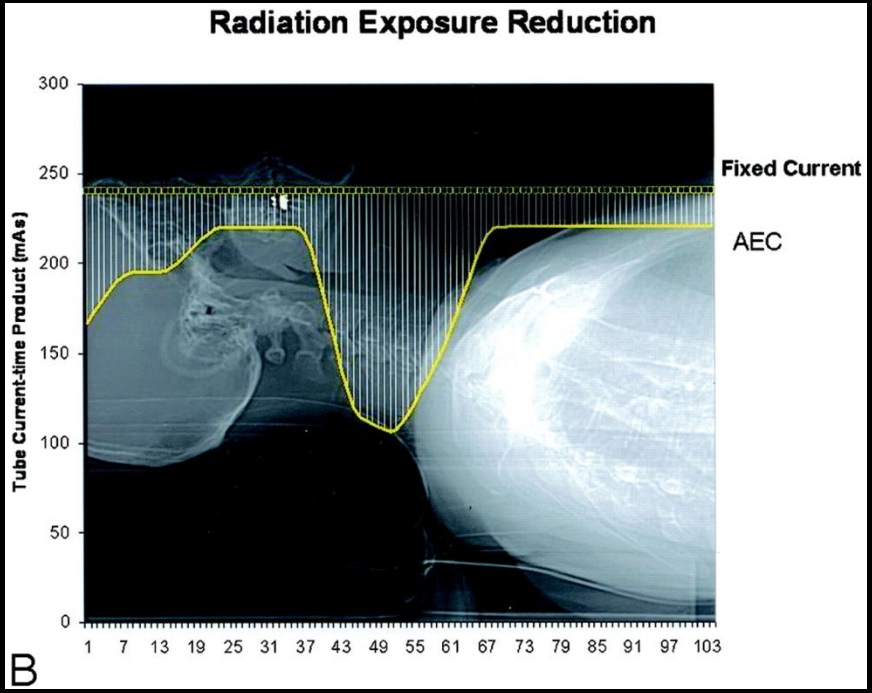
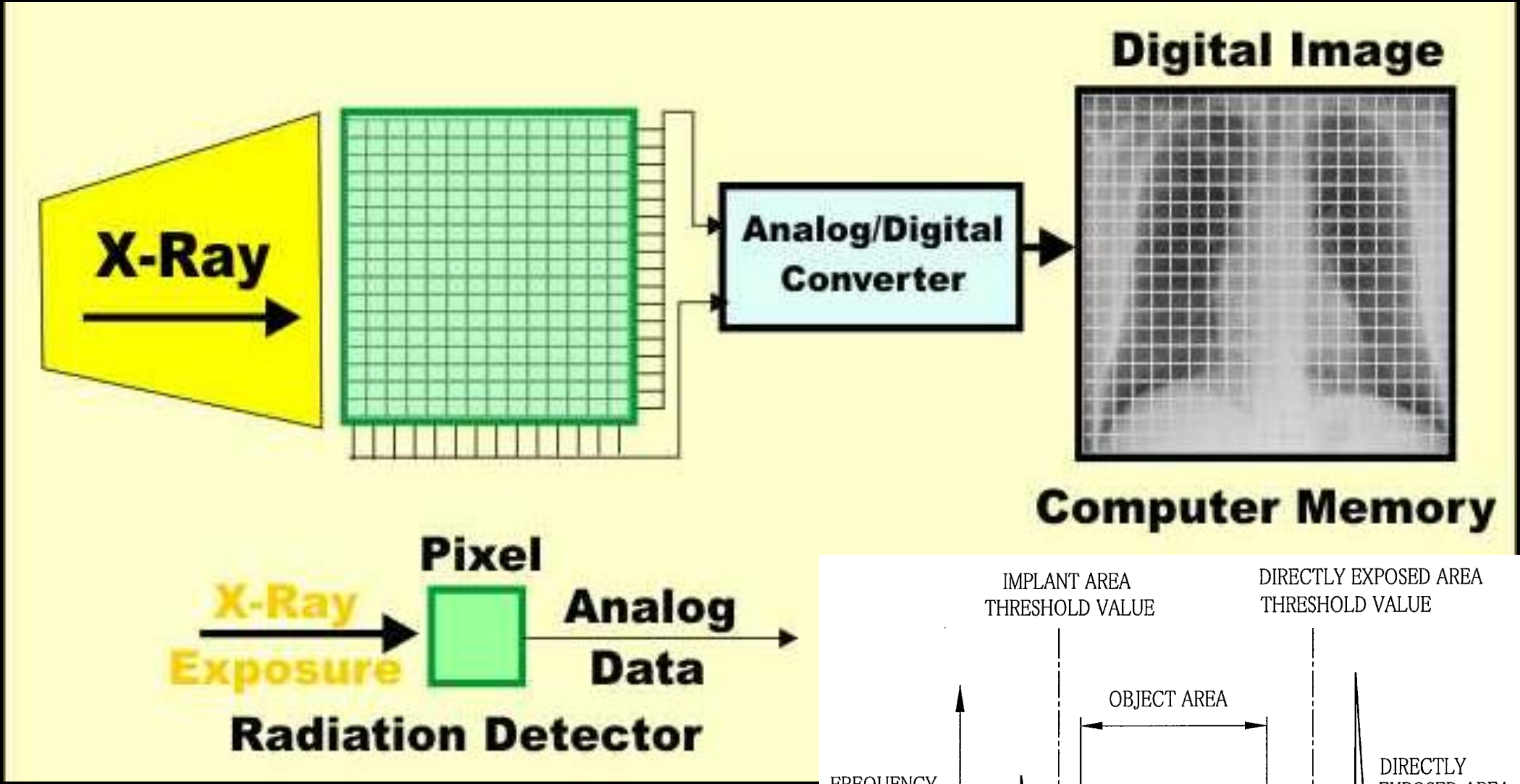
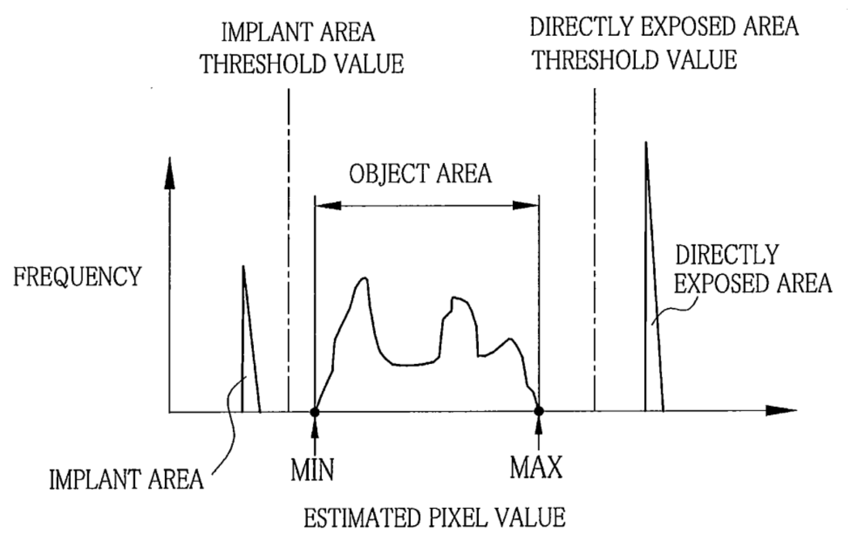


Image receptor
Light paddles
Light paddles, together with photomultiplier tubes, measure radiation exposure after it passes through the cassette.


Radiation Exposure Reduction
Tube Current-time Product (mAs)
300
250
200
150
100
50
0
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97 103
Fixed Current
AEC
B

曝露轉換為像素值

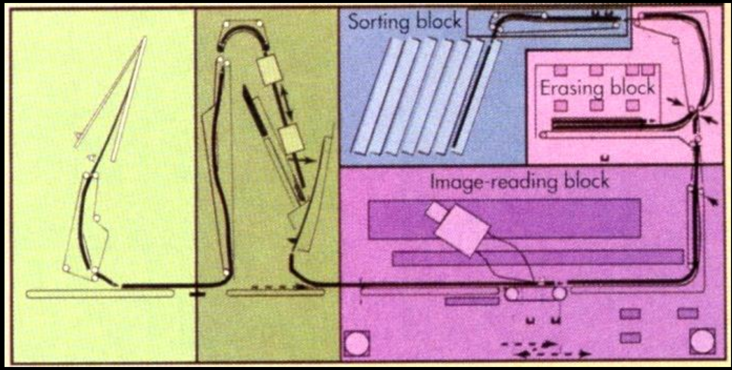

Digital Image
X-Ray
Analog/Digital
Converter
Computer Memory
Pixel
X-Ray
Exposure
Analog
Data
Radiation Detector


IMPLANT AREA
THRESHOLD VALUE
DIRECTLY EXPOSED AREA
THRESHOLD VALUE
OBJECT AREA
FREQUENCY
DIRECTLY
EXPOSED AREA
IMPLANT AREA
MIN
MAX
ESTIMATED PIXEL VALUE

曝露指標

- 儀器類型: plain x-ray exams (CR or DR)
- 廠牌範例:

Manufacturer	Symbol	5 µGy	10 µGy	20 µGy
Canon (brightness = 16, contrast = 10)	REX	50	100	200
IDC (ST = 200)	F#	−1	0	1
Philips	EI	200	100	50
Fuji, Konica	S	400	200	100
Carestream (CR, STD)	EI	1,700	2,000	2,300
Siemens	EI	500	1,000	2,000

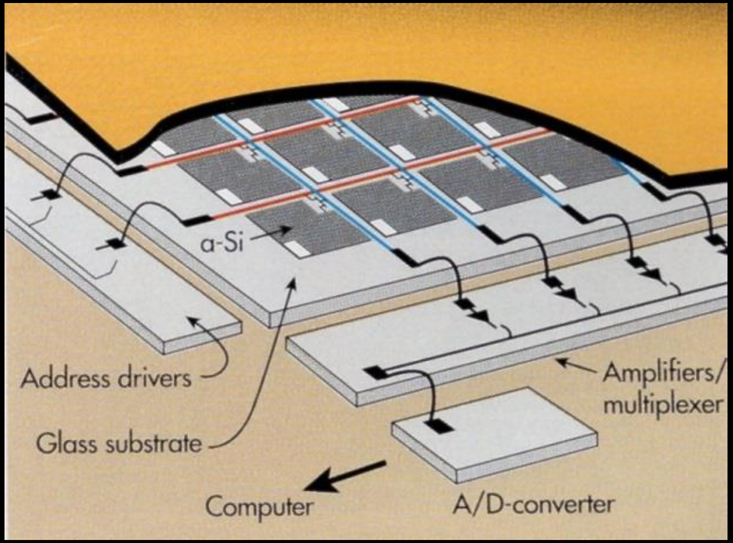


例： Carestream (for plain radiography)

Pixel value $= 2000 + 1000 \times log_{10}(exposure)$

Coded value (CV)

exposure is measured in mR



曝露指標之校正

- 以Carestream CR/DR 為例:
  - a heavily filtered (an additional 0.5 mm copper and 1 mm aluminum) 80 kVp x-ray beam
  - Choose proper mAs approximate to have 1 mR exposure
  - 15 minutes delay after exposure
  - Read the imaging plate
  - Acceptable range: +/- 100 (diff. of calculated and displayed EIs)

EI =1000 log(E) + 2000 (or +1000 for MG)

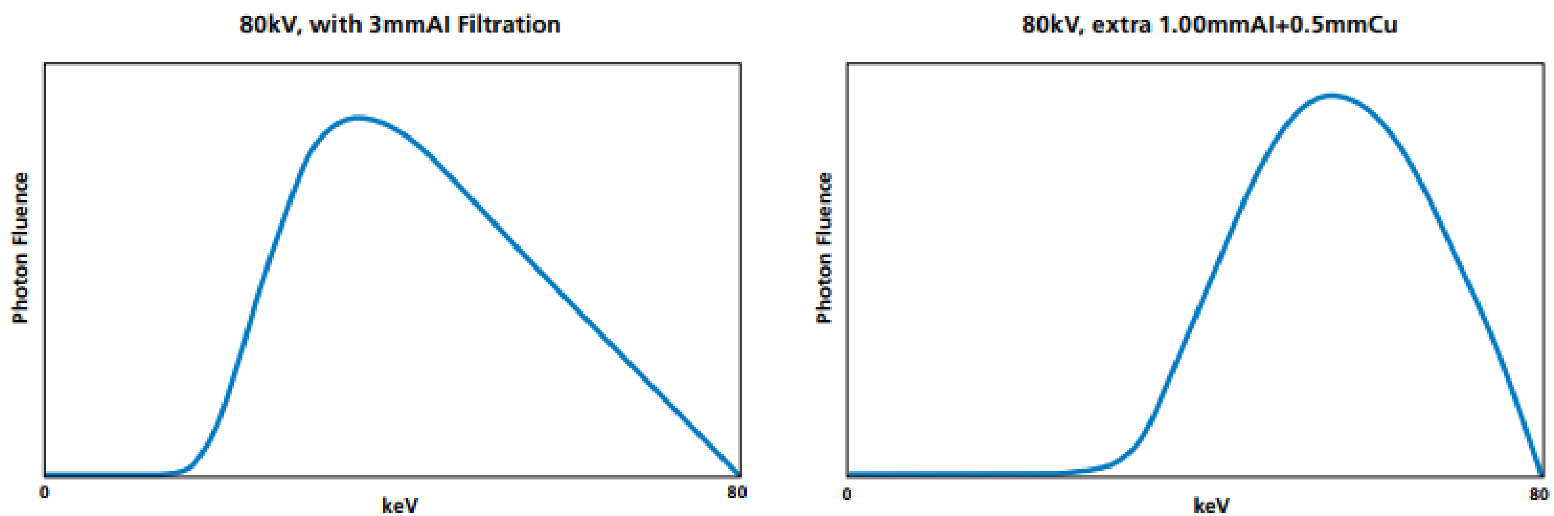


Figure 1 (a) Simulated tungsten anode 80kVp spectrum with an equivalent 3.00mmAl total filtration. Mean X-ray energy is approximately 48keV.

Figure 1(b) Simulated tungsten anode 80kVp spectrum with additional filtration of 0.5mmCu and 1.0mmAl. Mean x-ray photon energy is approximately 57keV.

例：在對Carestream CR 系統進行曝寶測試時，使用 80 kVp, 25 mAs 後測得曝露值為 1.25 mR, 而讀片後系統判定的 EI 為 1991。請問此系統是否需要進行 EI 的校正？

例：在對Carestream CR 系統進行曝寶測試時，使用 80 kVp, 25 mAs 後測得曝露值為 1.25 mR, 而讀片後系統判定的 EI 為 1991。請問此系統是否需要進行 EI 的校正？

理論上的 EI = 1000 log(1.25) + 2000
= 1000 x 0.09691 + 2000
= 2096.9

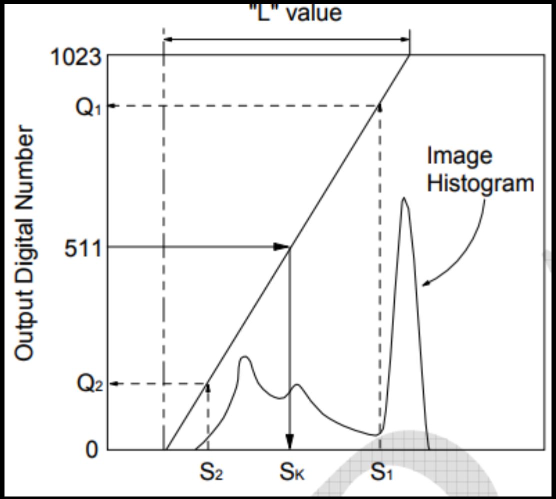
讀出的 EI 與理論上的 EI 相差：
2097-1993 = 104 (> 100)

應判定為失敗，需要重新執行 EI 校正

曝露指標之校正

- Fujijfilm CR/DR 系統:
  - a filtered (~ 3 mm Al HVL) 80 kVp x-ray beam
  - Choose proper mAs approximate to have 1 mR exposure
  - 10 minutes delay after exposure $exposure \cong 200/S$
  - Read the imaging plate

    S is inverse proportional to exposure
  - Acceptable range: +/- 20%



In automatic processing mode:

$$S = 4 \times 10^{(4-S_k)}$$

$$L = 1023 \times (S_1 - S_2) / (Q_1 - Q_2)$$

$$\boldsymbol{Pixel\ value} = \frac{\mathbf{1024}}{\boldsymbol{L}} \times \boldsymbol{log_{10}(k \times S \times E)} + \mathbf{511}$$

Raw data is recorded in 12-bit pixel depth

Image data is recorded in 10-bit pixel depth

例：若 S_k 值為 2.30 ，對應的曝露是 2.0 mR，請問：

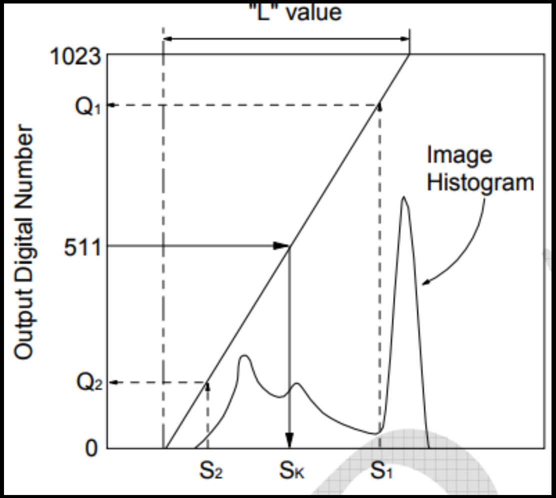
1. 本次曝露/攝影時，系統顯示的 S 值為何？
2. 2.0 mR 的像素值為何？
3. L = 1 時，本系統的 K 值為何？
4. 當像素值為 1023 ，此像素接收到多少曝露 (mR)？

例：若 S_k 值為 2.30 ，對應的曝露是 2.0 mR，請問：

1. 本次曝露/攝影時，系統顯示的 S 值為何？
2. 2.0 mR 的像素值為何？
3. L = 1 時，本系統的 K 值為何？
4. 當像素值為 1023 ，此像素接收到多少曝露 (mR)？

1. $S = 4 \times 10^{(4-2.3)} = 200$

2.



