# Comprehensive Assessment of Medical Radiation Dose in Taiwan: Trends and Implications

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# Disclosure

- Funding:
  - This study was supported by the Radiation Monitoring Center, Nuclear Safety Commission.
- Conflicts of Interest:
  - The authors declare no conflicts of interest.
- Acknowledgments:
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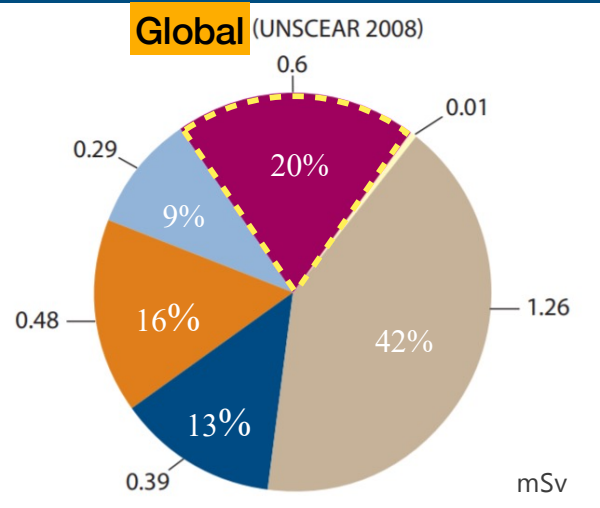
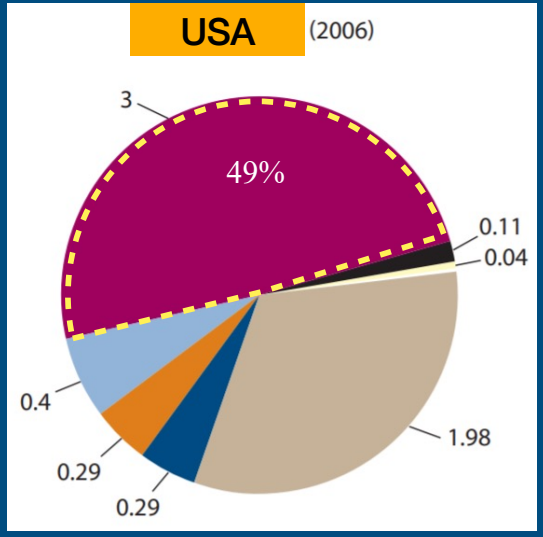
# Why is it necessary to evaluate the Medical Radiation Dose?

**Global** (UNSCEAR 2008)

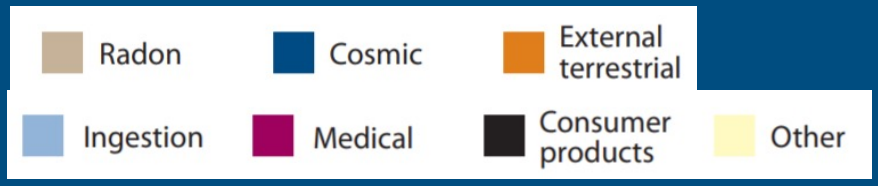



UNSCEAR REPORT, 2008

**USA** (2006)

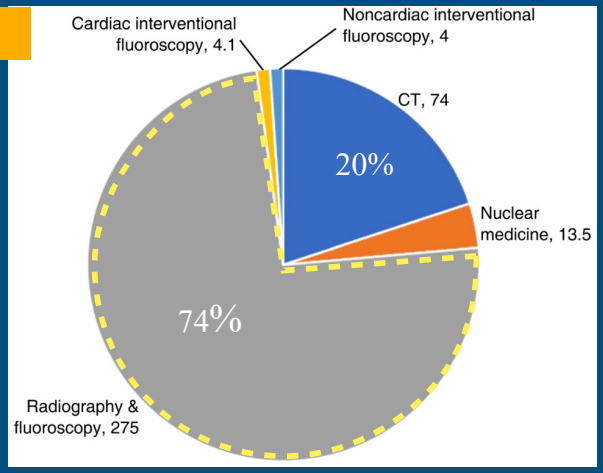



NCRP 