則此時的像素值必為 511

3.

$$511 = \frac{1024}{1} \times \log_{10}(k \times 200 \times 2.0) + 511$$

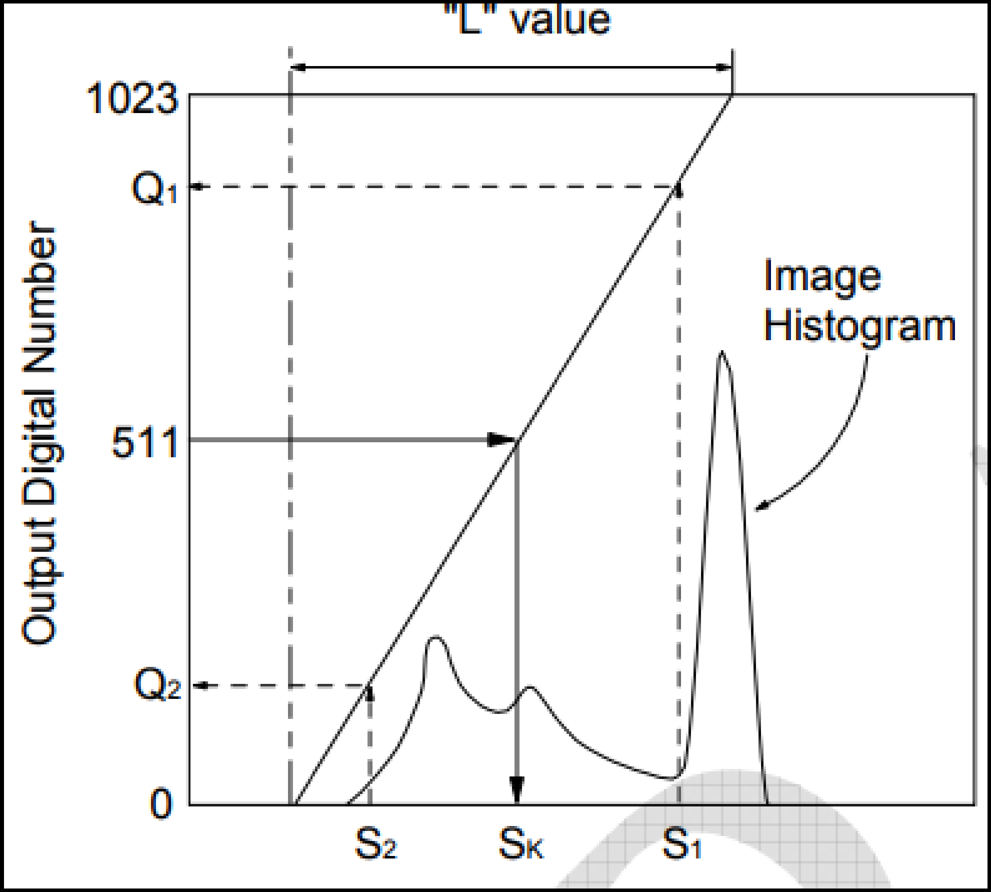
k = 1/400

4. $1023 = 1024 \times \log_{10}(1/400 \times 200 \times E) + 511$

E = 6.32 mR

討論

- 在固定 S 值時，若以手動方式將 L 值增加為兩倍，對影像會有何影響？



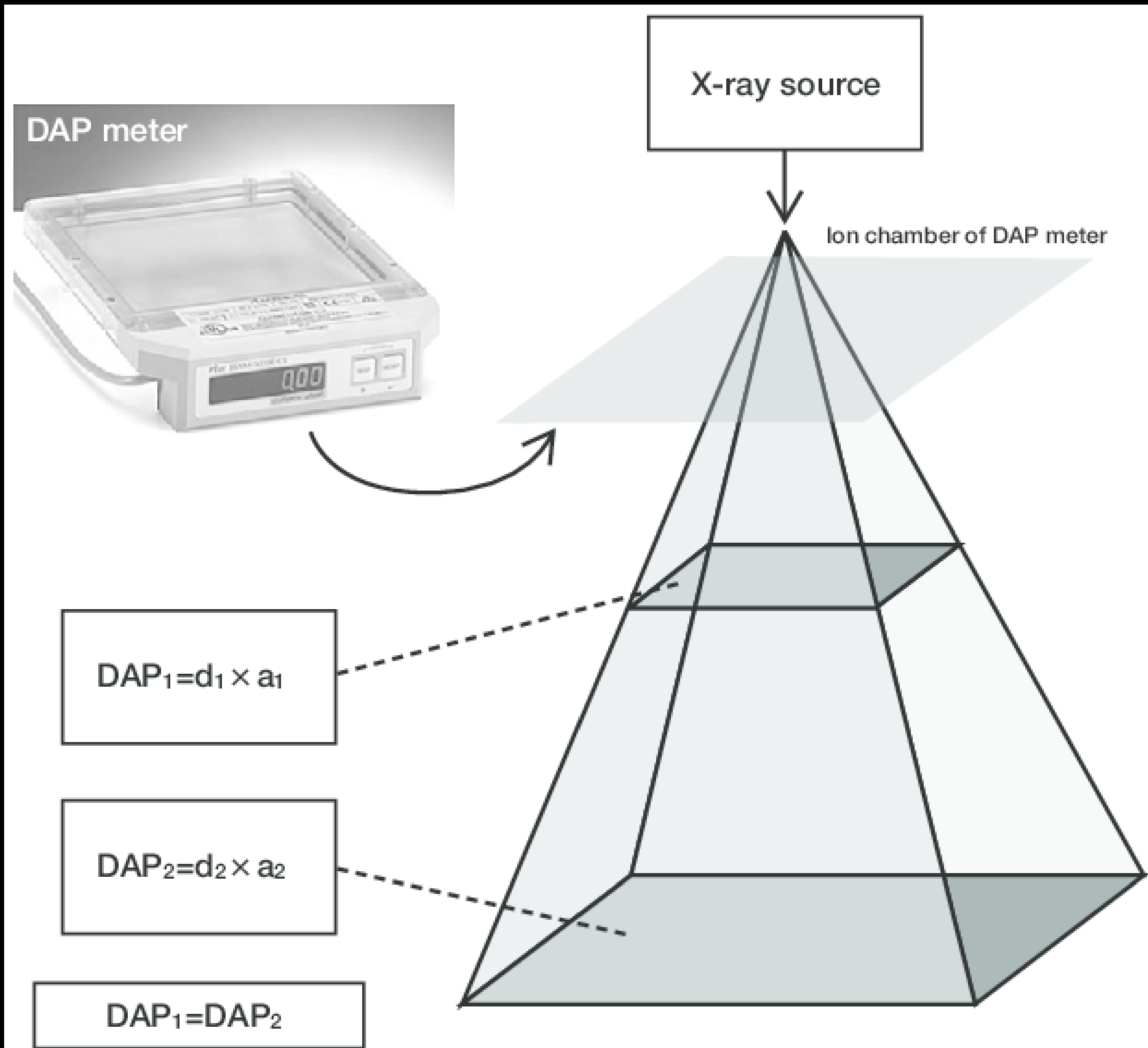
$$L = 1023 \times (S_1 - S_2) / (Q_1 - Q_2)$$

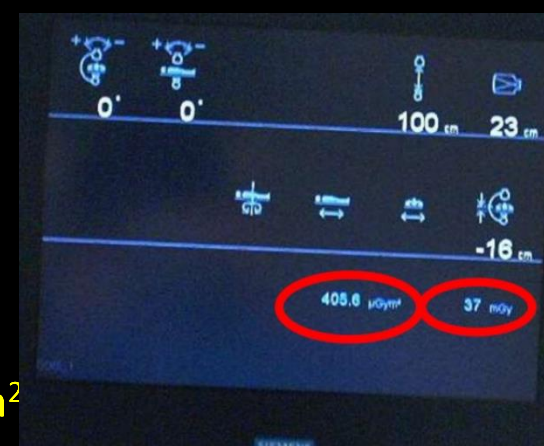
常見影像接收系統的校正規範

Manufacturer	Exposure indicator name	Symbol	Units	Exposure dependence, X	Detector calibration conditions
Fujifilm	S value	S	Unitless	$200/S \propto X$ (mR)	80 kVp, 3 mm Al "total filtration" $S = 200$ @ 1 mR
Carestream	Exposure index	EI	Mbels	$EI + 300 = 2X$	80 kVp, 1.0 mm Al + 0.5 mm Cu; EI = 2000 @ 1 mR
Agfa	Log of median of histogram	lgM	Bels	$lgM + 0.3 = 2X$	400 speed class, 75 kVp + 1.5 mm Cu; lgM = 1.96 @ 2.5 μGy
Konica	Sensitivity number	S	Unitless	For QR = k, $200/S \propto X$(mR)	QR = 200, 80 kVp, S = 200 @ 1 mR
Canon	Reached exposure value	REX	Unitless	Brightness = c_1, Contrast = c_2, REX $\propto X^1$	Brightness = 16 Contrast = 10 REX ≈ 106 @ 1 mR[1]
Canon	EXP	EXP	Unitless	$EXP \propto X$	80 kVp, 26 mm Al, HVL = 8.2 mm Al, DFEI = 1.5 EXP = 2000 @ 1 mR
GE	Uncompensated detector exposure	UDExp	μGy air kerma	$UDExp \propto X$ (μGy)	80 kVp, standard filtration, no grid
GE	Compensated detector exposure	CDExp	μGy air kerma	$CDExp \propto X$ (μGy)	Not available
GE	Detector exposure index	DEI	Unitless	DEI ≈ratio of actual exposure to expected exposure scaled by technique and system parameters. Expected exposure values can be edited by user as preferences.	Not available
Swissray	Dose indicator	DI	Unitless	Not available	Not available
Imaging Dynamics	Accutech	F#	Unitless	$2^{f\#} = X(mR)/X_{tgt}(mR)$	80 kVp + 1 mm Cu
Philips	Exposure index	EI	Unitless	1000/X (μGy)	RQA5, 70 kV, + 21 mm Al, HVL = 7.1 mm Al
Siemens	Exposure index	EXI	μGy air kerma	$X(\mu Gy) = EI/100$	RQA5, 70 kV + 0.6 mm Cu, HVL = 6.8 mm Al
Alara CR	Exposure indicator value	EIV	Mbels	$EIV + 300 = 2X$	1 mR at RQA5, 70 kV, + 21 mm Al, HVL = 7.1 mm Al = > EIV = 2000
iCRco	Exposure index	None	Unitless	Exposure index $\propto$ log[X (mR)]	1 mR @ 80 kVp + 1.5 mm Cu => 0

$$IgM = 1.9607 + \log\left(\frac{E(\mu Gy)}{2.5}\right) + \log\left(\frac{SpeedClass}{400}\right)$$

Dose area product (DAP, kerma area product)





DAP 的記讀單位為 Gy·cm²

Eur Radiol (2003) 13:2259–2263
DOI 10.1007/s00330-003-1831-x

VASCULAR–INTERVENTIONAL

V. Neofotistou
E. Vano
R. Padovani
J. Kotre
A. Dowling
M. Toivonen
S. Kottou
V. Tsapaki
S. Willis
G. Bernardi
K. Faulkner

Preliminary reference levels in interventional cardiology

Europe 2003

Diagnostic Reference Levels (DRLs) for Cardiology

Table 3 Preliminary reference levels proposed

	PTCA	CA
DAP (Gy×cm^2)	94	57
FT (min)	16	6
No. of frames	1355	1270

Catheterization and Cardiovascular Interventions 83:729–738 (2014)

Patient Exposure to X-rays During Coronary Angiography and Percutaneous Transluminal Coronary Intervention: Results of a Multicenter National Survey

Jean-Louis Georges,[1,2*] MD, MSc, Loic Belle,[2,3] MD, Cécile Ricard,[3] MSc,
Simon Cattan,[2] MD, Franck Albert,[2] MD, Jean-Lou Hirsch,[2] MD, Jacques Monsegu,[2] MD,
Alain Dibie,[2] MD, Khalife Khalife,[2] MD, Christophe Caussin,[2] MD, Carlo Maccia,[1] PhD,
Bernard Livarek,[1,2] MD, and Michel Hanssen,[2] MD,
on behalf of the RAY'ACT investigators

France 2014

- To update reference values for the main radiation dose parameters for coronary angiography (CA) and percutaneous coronary intervention (PCI).
- Multicenter, nationwide French survey, with retrospective analysis. Radiation parameters registered for 33,937 CAs and 27,826 PCIs performed at 44 centers during 2010.
- Updated diagnostic reference values are established. **KAP, 45 Gy cm^2 for CA and 95 Gy cm^2 for PCI.**

REVISTA ESPAÑOLA DE
CARDIOLOGIA

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Previous Article | Vol 67. Num 01. January 2014 | Next article

Rev Esp Cardiol. 2014;67:63-5 - Vol. 67 Num.01 DOI: 10.1016/j.r

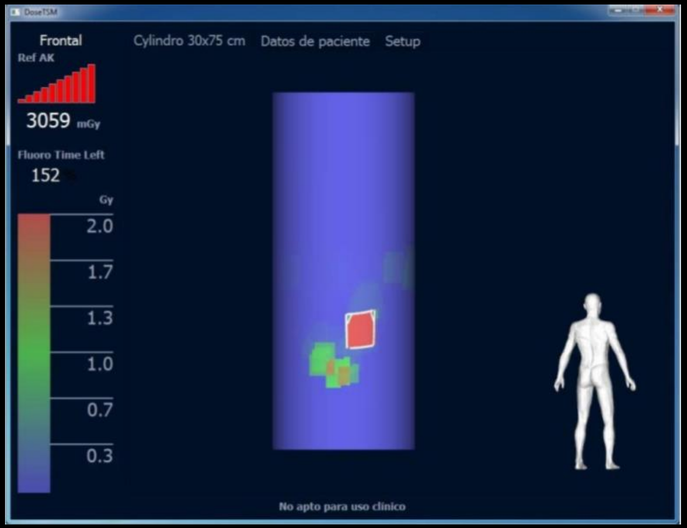
Initial Results From a National Follow-up Program to Monitor Radiation Doses for Patients in Interventional Cardiology

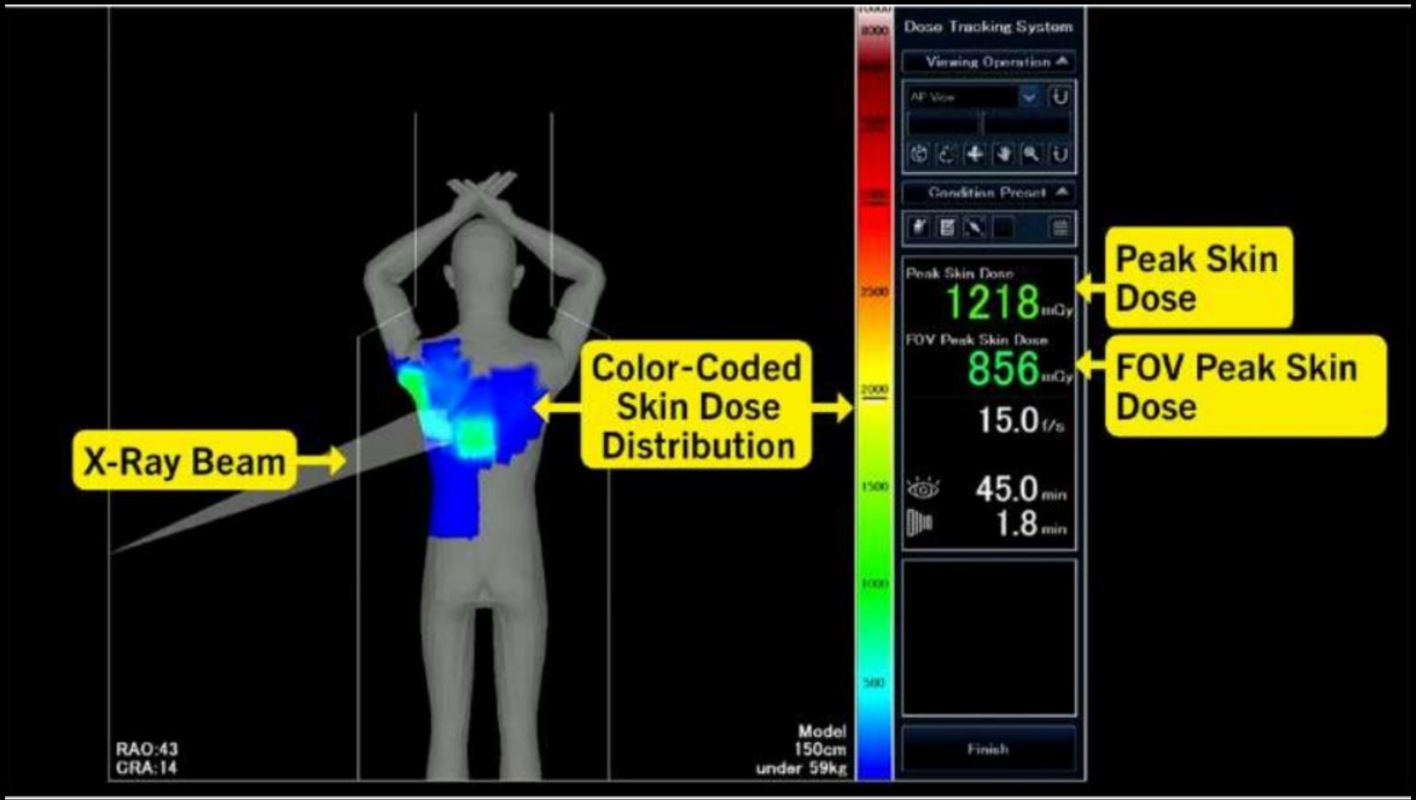
Roberto M. Sánchez[a], Eliseo Vano[ab], José M. Fernández[ab], Javier Escaned[c], Javier Goicolea[d], Xavier Pifarré[e]

Spain 2014

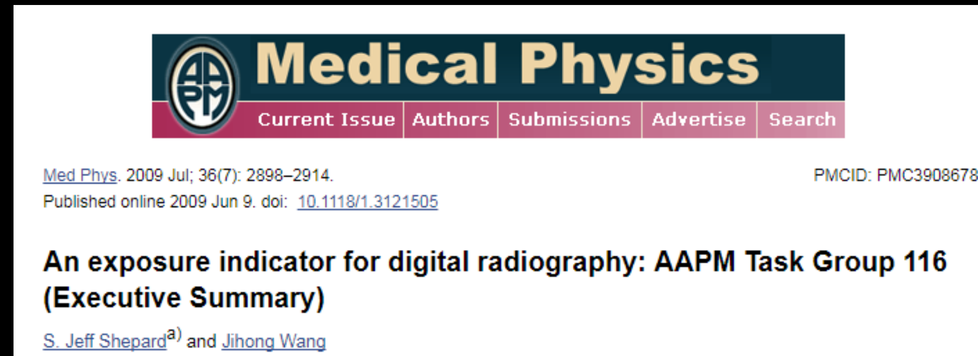
Median values at the SCUH in 2013
CA: 31 Gy cm^2
PCI: 54 Gy cm^2

Spanish DRLs values :
32 Gy cm^2 for CA and
76 Gy cm^2 for PCI


Frontal
Cylindro 30x75 cm
Datos de paciente
Setup
Ref AK
3059 mGy
Fluoro Time Left
152
Gy
2.0
1.7
1.3
1.0
0.7
0.3
No apto para uso clínico


Dose Tracking System
Viewing Operation
Condition Preset
Peak Skin Dose
1218 mGy
FOV Peak Skin Dose
856 mGy
15.0 f/s
45.0 min
1.8 min
Finish
Peak Skin Dose
FOV Peak Skin Dose
Color-Coded Skin Dose Distribution
X-Ray Beam
RAO:43
CRA:14
Model
150cm
under 59kg

其他曝露指標：Deviation index

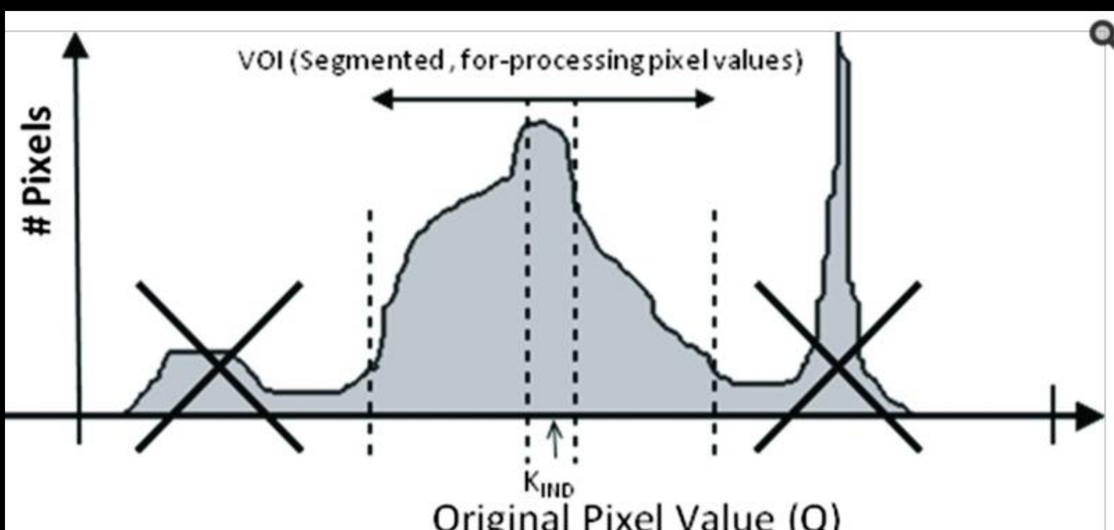


Medical Physics
Current Issue | Authors | Submissions | Advertise | Search

Med Phys. 2009 Jul; 36(7): 2898–2914.
Published online 2009 Jun 9. doi: 10.1118/1.3121505
PMCID: PMC3908678

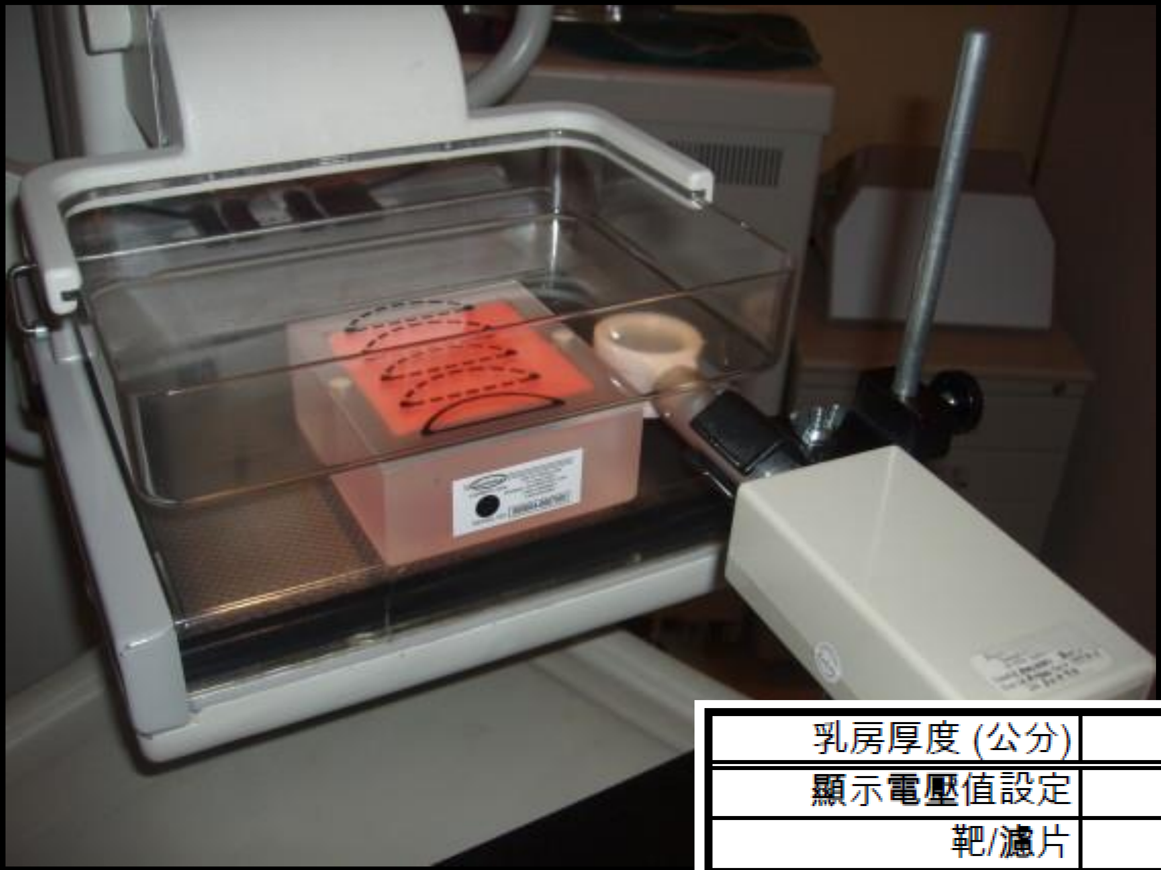
An exposure indicator for digital radiography: AAPM Task Group 116 (Executive Summary)

S. Jeff Shepard[a] and Jihong Wang



	Dev Index	mGy cm^2
K_{3x}	4.8	30
K_{2x}	3.0	20
K_{TGT}	1.0	10
$K_{1/2}$	-3.0	5
$K_{1/4}$	-6.0	2.5

平均乳腺劑量
AVERAGE (MEAN) GLANDULAR DOSE



Procedures:

1. Determine the beam quality (HVL)
2. Make at least 4 exposures for ACR phantom using clinical mode
3. Record the readouts from dose meter
4. Calculate the mean value of the exposures (readouts)

乳房厚度 (公分)	4.2	4.2
顯示電壓值設定	26	28
靶/濾片	Mo/Mo	Mo/Mo
AEC模式	Semi-Auto	Semi-Auto
AEC位置	1	1
光密度控制設定	+3	0
半值層(mmAl)	0.34	0.37

顯示的管電壓峰值設定	23	24	25	26	27
靶/濾片	Mo/Mo	Mo/Mo	Mo/Mo	Mo/Mo	Mo/Mo
管電流時間乘積（mAs）	80	80	63	63	50
曝露量測（mR）：					
沒有鋁片時，E（0a）	522.2	608.5	556.3	625.7	561.7
算得之半值層（mmAl）	0.30	0.32	0.33	0.34	0.35
容許之最小半值層（mmAl）	0.26	0.27	0.28	0.29	0.30
容許之最大半值層（mmAl）	0.35	0.36	0.37	0.38	0.39
判定結果	Passed	Passed	Passed	Passed	Passed

顯示的管電壓峰值設定	28	29
靶/濾片	Mo/Mo	Mo/Mo
管電流時間乘積（mAs）	50	40
曝露量測（mR）：		
沒有鋁片時，E（0a）	629.6	559.6
算得之半值層（mmAl）	0.37	0.38
容許之最小半值層（mmAl）	0.31	0.32
容許之最大半值層（mmAl）	0.40	0.41
判定結果	Passed	Passed

Conversion factor (K) table for Mo/Mo

	X-ray tube voltage (kVp)										
HVL	23	24	25	26	27	28	29	30	31	32	33
0.23	116										
0.24	121	124									
0.25	126	129	131								
0.26	130	133	135	138							
0.27	135	138	140	142	143						
0.28	140	142	144	146	147	149					
0.29	144	146	148	150	151	153	154				
0.3	149	151	153	155	156	157	158	159			
0.31	154	156	157	159	160	161	162	163	164		
0.32	158	160	162	163	164	166	167	168	168	170	171
0.33	163	165	166	168	169	170	171	173	173	174	175
0.34	168	170	171	172	173	174	175	176	177	178	179
0.35		174	175	176	177	178	179	180	181	182	183
0.36			179	181	182	183	184	185	185	186	187
0.37				185	186	187	188	189	190	191	191
0.38					190	191	192	193	194	195	195
0.39						196	197	198			
0.4							201	202			
0.41								206			
0.42											
0.43											
0.44											
0.45											

HVL of 26 kVp = 0.34 mmAl
Find K = 172

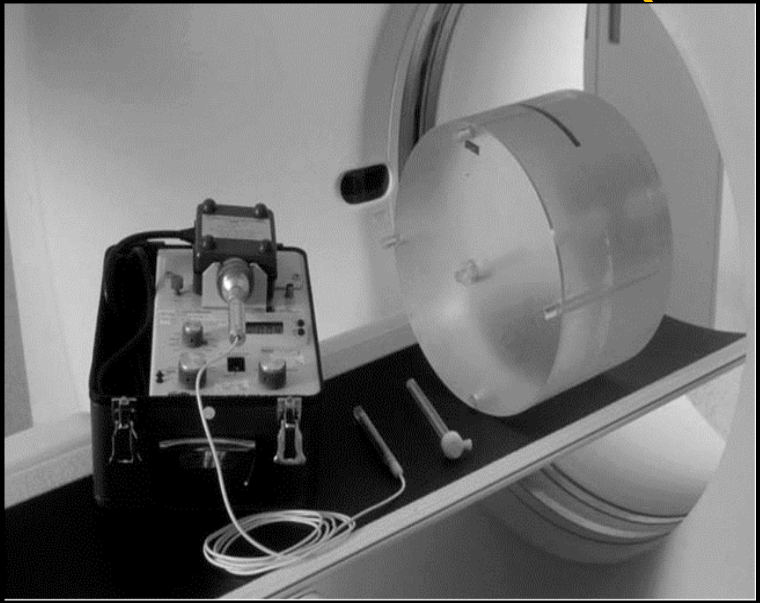
$$AGD = Exposure \times K$$

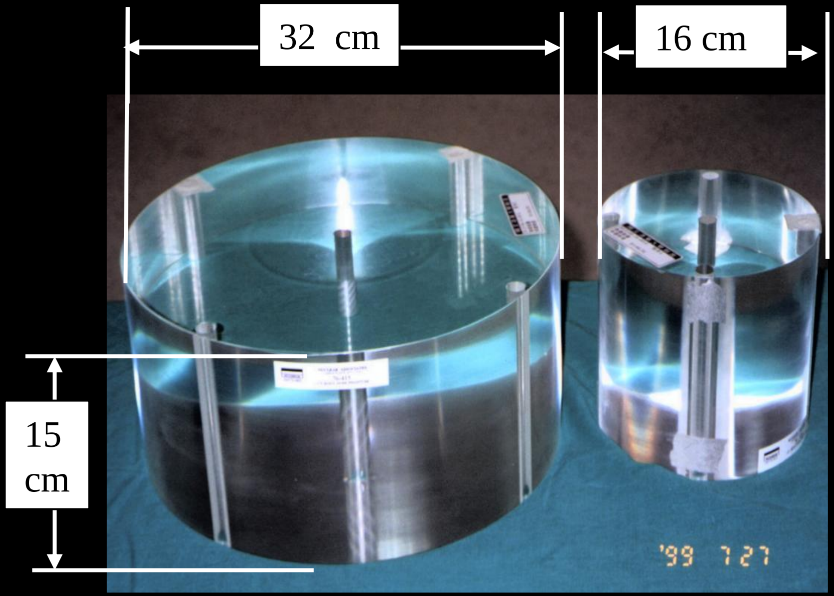
AGD using 26 kVp
= 172 x 686.6 / 1000 = 118.1 mrad

	mR	mAs	mR	mAs
第一次曝露	687.1	61.7	501.7	35.6
第二次曝露	687	61.7	503.1	35.6
第三次曝露	685.6	61.6	506.7	35.9
第四次曝露	686.8	61.7	502.8	35.6
校正因子	1		1	
平均值	686.6	61.675	503.6	35.675
標準差	0.602	0.043	1.878	0.130
變異係數	0.001	0.001	0.004	0.004
判定結果	Passed	Passed	Passed	Passed

AGD < 300 mrad or 3.0 mGy

CTDI (CT dose index)



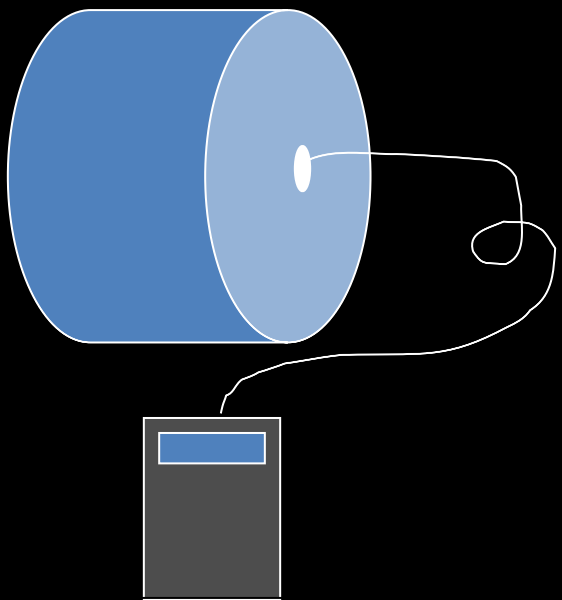


Procedures:

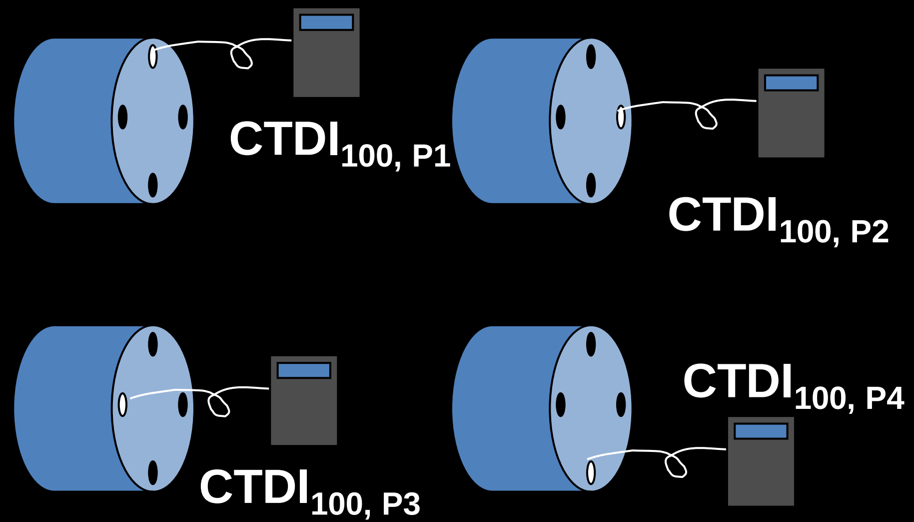
1. Find the routine CT scan protocols (i.e adult abdomen, adult head, …) and the scan parameters
2. Setup the phantom and align it with the bore center of the gantry
3. Make at least 5 exposures with axial scan mode (change the ion chamber positions – center and 4 peripherals) and using the parameters found in step 1
4. Record the readouts

Computed Tomography Dose Index

- Weighted CTDI : $CTDI_w$



$CTDI_{100,center}$



$$CTDI_{100,edge} = \frac{CTDI_{100,\ P1+P2+P3+P4}}{4}$$

劑量計讀值計算

$$\mathrm{CTDI}_{100} = \frac{f \cdot C \cdot E \cdot L}{N \cdot T}$$

- f=8.7 mGy/R (if readout in R)

C: calibration factor for electrometer (1.0-2.0)

E: average measured value

L: active length of pencil ion chamber (100 mm or 160 mm)

N: actual number of data channels (axial)

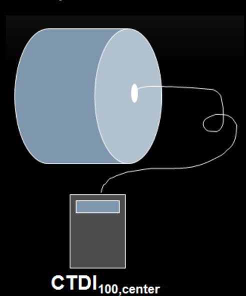
T: nominal slice width (axial)

範例:

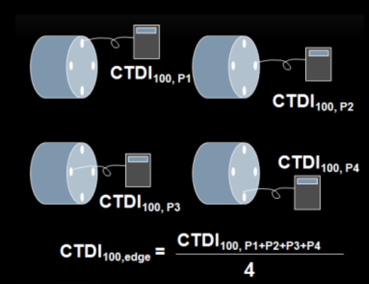
- Multi-slice scanner
  - 120 kVp, 400 mA, 0.8-s scan, 4×2.5 mode
  - Reading: 540 mR
- 計算:

$$\mathrm{CTDI}_{100} = \frac{8.7 \times 1.0 \times 0.54 \times 100}{4 \times 2.5}$$

=47 mGy



$\mathrm{CTDI_C}$



$\mathrm{CTDI_P}$

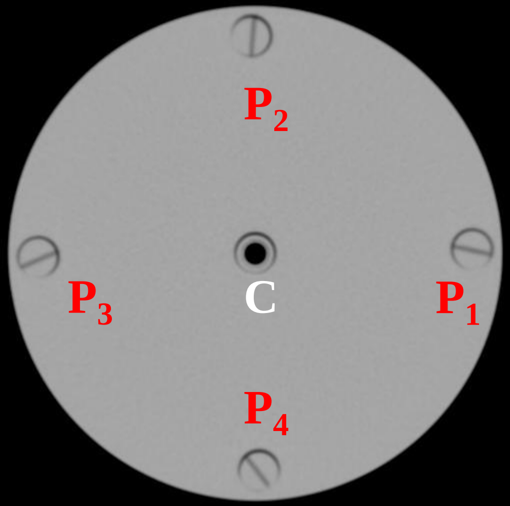
劑量計算

$$CTDI_w = \frac{1}{3} \cdot CTDI_c + \frac{2}{3} \cdot CTDI_p$$ (mGy)

$$CTDI_{vol} = \frac{CTDI_w}{Pitch}$$ (mGy)

$$DLP = CTDI_{vol} \cdot \text{total scan length}$$ (mGy cm)

$$E = k \cdot DLP$$ (mSv)



Computed Tomography Dose Index

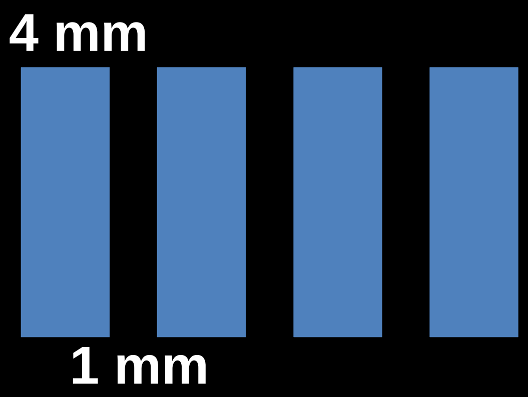
- Volume CTDI: $CTDI_{vol}$

$$CTDI_{vol} = \frac{N \times T}{I} \times CTDI_w$$

$$CTDI_{vol} = \frac{CTDI_w}{Pitch}$$

In axial scan :

Example:
Slice thickness = 4 mm
Inter-slice gap = 1 mm



Pitch = 4 ÷ (4 + 1) = 0.8

例：請依下表的數據計算 $CTDI_w$ 以及 $CTDI_{vol}$

(the scan pitch are: brain=0.624, abd=0.641)

代表性檢查	成人頭部 Brain Routine	成人腹部 Abd Routine
mAs 設定值	250	113
射束寬度 (mm)	25	40
讀值一 (mGy)	5.00	1.12
讀值二 (mGy)	4.97	1.11
讀值三 (mGy)	4.98	1.11
校正因子	1.00	1.00
平均值	4.99	1.11
標準差	0.012	0.004
變異係數	0.002	0.003
結果判定	Passed	Passed
CTDIc (mGy)	19.94	2.79
上方讀值 (mGy)	5.71	2.18
下方讀值 (mGy)	5.22	1.94
左側讀值 (mGy)	5.51	2.25
右側讀值 (mGy)	5.26	2.53

例：請依下表的數據計算 $CTDI_w$ 以及 $CTDI_{vol}$
(the scan pitch are: brain=0.624, abd=0.641)

代表性檢查	成人頭部 Brain Routine	成人腹部 Abd Routine
mAs 設定值	250	113
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下方讀值 (mGy)	5.22	1.94
左側讀值 (mGy)	5.51	2.25
右側讀值 (mGy)	5.26	2.53

成人頭部：

$(5.71+5.22+5.51+5.26)/4 = 5.42$

$CTDI_P = 5.42 \times 100 / 25 = 21.69$

$CTDI_W = (50.86+21.69 \times 2)/3 = 21.11$

$CTDI_{vol} = 21.11/0.624 = 33.83$

成人腹部：

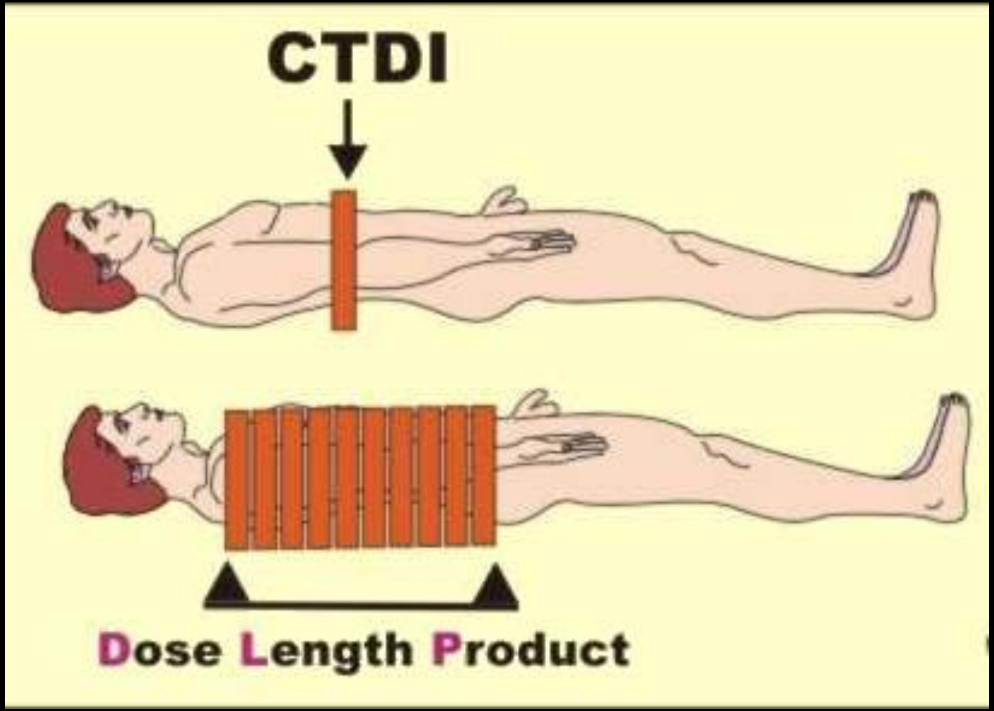
$(2.18+1.94+2.25+2.53)/4 = 2.23$

$CTDI_P = 2.23 \times 100 / 40 = 5.58$

$CTDI_W = (2.79+5.58 \times 2)/3 = 4.65$

$CTDI_{vol} = 4.65/0.641 = 7.25$

DLP – dose length product

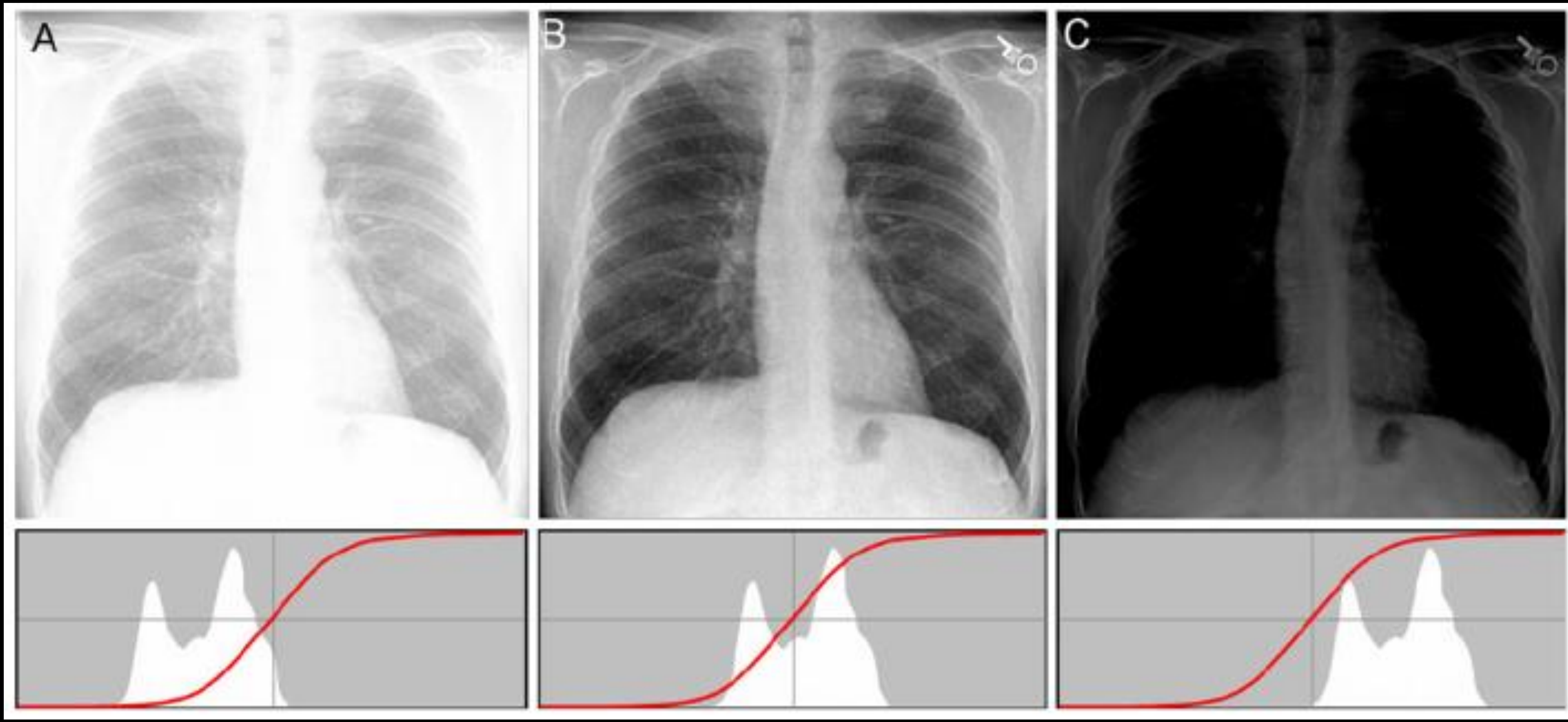


$$E = k \cdot \mathrm{DLP}$$ (mSv)

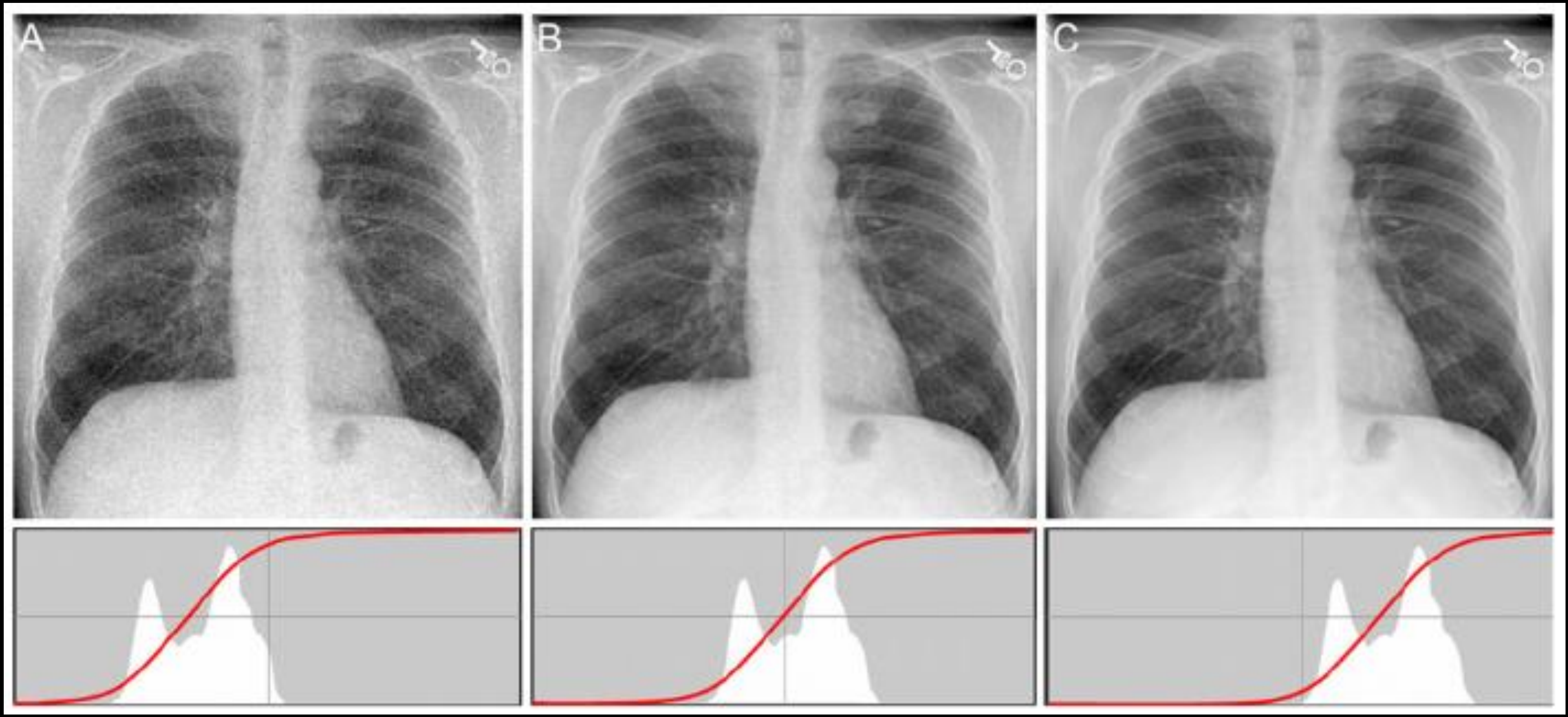
Table 3. Normalized effective dose per dose-length product (DLP) for adults (standard physique) and pediatric patients of various ages over various body regions. Conversion factor for adult head and neck and pediatric patients assume use of the head CT dose phantom (16 cm). All other conversion factors assume use of the 32-cm diameter CT body phantom[78,79]

Region of Body	***k (mSv mGy^{-1} cm^{-1})***				
	0 year old	***1 year old***	***5 year old***	***10 year old***	***Adult***
Head and neck	0.013	0.0085	0.0057	0.0042	0.0031
Head	0.011	0.0067	0.0040	0.0032	0.0021
Neck	0.017	0.012	0.011	0.0079	0.0059
Chest	0.039	0.026	0.018	0.013	0.014
Abdomen ≈& pelvis	0.049	0.030	0.020	0.015	0.015
Trunk	0.044	0.028	0.019	0.014	0.015

軟片系統曝光不足與曝光過度



數位影像中曝光不足與曝光過度



常見廠商建議之臨床檢查時曝露指標數值

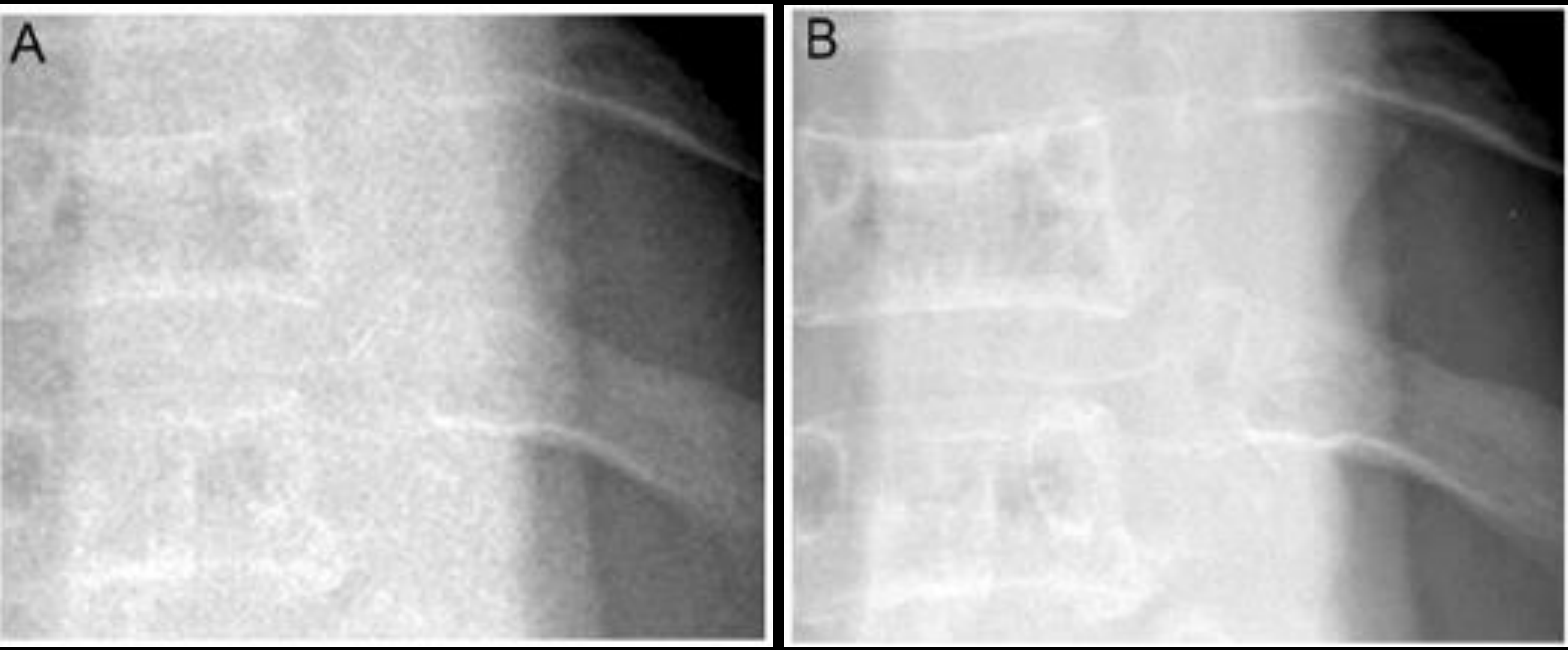
Proprietary Exposure Indicators and Selected Vendor Recommendations

Fuji (S Number)	AGFA (IgM)	Kodak (EI)	Detector Exposure Estimate (mR)	Action
> 1000	<1.45	<1250	<0.20	Underexposed: Repeat
601-1000	1.45-1.74	1250-1549	0.2-0.3	Underexposed: QC exception
301-600	1.75-2.04	1550-1849	0.3-0.7	Underexposed: QC review
150-300	**2.05-2.35**	**1850-2150**	**0.7-1.3**	**Acceptable Range**
75-149	2.36-2.65	2151-2450	1.3-2.7	Overexposed: QC review
50-74	2.66-2.95	2451-2750	2.7-4.0	Overexposed: QC exception
<50	>2.95	>2750	>4.0	Overexposed: Repeat if necessary

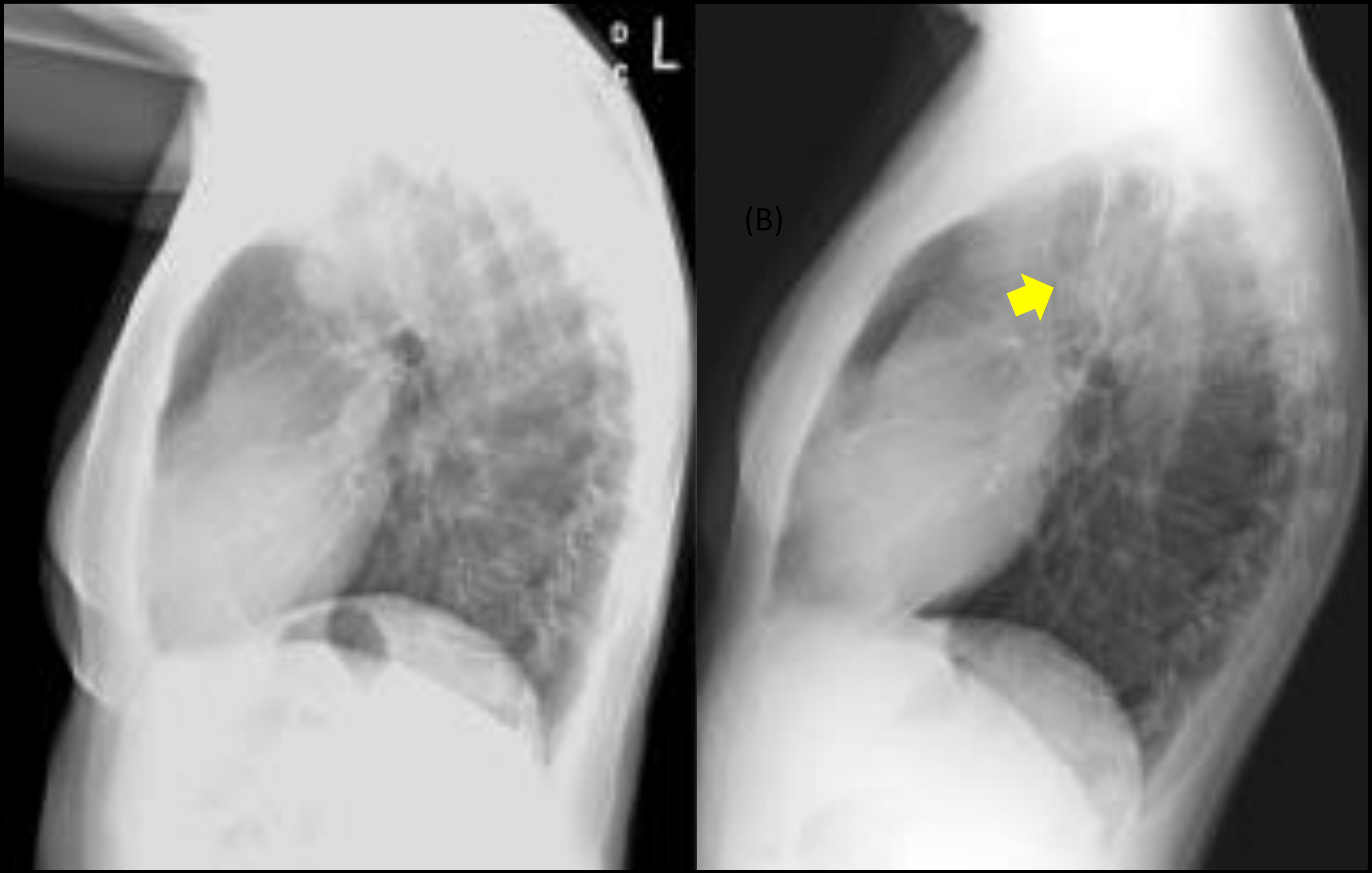
https://www.imagegently.org/Procedures/Digital-Radiography/Educational-Materials

數位影像中曝光不足與曝光過度

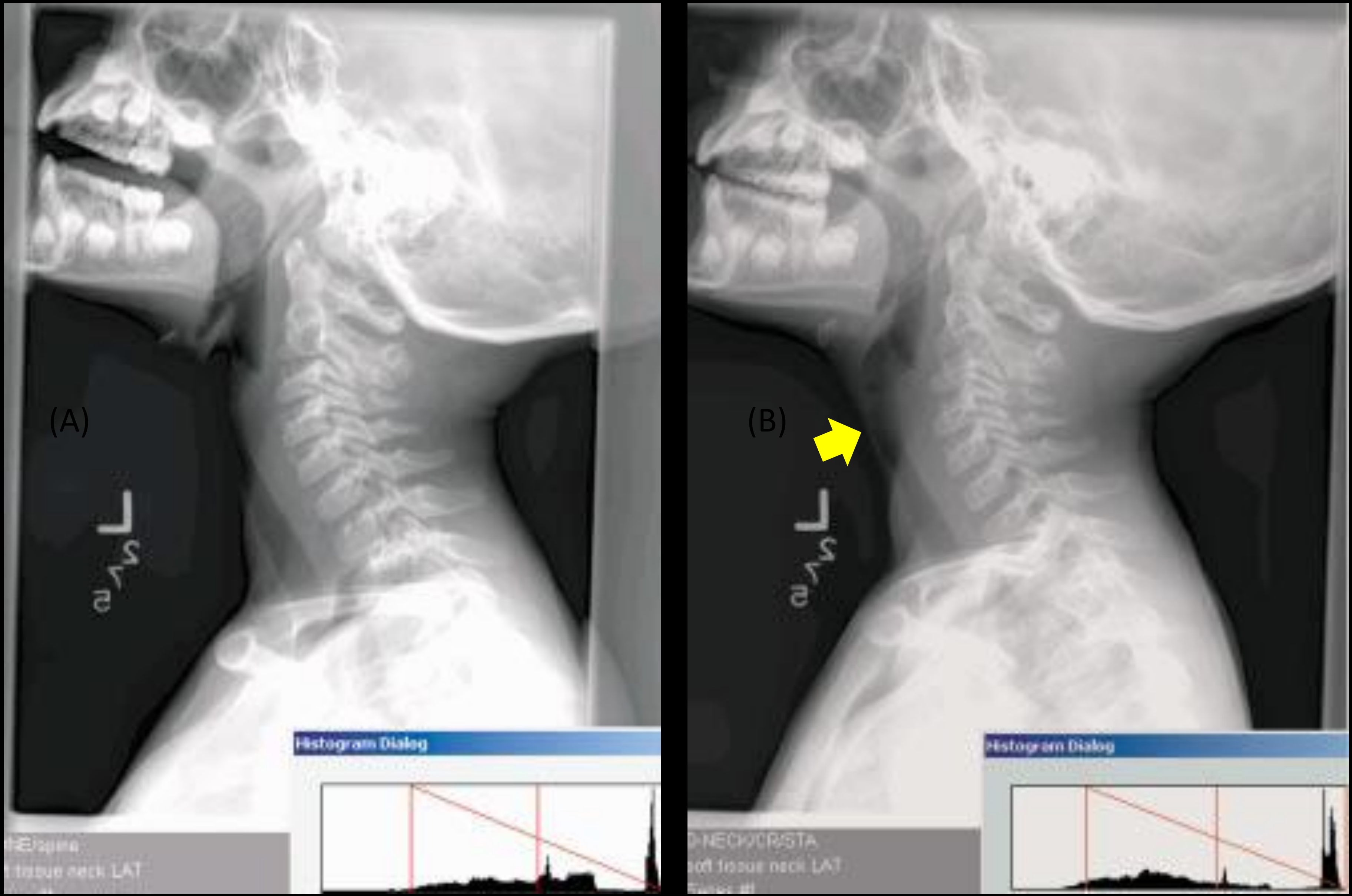
曝光不足



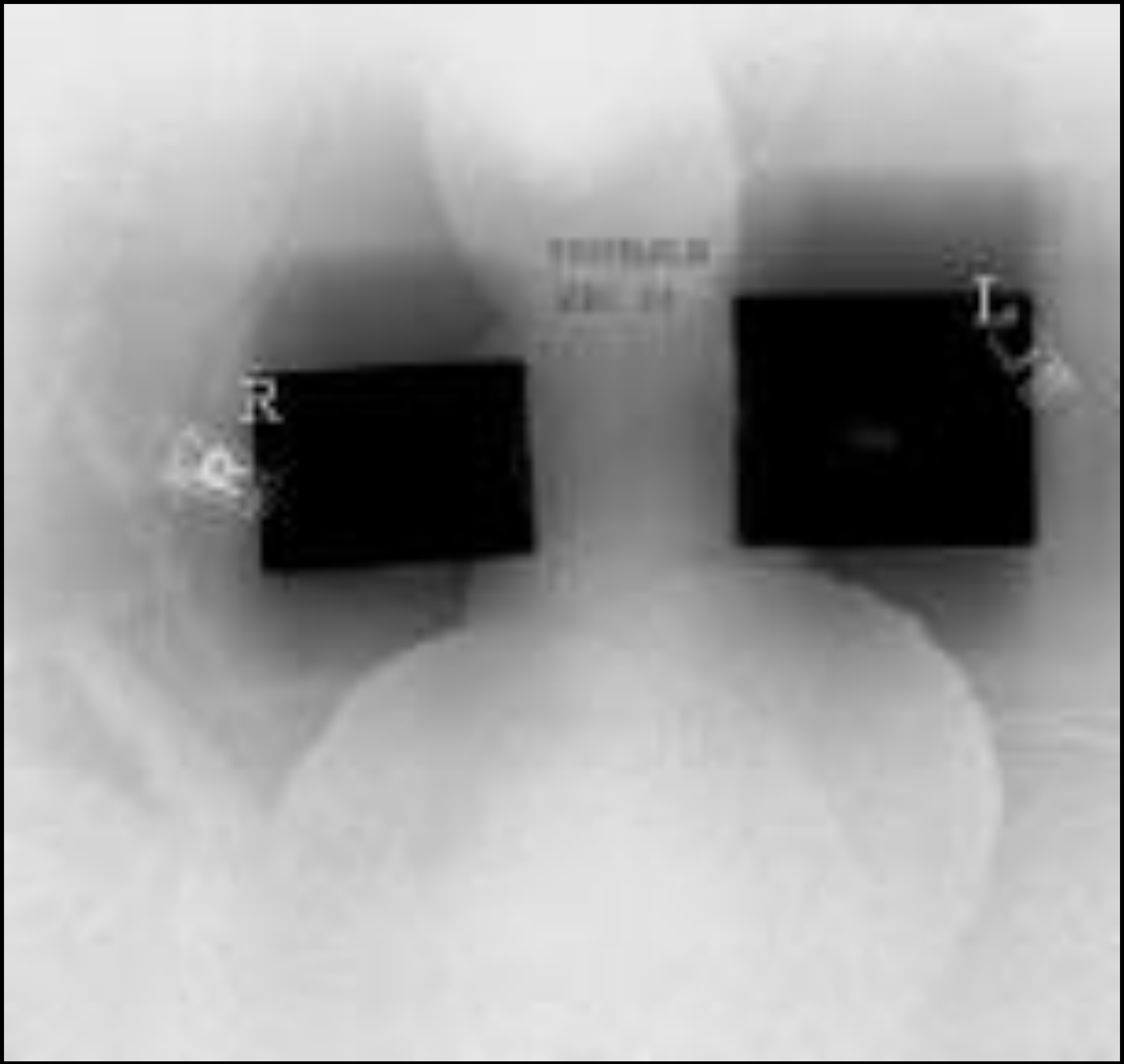
量子斑駁效應
Quantum mottle effect



Underexposed direct digital radiography (DR) at 125 kVp and 4.4 mAs caused an exposure data recognition failure. (B) Repeated exposure at 7 mAs.



Overexposed computed radiography (CR) images demonstrate loss of contrast in skin and dense features.



automatic

detection of the collimation field


R
L

R
L

NCRP REPORT No. 147

Structural Shielding Design for Medical X-Ray Imaging Facilities

Introduction-1

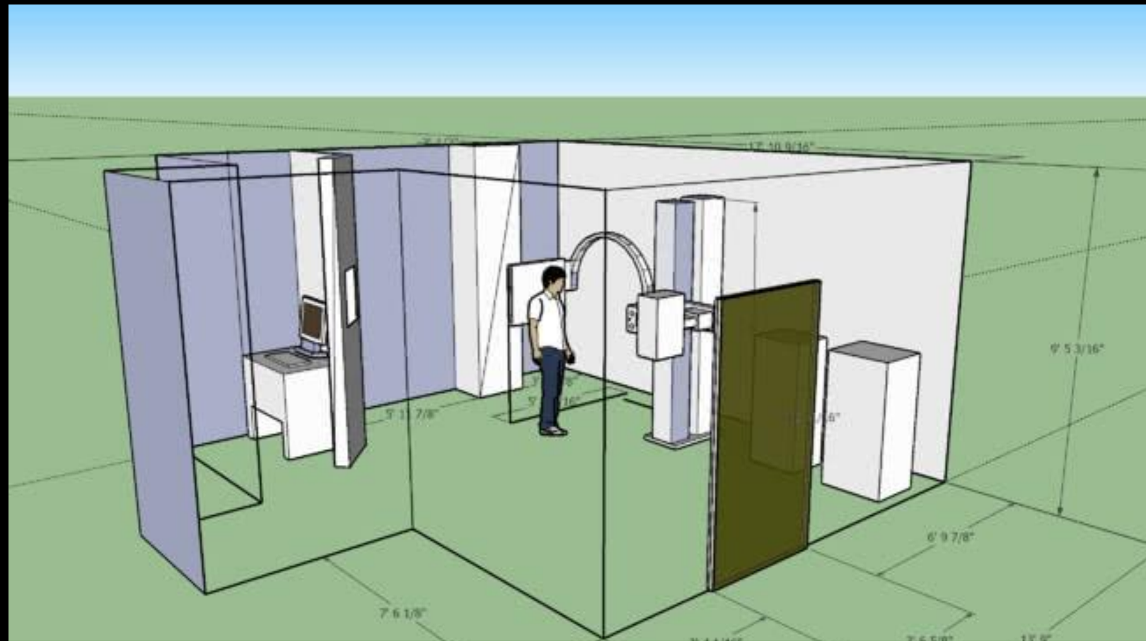
- Terms
  - Shall indicates a recommendation that is necessary to meet the currently accepted standards of radiation protection.
  - Should indicates an advisory recommendation that is to be applied when practicable or practical.
- $D_T \times W_R = H_T$
- $H_T \times W_T = E$

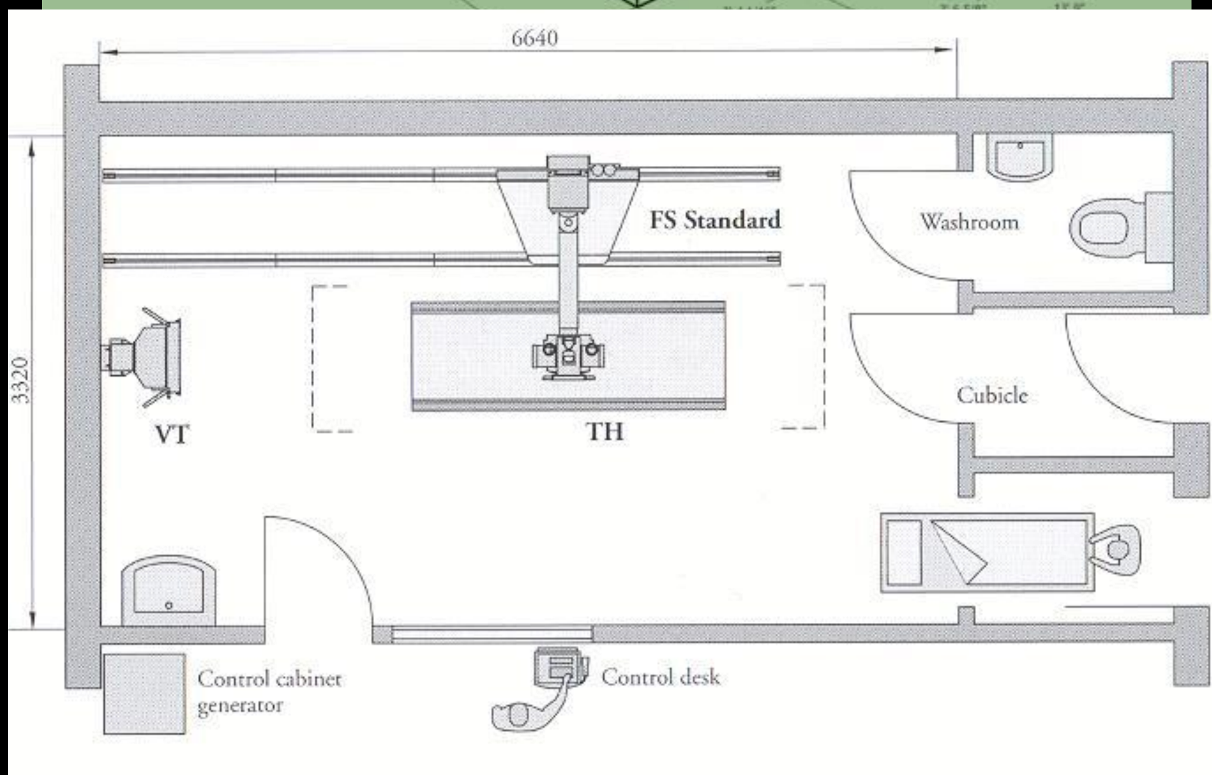
表一　各類輻射加權因數[1]

輻射種類與能量區間[2]	輻射加權因數 W_R
所有能量之光子	1
所有能量之電子及 μ 介子[3]	1
中子[4]能量<10 千電子伏(keV)	5
10 千電子伏(keV)—100 千電子伏(keV)	10
>100 千電子伏(keV)—2 百萬電子伏(MeV)	20
>2 百萬電子伏(MeV)—20 百萬電子伏(MeV)	10
>20 百萬電子伏(MeV)	5
質子(回跳質子除外)能量>2 百萬電子伏(MeV)	5
α 粒子，分裂碎片，重核	20

表二　組織加權因數[1]

組織或器官	組織加權因數 W_T	組織或器官	組織加權因數 W_T
性腺	0.20	肝	0.05
紅骨髓	0.12	食道	0.05
結腸	0.12	甲狀腺	0.05
肺	0.12	皮膚	0.01
胃	0.12	骨表面	0.01
膀胱	0.05	其餘組織或器官	0.05[2][3]
乳腺	0.05		




6640
3320
FS Standard
Washroom
Cubicle
VT
TH
Control cabinet
generator
Control desk

Introduction-2

- Controlled area and uncontrolled area
  - Recommendation for controlled areas—Shielding design goal (P) (in air kerma):

    0.1 mGy / week (5 mGy / year, 2.5 uGy/h)

    NCRP 49: 1 mSv/week = 50 mSv/year
  - Recommendation for uncontrolled areas—Shielding design goal (P) (in air kerma):

    0.02 mGy / week (1 mGy / year, 0.5 uGy/h)

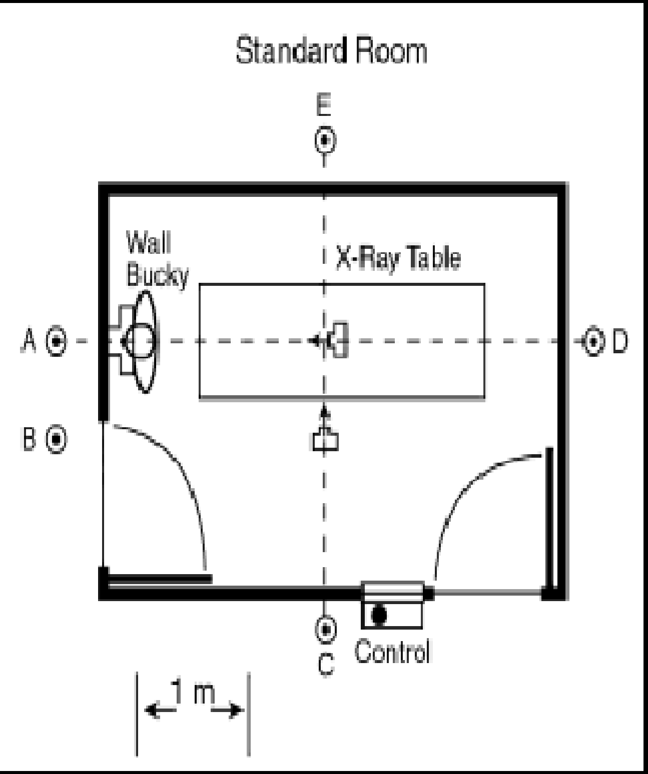
    NCRP 49: 0.1 mSv/week = 5 mSv/year

(測定條件______kVp______mA______sec	
□管制區內操作人員或工作人居佔位置之劑量率最高不超過10μSv/h。(≥10μSv/h者需附符合工作人員年劑量限度說明)。	□管制區外距任何可以接近X光室四週障壁外表面30cm處之劑量率最高不超過0.5μSv/h。(>0.5μSv/h者需附符合一般人年劑量限度說明)。

10 uGy/h = 400 uGy/week = 0.4 mGy/week = 20 mGy/year

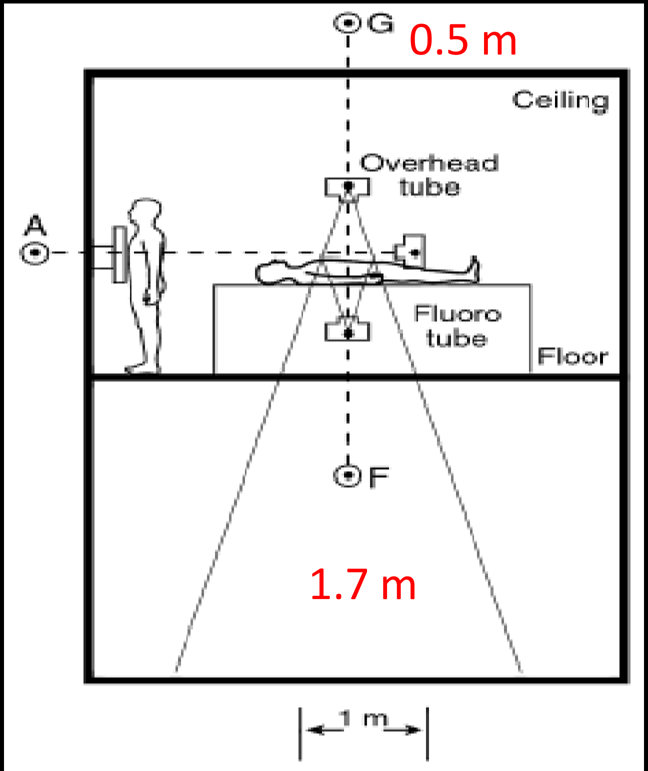
Concepts and terminology

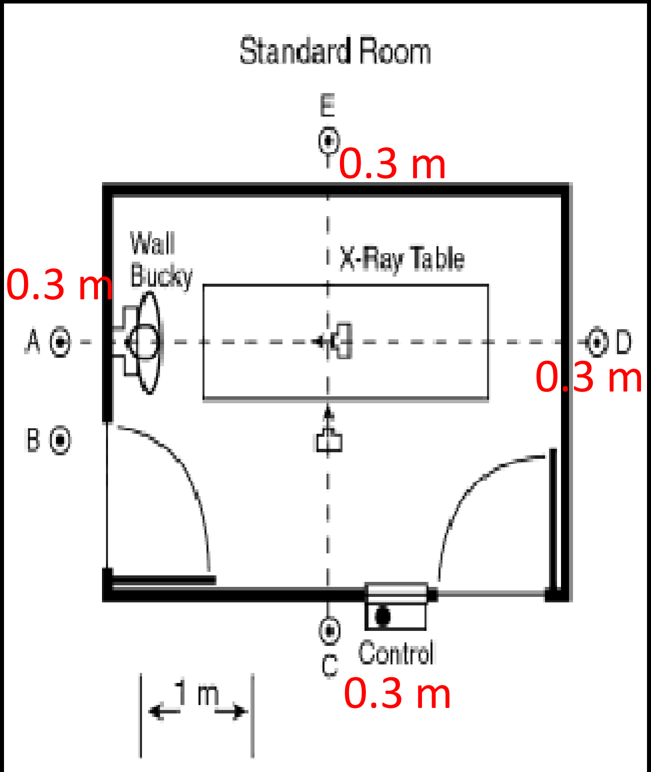
- Shielding design goals (P)
- Distance to the occupied area (d)
- Occupancy factors (T)
- Workload and workload distribution (W)
- Use factor (U)
- Primary barriers
- Secondary barriers



Distance to the occupied area (d)

- The source to the nearest likely approach of the sensitive organs of a person to the barrier
  - For a wall this may be assumed to be not <0.3 m.
  - For a source located above potentially occupied spaces, the sensitive organs of the person below can be assumed to be not >1.7 m above the lower floor, while for ceiling transmission the distance of at least 0.5 m above the floor of the room above is generally reasonable.





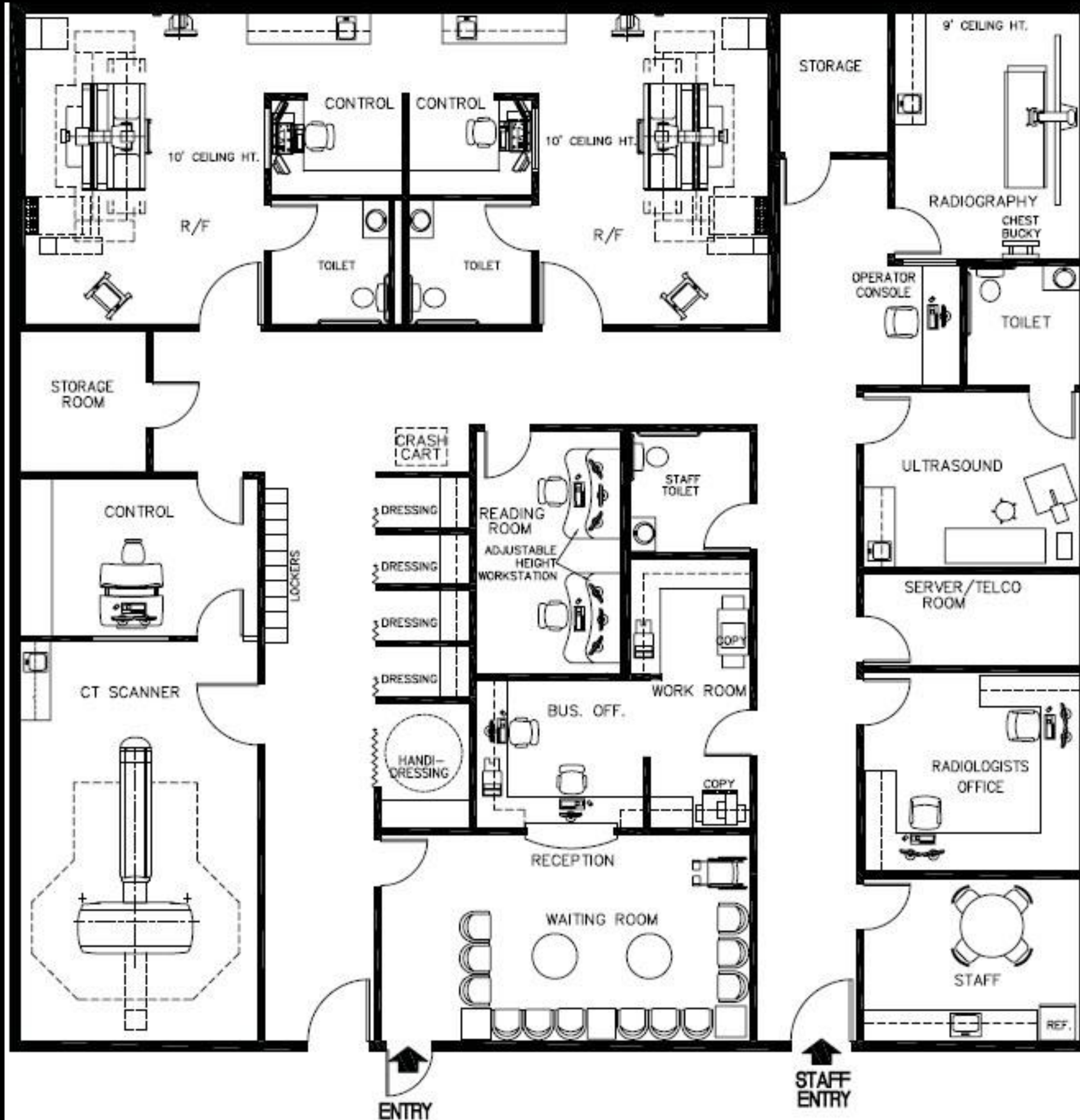
Elevation (left) and plan (right) views of a representative radiographic (or radiographic and fluoroscopic) room.

Points A, B, C, D and E represent a distance of 0.3 m from the respective walls. Point F is 1.7 m above the floor below. Point G is taken at 0.5 m above the floor of the room above.

Occupancy factors (T)

- The average fraction of time that the maximally exposed individual is present while the x-ray beam is on.
  - the fraction of the working hours in the week that a given person would occupy the area

Location	Occupancy Factor (T)
Administrative or clerical offices; laboratories, pharmacies and other work areas fully occupied by an individual; receptionist areas, attended waiting rooms, children's indoor play areas, adjacent x-ray rooms, film reading areas, nurse's stations, x-ray control rooms	1
Rooms used for patient examinations and treatments	1/2
Corridors, patient rooms, employee lounges, staff rest rooms	1/5
Corridor doors[b]	1/8
Public toilets, unattended vending areas, storage rooms, outdoor areas with seating, unattended waiting rooms, patient holding areas	1/20
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), attics, stairways, unattended elevators, janitor's closets	1/40



CONTROL
CONTROL
10' CEILING HT.
10' CEILING HT.
R/F
R/F
TOILET
TOILET
STORAGE
9' CEILING HT.
RADIOGRAPHY
CHEST BUCKY
OPERATOR CONSOLE
TOILET
STORAGE ROOM
CRASH CART
CONTROL
LOCKERS
DRESSING
DRESSING
DRESSING
DRESSING
READING ROOM
ADJUSTABLE HEIGHT WORKSTATION
STAFF TOILET
ULTRASOUND
SERVER/TELCO ROOM
COPY
CT SCANNER
BUS. OFF.
WORK ROOM
HANDI-DRESSING
COPY
RADIOLOGISTS OFFICE
RECEPTION
WAITING ROOM
STAFF
REF.
ENTRY
STAFF ENTRY

Workload (W) and workload distribution

- The time integral of the x-ray tube current over a specified period
  - milliampere-minutes (mAmin/week)
- The total workload per week (W_{tot})

$$W_{tot} = N\,W_{norm}$$

  - The normalized workload (W_{norm}), the average workload per patient
  - The average number of patients per week (N)

mAmin/wk =

Pt/day x 5 days/wk x projections/Pt x mAs/projection x 1/60 min/s

NCRP 147 report survey:

General x-ray room: 277 mAmin/wk

Chest x-ray room: 45 mAmin/wk

Cardiac angio room: 3050 mAmin/wk

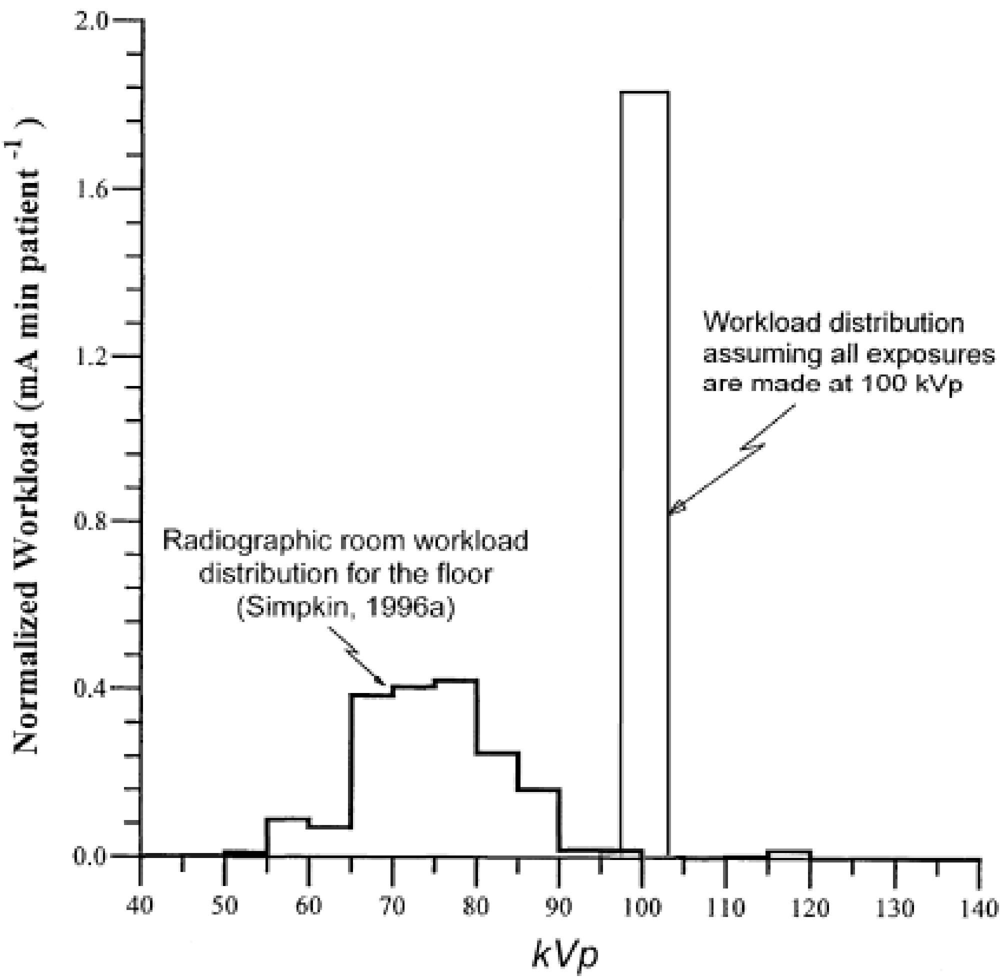
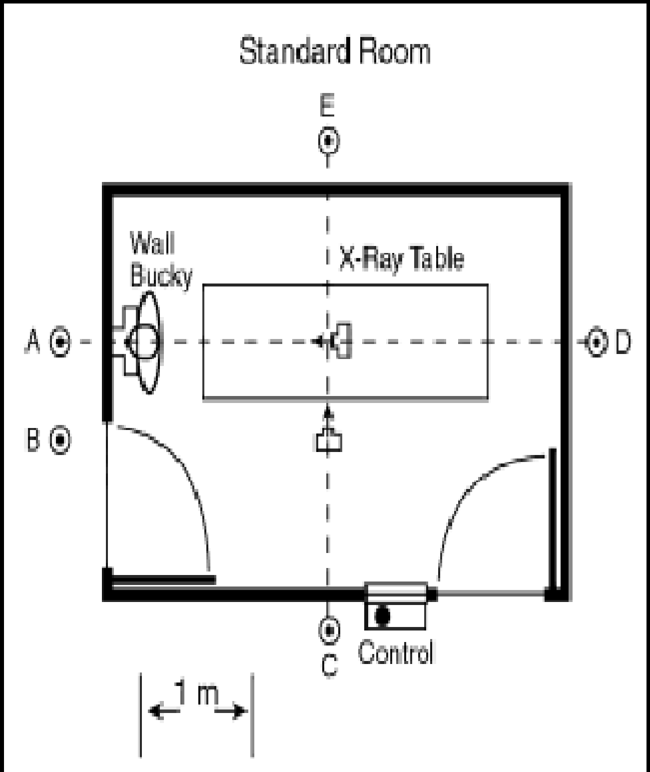
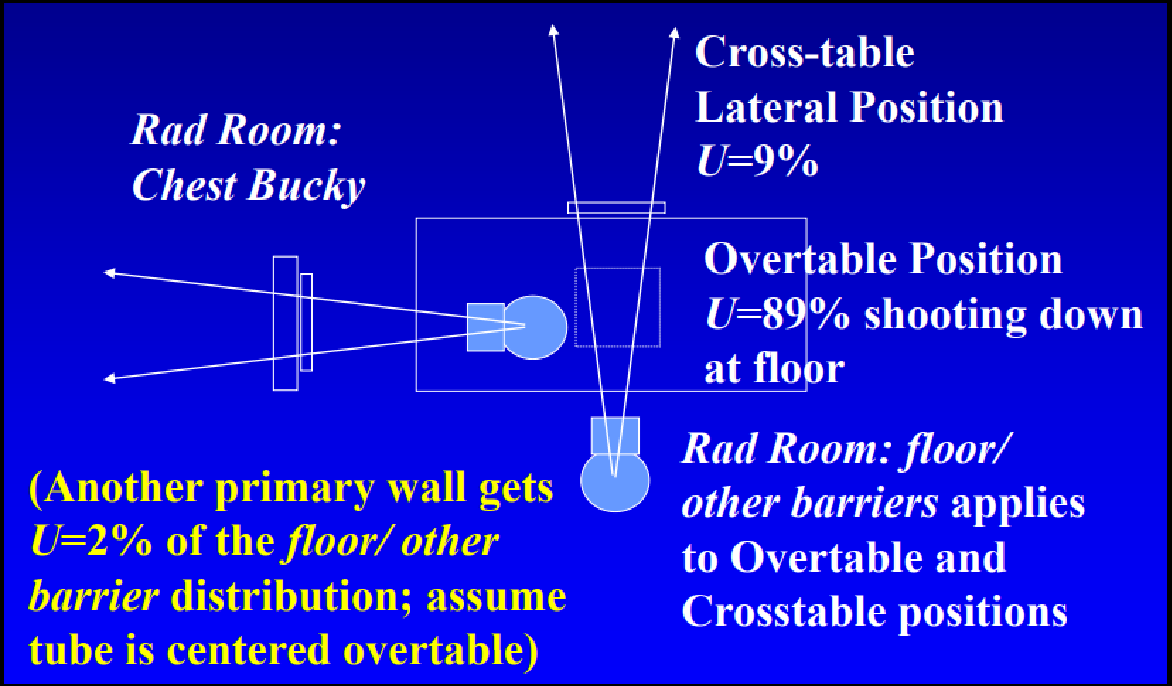


Fig. 4.1. The workload distribution *Rad Room (floor or other barriers)* obtained from the AAPM-TG9 survey (Simpkin, 1996a) for the x-ray beam directed at the floor of a radiographic room compared to the workload distribution assuming all exposures are made at 100 kVp.

Use factor (U)

- The fraction of the primary beam workload that is directed toward a given primary barrier.
- Type of radiation installation

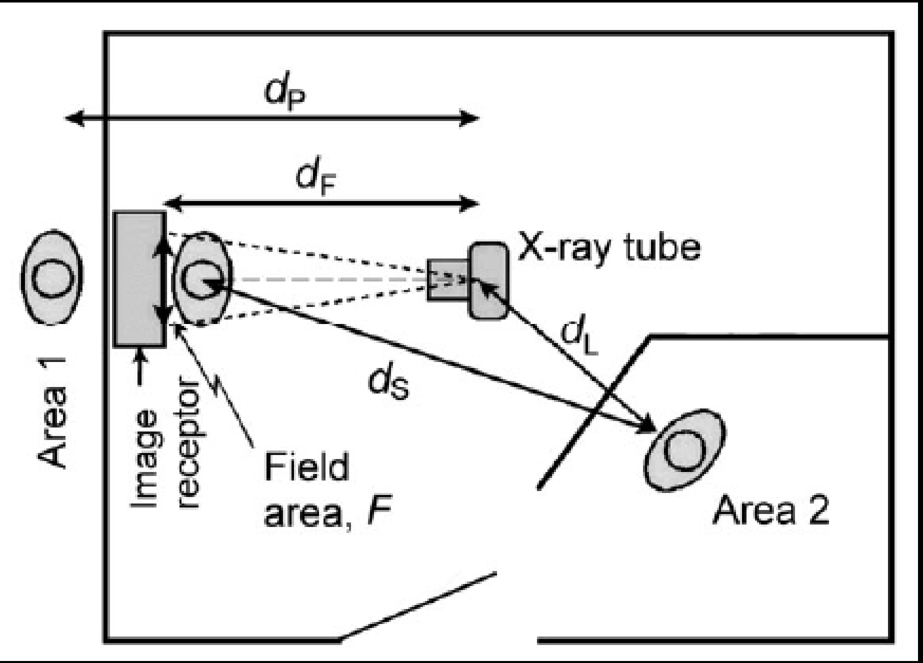




1 for floor, 0.25 for other possible walls
1 for chest bucky wall
1 for all secondary barriers

Distances (d)

- d_{pri}: focal spot to barrier + 0.3 m
- d_{sec}: patient surface to barrier + 0.3 m
- d_{leak}: tube housing to barrier + 0.3 m
- d_{sca}: d_{sec}



E: exposure level

1. E_P: W (mAmin/wk) x tube output (mR/mAmin)

2. E_S: (E_P/d_{sca}^2) x S x (field size/400)

   S ~ 0.1 – 0.15 %

3. E_L: 1.67/I (mR/mAmin) x W (mAmin/wk) = 1.67 W/I (mR/wk)

   100 mR/I mA/hr = 1.67/I (mR/mAmin)

   I ~ 3-5 mA

4. $E = (E_P/d_{pri}^2) \times U + (E_S/d_{sec}^2) + (E_L/d_{leak}^2)$

5. $E_T = E \times T$

$P = E_T e^{-\mu x}$ → find x = ?

E_T: total exposure at test point without shield

Primary barriers

- Unshielded Primary Air Kerma
  - The weekly unshielded primary air kerma [$K_P(0)$] in the occupied area due to *N* patients examined per week in the room

$$K_p(0) = \frac{K_p^1 UN}{d_p^2} = \frac{K_p^1 UW}{d_p^2 W_{norm}}$$

  - K_p^1 the unshielded primary air kerma per patient at 1 m
- Preshielding

TABLE 4.6—*Equivalent thickness of primary beam preshielding (x_{pre}) (Dixon, 1994).*[a,b]

Application	x_{pre} (in mm)		
	Lead	Concrete	Steel
Image receptor in radiographic table or wall-mounted cassette holder (attenuation by grid, cassette, and image-receptor supporting structures)	0.85	72	7
Cross-table lateral (attenuation by grid and cassette only)	0.3	30	2

[a]Since patient attenuation is ignored, potential variations in image-receptor attenuation from different manufacturers is not a significant factor.
[b]Caveats for the use of preshielding are discussed in Section 4.1.6.2.

Secondary barriers

- Leakage radiation
- Scatter radiation
- Total contribution from secondary radiation
  - The air kerma from unshielded secondary radiation [$K_{sec}(0)$] at a distance d_{sec} for N patients

$$K_{sec}(0) = \frac{K_{sec}^{1} N}{d_{sec}^{2}}$$

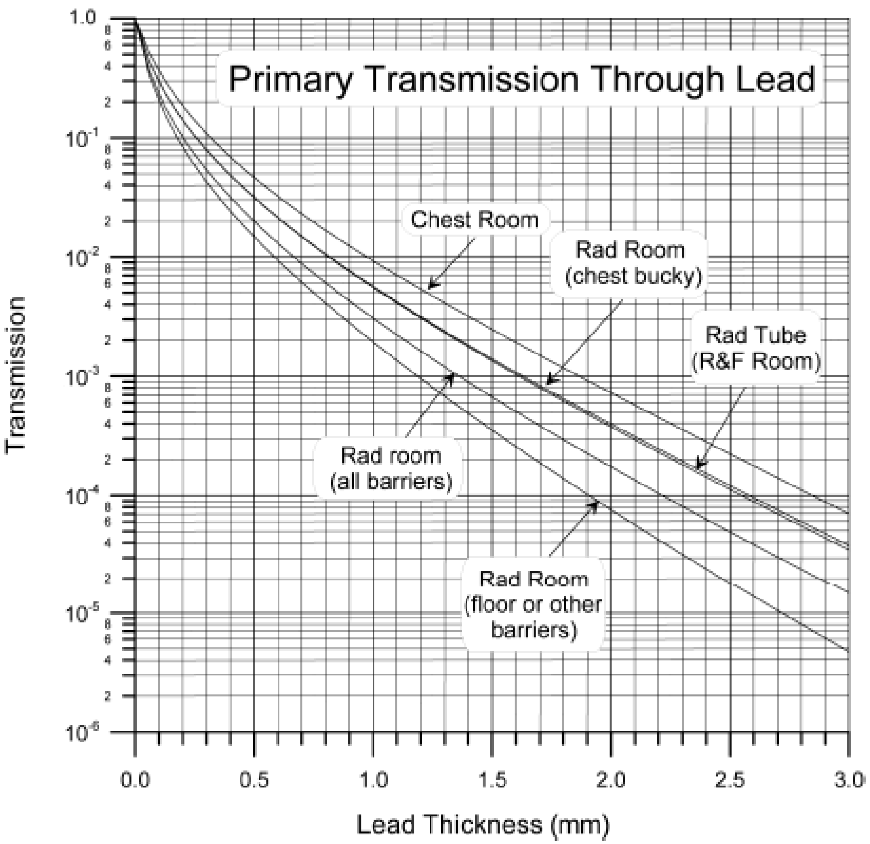
Shielding for primary barriers

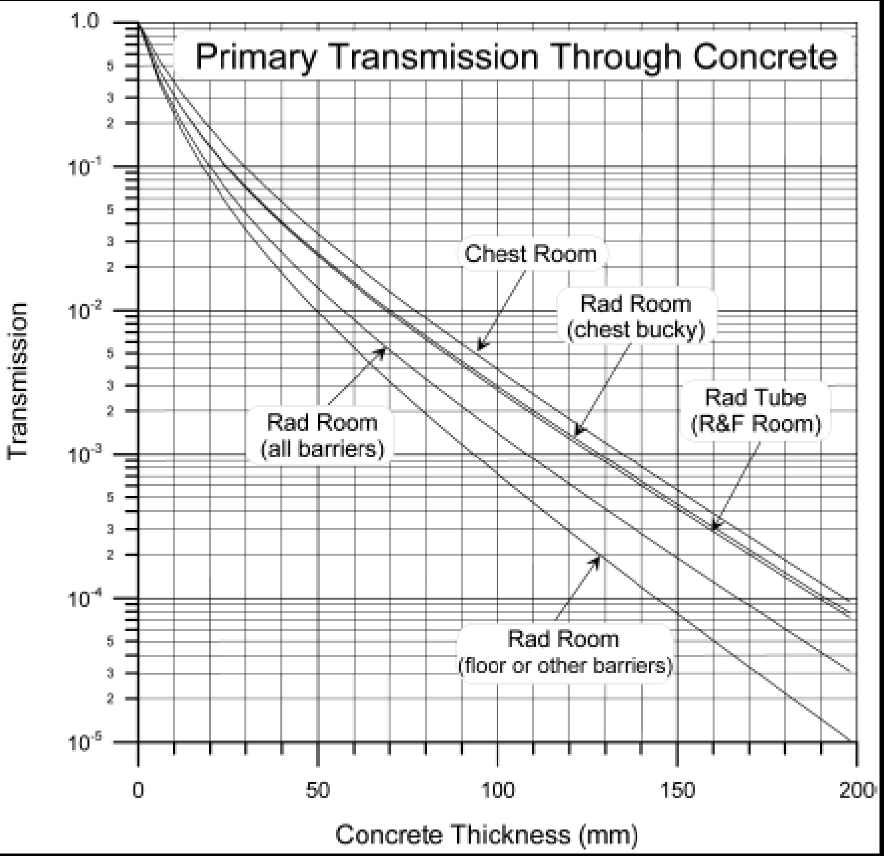
- The barrier transmission factor (B_p)

$$B_p(x_{barrier} + x_{pre}) = \frac{P/T}{K(0)} = \left(\frac{P}{T}\right)\frac{d_p^2}{K_p^1 UN} = \frac{Pd^2 W_{norm}}{W_{tot} TUD^1}$$

- The structural barrier thickness ($x_{barrier}$)

$$x_{barrier} = \frac{1}{\alpha\gamma}\ln\left[\frac{\left(\frac{NTUK_p^1}{Pd_p^2}\right) + \frac{\beta}{\alpha}}{1 + \frac{\beta}{\alpha}}\right] - x_{pre}$$


Primary Transmission Through Lead
Chest Room
Rad Room (chest bucky)
Rad Tube (R&F Room)
Rad room (all barriers)
Rad Room (floor or other barriers)
Transmission
Lead Thickness (mm)


Primary Transmission Through Concrete
Chest Room
Rad Room (chest bucky)
Rad Tube (R&F Room)
Rad Room (all barriers)
Rad Room (floor or other barriers)
Transmission
Concrete Thickness (mm)

kV_p[b]	Lead α (mm^{-1})	Lead β (mm^{-1})	Lead γ	Concrete[a] α (mm^{-1})	Concrete[a] β (mm^{-1})	Concrete[a] γ
25	4.952×10^{1}	1.940×10^{2}	3.037×10^{-1}	3.904×10^{-1}	1.645	2.757×10^{-1}
30	3.880×10^{1}	1.780×10^{2}	3.473×10^{-1}	3.173×10^{-1}	1.698	3.593×10^{-1}
35	2.955×10^{1}	1.647×10^{2}	3.948×10^{-1}	2.528×10^{-1}	1.807	4.648×10^{-1}
40				1.297×10^{-1}	1.780×10^{-1}	2.189×10^{-1}
45				1.095×10^{-1}	1.741×10^{-1}	2.269×10^{-1}
50	8.801	2.728×10^{1}	2.957×10^{-1}	9.032×10^{-2}	1.712×10^{-1}	2.324×10^{-1}
55	7.839	2.592×10^{1}	3.499×10^{-1}	7.422×10^{-2}	1.697×10^{-1}	2.454×10^{-1}
60	6.951	2.489×10^{1}	4.198×10^{-1}	6.251×10^{-2}	1.692×10^{-1}	2.733×10^{-1}
65	6.130	2.409×10^{1}	5.019×10^{-1}	5.528×10^{-2}	1.696×10^{-1}	3.217×10^{-1}
70	5.369	2.349×10^{1}	5.881×10^{-1}	5.087×10^{-2}	1.696×10^{-1}	3.847×10^{-1}
75	4.666	2.269×10^{1}	6.618×10^{-1}	4.797×10^{-2}	1.663×10^{-1}	4.492×10^{-1}
80	4.040	2.169×10^{1}	7.187×10^{-1}	4.583×10^{-2}	1.549×10^{-1}	4.926×10^{-1}
85	3.504	2.037×10^{1}	7.550×10^{-1}	4.398×10^{-2}	1.348×10^{-1}	4.943×10^{-1}
90	3.067	1.883×10^{1}	7.726×10^{-1}	4.228×10^{-2}	1.137×10^{-1}	4.690×10^{-1}
95	2.731	1.707×10^{1}	7.714×10^{-1}	4.063×10^{-2}	9.705×10^{-2}	4.406×10^{-1}
100	2.500	1.528×10^{1}	7.557×10^{-1}	3.925×10^{-2}	8.567×10^{-2}	4.273×10^{-1}
105	2.364	1.341×10^{1}	7.239×10^{-1}	3.808×10^{-2}	7.862×10^{-2}	4.394×10^{-1}
110	2.296	1.170×10^{1}	6.827×10^{-1}	3.715×10^{-2}	7.496×10^{-2}	4.752×10^{-1}
115	2.265	1.021×10^{1}	6.363×10^{-1}	3.636×10^{-2}	7.201×10^{-2}	5.319×10^{-1}
120	2.245	8.950	5.873×10^{-1}	3.566×10^{-2}	7.109×10^{-2}	6.073×10^{-1}
125	2.219	7.923	5.386×10^{-1}	3.502×10^{-2}	7.113×10^{-2}	6.974×10^{-1}
130	2.174	7.094	4.909×10^{-1}	3.445×10^{-2}	7.160×10^{-2}	7.969×10^{-1}
135	2.102	6.450	4.469×10^{-1}	3.394×10^{-2}	7.263×10^{-2}	9.099×10^{-1}
140	2.009	5.916	4.018×10^{-1}	3.345×10^{-2}	7.476×10^{-2}	1.047
145	1.895	5.498	3.580×10^{-1}	3.296×10^{-2}	7.875×10^{-2}	1.224
150	1.757	5.177	3.156×10^{-1}	3.243×10^{-2}	8.599×10^{-2}	1.467

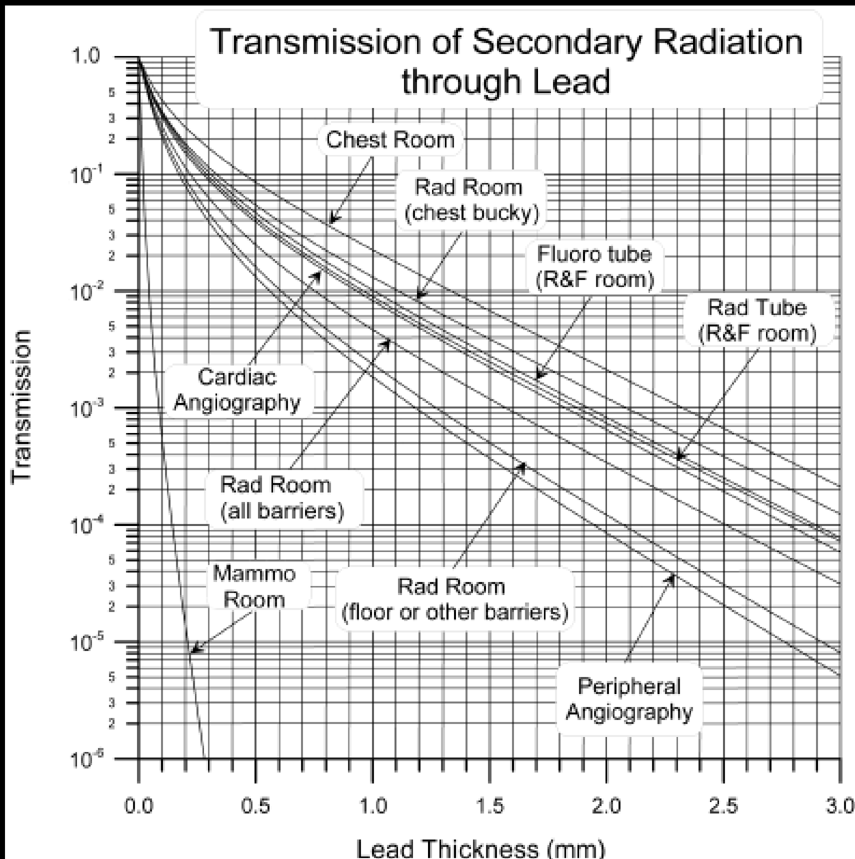
Shielding for secondary barriers

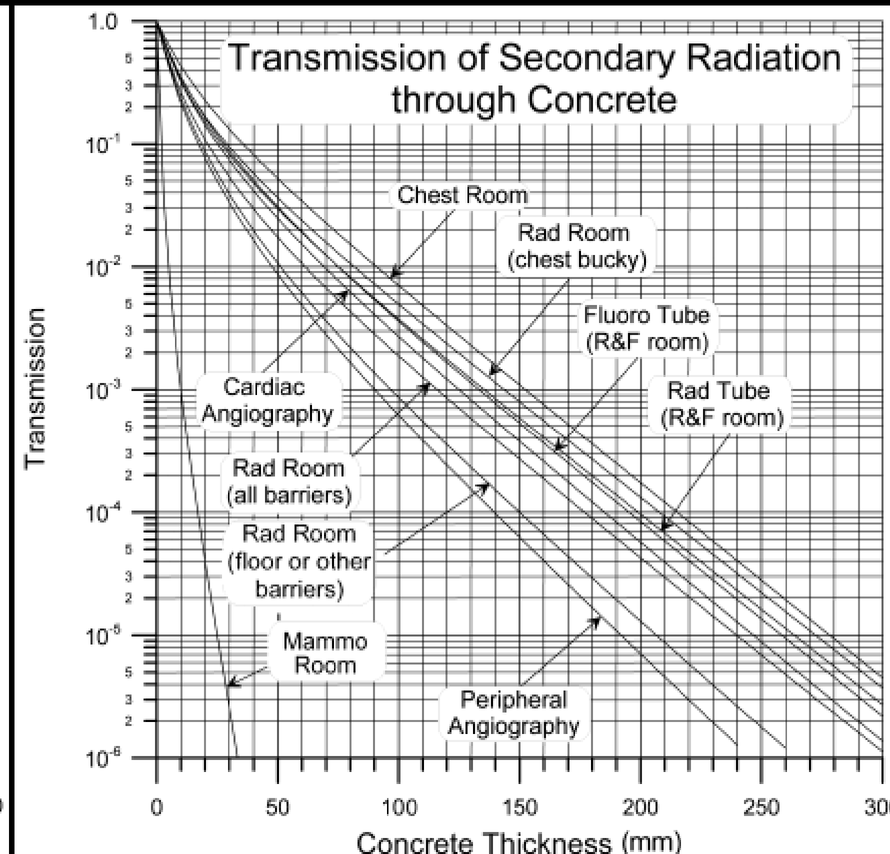
- The barrier transmission factor ($B_{sec}(x_{barrier})$)

$$B_{\sec}(x_{barrier}) = \left(\frac{P}{T}\right)\frac{d_{\sec}^{2}}{K_{\sec}^{1}N}$$

- The thickness of secondary barrier

$$x_{barrier} = \frac{1}{\alpha\gamma}\ln\left[\frac{\left(\frac{NTUK_{\sec}^{1}}{Pd_{\sec}^{1}}\right)+\frac{\beta}{\alpha}}{1+\frac{\beta}{\alpha}}\right]$$


Transmission of Secondary Radiation through Lead
Chest Room
Rad Room (chest bucky)
Fluoro tube (R&F room)
Rad Tube (R&F room)
Cardiac Angiography
Rad Room (all barriers)
Mammo Room
Rad Room (floor or other barriers)
Peripheral Angiography
Transmission
Lead Thickness (mm)


Transmission of Secondary Radiation through Concrete
Chest Room
Rad Room (chest bucky)
Fluoro Tube (R&F room)
Rad Tube (R&F room)
Cardiac Angiography
Rad Room (all barriers)
Rad Room (floor or other barriers)
Mammo Room
Peripheral Angiography
Transmission
Concrete Thickness (mm)

Workload Distribution[b]	Lead			Concrete[c]		
	α (mm^{-1})	β (mm^{-1})	γ	α (mm^{-1})	β (mm^{-1})	γ
30 kVp	3.879×10^{1}	1.800×10^{2}	3.560×10^{-1}	3.174×10^{-1}	1.725	3.705×10^{-1}
50 kVp	8.801	2.728×10^{1}	2.957×10^{-1}	9.030×10^{-2}	1.712×10^{-1}	2.324×10^{-1}
70 kVp	5.369	2.349×10^{1}	5.883×10^{-1}	5.090×10^{-2}	1.697×10^{-1}	3.849×10^{-1}
100 kVp	2.507	1.533×10^{1}	9.124×10^{-1}	3.950×10^{-2}	8.440×10^{-2}	5.191×10^{-1}
125 kVp	2.233	7.888	7.295×10^{-1}	3.510×10^{-2}	6.600×10^{-2}	7.832×10^{-1}
150 kVp	1.791	5.478	5.678×10^{-1}	3.240×10^{-2}	7.750×10^{-2}	1.566
Rad Room (all barriers)	2.298	1.738×10^{1}	6.193×10^{-1}	3.610×10^{-2}	1.433×10^{-1}	5.600×10^{-1}
Rad Room (chest bucky)	2.256	1.380×10^{1}	8.837×10^{-1}	3.560×10^{-2}	1.079×10^{-1}	7.705×10^{-1}
Rad Room (floor or other barriers)	2.513	1.734×10^{1}	4.994×10^{-1}	3.920×10^{-2}	1.464×10^{-1}	4.486×10^{-1}
Fluoroscopy Tube (R&F room)	2.322	1.291×10^{1}	7.575×10^{-1}	3.630×10^{-2}	9.360×10^{-2}	5.955×10^{-1}
Rad Tube (R&F room)	2.272	1.360×10^{1}	7.184×10^{-1}	3.560×10^{-2}	1.114×10^{-1}	6.620×10^{-1}
Chest Room	2.288	9.848	1.054	3.640×10^{-2}	6.590×10^{-2}	7.543×10^{-1}
Mammography Room	2.991×10^{1}	1.844×10^{2}	3.550×10^{-1}	2.539×10^{-1}	1.8411	3.924×10^{-1}
Cardiac Angiography	2.354	1.494×10^{1}	7.481×10^{-1}	3.710×10^{-2}	1.067×10^{-1}	5.733×10^{-1}
Peripheral Angiography[d]	2.661	1.954×10^{1}	5.094×10^{-1}	4.219×10^{-2}	1.559×10^{-1}	4.472×10^{-1}

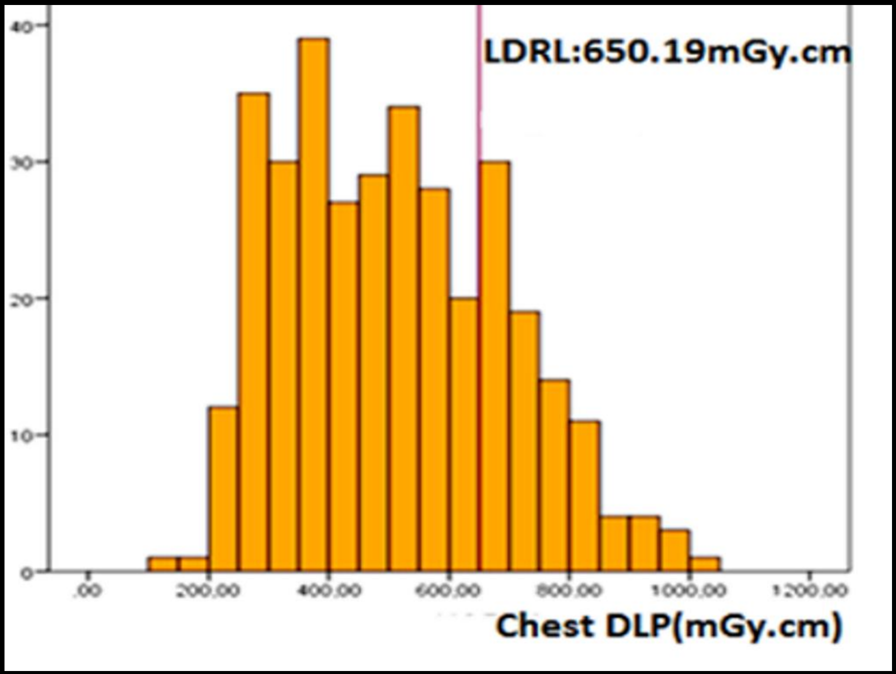
DRL – diagnostic reference level

- DRLs should be set for representative examinations or procedures performed in the local area, country or region where they are applied.
  - NDRL (National DRL): set on the basis of wide scale surveys of the median doses representing typical practice for a patient group (e.g. adults or children of different sizes) at a range of representative healthcare facilities for a specific type of examination or procedure.
  - LDRL (Local DRL): represent the typical local practice at a single large centre or group of healthcare facilities, set as the third quartile of the median doses determined from samples of patients in the different healthcare facilities of the group.

部位	Protocol
Brain	Orbital
Brain	Sella
Brain	IAC
Brain	Seisure
Brain	Trigeminal Neuralgia
Brain	Routine
Brain	MRA (AVM, Cavernoma, SAH, ICH, fistula)
Brain	Tumor
Brain	Orbital
Brain	Sella
Brain	IAC
Brain	Seisure
Brain	Routine
Brain	MRA (AVM, Cavernoma, Infarct)
Brain	Tumor
Brain	Orbital
Brain	Sella
Brain	IAC
Brain	Seisure
Brain	Routine

Setup DRLs

- Define DRL scale (national or local)
- Define exam types
- Define patient group (adult/child, body size/weight)
- Collect dose report data (Dose index, DAP, CTDI, AGD, ...)
- Find the 3rd quarter of the dataset → DRL
- Repeat setup periodically



Dose length product (DLP) distribution for chest CT and local diagnostic reference level(LDRL).
References: Department of Radiology,La Rabta Hospital,Tunis,Tunisia 2015.

英國的 DRL

Public Health England

Guidance

National Diagnostic Reference Levels (NDRLs)

Published 22 January 2016

Contents

1. Introduction

The following tables list the National Diagnostic Reference Levels (NDRLs) for the UK. These values should be considered by employers when settings their local DRLs as required by the Ionising Radiation (Medical Exposure) Regulations 2000 (as amended).

These NDRLs supersede those previously published by the Department of Health.

The NDRLs are based on National Reference Doses (NRDs) previously published by Public Health England (PHE). For details of how these values were obtained please refer to the PHE reports referenced below.

The values for CT examinations are taken from PHE-CRCE-013: Doses from computed tomography (CT) examinations in the UK (2011 Review).

The values for radiography, fluoroscopy and dental radiography are taken from HPA-

National DRLs

- CT:
  - adult and pediatric
- General radiology and Fluoroscopy:
  - individual radiographs on adult patients
  - diagnostic examinations on adult patients
  - interventional procedures on adult patients
  - diagnostic examinations on paediatric patients
- Dental radiography

2.1 Adult CT examinations

Examination	Clinical indication	Scan region/technique	$CTDI_{vol}$ per sequence (mGy)	DLP per complete examination (mGy cm)
Head [1]	Acute stroke	Post fossa	80	
		Cerebrum	60	
		Brain (whole)	60	
		All sequences		970
Cervical spine [1]	Fracture	All sequences	28	600
Chest [2]	Lung cancer	All sequences	12	610
Chest – high resolution [2]	Interstitial lung disease	Axial	4	140
		Helical	12	350
Chest-abdomen-pelvis [2]	Cancer	All sequences	*	1000

About Diagnostic Reference Levels (DRLs)

FAQs for health professionals

Health professionals

- RPOP Home
- Radiology
  - Responsibilities of health professionals
  - Children
  - Pregnant women
  - Cataract

Frequently asked questions by the health professionals

- » What is the purpose of DRLs?
- » How to set DRLs?
- » Who is responsible for setting and updating DRLs?
- » Do DRLs apply to individual patients?
- » What is the difference between national DRLs (NDRLs) and local DRLs (LDRLs)?
- » Are DRLs effective in improving patient radiation protection?

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Right Dose for Accurate Diagnosis: Track Radiation Dose to Patients and Use Diagnostic Reference Levels

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Diagnostic Reference Levels (DRLs)

RSNA
Radiology

July 2017
Volume 284, Issue 1

Original Research
Medical Physics

U.S. Diagnostic Reference Levels and Achievable Doses for 10 Adult CT Examinations

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Address correspondence to P.F.B. (e-mail: pbutler@acr.org).

https://doi.org/10.1148/radiol.2017161911

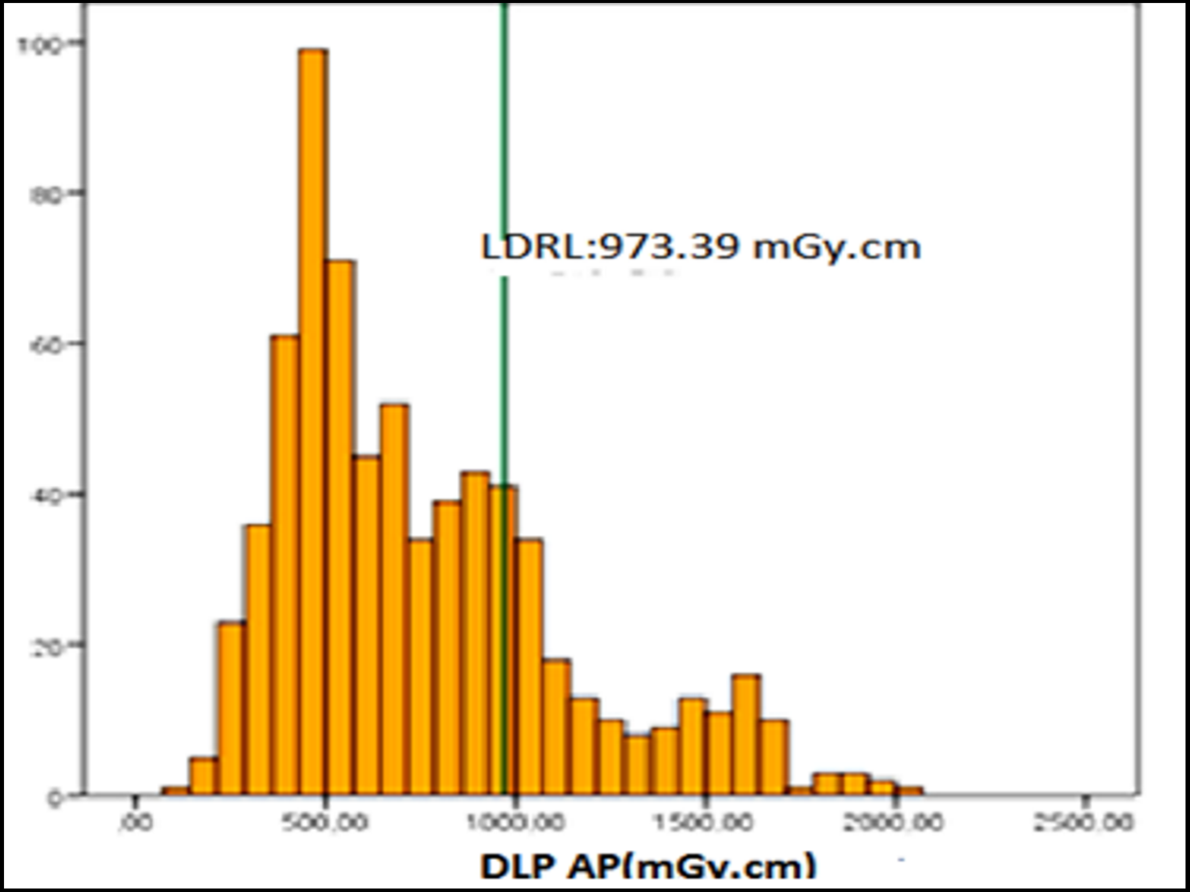
Body Part and Examination	No. of Examinations	Percentage
Head		
CT of head and brain without contrast material	223 908	17.1
Total	223 908	17.1
Neck or cervical spine		
CT of neck with contrast material	33 740	2.6
CT of cervical spine without contrast material	97 586	7.4
Total	131 326	10.0
Chest		
CT of chest without contrast material	159 909	12.2
CT of chest with contrast material	111 898	8.5
CT of chest pulmonary arteries with contrast material	58 986	4.5
Total	330 793	25.2
Abdomen and pelvis		
CT of abdomen and pelvis without contrast material	201 754	15.4
CT of abdomen and pelvis with contrast material	338 056	25.8
CT of abdomen, pelvis, and kidney without contrast material	47 748	3.6
Total	587 558	44.8
Chest, abdomen, and pelvis		
CT of chest, abdomen, and pelvis with contrast material	37 142	2.8
Total	37 142	2.8
Grand total	1 310 727	

Examination	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy-cm)	
	AD	DRL	AD	DRL	AD	DRL
Chest without contrast material	9	12	11	15	334	443
Chest with contrast material	10	13	11	15	353	469
Chest and pulmonary arteries with contrast material	11	14	13	17	357	445
Abdomen and pelvis without contrast material	13	16	15	19	639	781
Abdomen and pelvis with contrast material	12	15	15	18	608	755
Abdomen, pelvis, and kidney without contrast material	12	15	14	19	576	705
Chest, abdomen, and pelvis with contrast material	12	15	14	18	779	947

Body Part, Examination, and Parameter	ACR DIR (2016)[*]	ACR-AAPM (2013)[†]	NCRP (2012)[‡]	Japan (2015)[§]	EU (2014)[‖]	UK (2014)[#]	Ireland (2012)[**]	Australia (2011)[††]	Canada (2016)[‡‡]	The Netherlands (2012)[§§]	Greece (2014)[‖‖]
	DRLs										
Head											
CT of head and brain without contrast material											
$CTDI_{vol}$ (mGy)	56	75	75	85	60	60	58	60	79		67
DLP (mGy-cm)	962			1350	1000	970	940	1000	1302		1055
Neck/cervical spine											
CT of neck with contrast material											
$CTDI_{vol}$ (mGy)	19							30			
DLP (mGy-cm)	563				500			600			
CT of cervical spine with contrast material											
$CTDI_{vol}$ (mGy)	28					28	19				
DLP (mGy-cm)	562				400–600	600	420				
Chest											
CT of chest without contrast material											
$CTDI_{vol}$ (mGy)	12	21	21	15	10	12	9	15	14		14
DLP (mGy-cm)	443			550	400	610	390	450	521		480
CT of chest with contrast material											
$CTDI_{vol}$ (mGy)	13	21	21	15	10	12	9	15	14		14
DLP (mGy-cm)	469			550	400	610	390	450	521		480
CT of chest pulmonary arteries with contrast material											
$CTDI_{vol}$ (mGy)	14					13	13			10	
DLP (mGy-cm)	445					440	430			350	
Abdomen and pelvis											
CT of abdomen and pelvis without contrast material											
$CTDI_{vol}$ (mGy)	16	25	25	20	25	15	12	15	18	15	16
DLP (mGy-cm)	781			1000	800	745	600	700	874	700	760
CT of abdomen and pelvis with contrast material											
$CTDI_{vol}$ (mGy)	15	25	25	20	25	15	12	15	18	15	16
DLP (mGy-cm)	755			1000	800	745	600	700	874	700	760
CT of abdomen, pelvis, and kidney without contrast material											
$CTDI_{vol}$ (mGy)	15					10					
DLP (mGy-cm)	705					460					
Chest, abdomen, and pelvis											
CT of chest, abdomen, and pelvis with contrast material											
$CTDI_{vol}$ (mGy)	15			18			13	30	17		17
DLP (mGy-cm)	947			1300		1000	12	1200	1269		1020

討論

- 請指出 NDRL 與 LDRL 的優缺點



Dose length product (DLP) distribution for abdomen and pelvis CT (AP) and local diagnostic reference level(LDRL). ***References:*** Department of Radiology, Rabta Hospital, Tunis, Tunisia 2015.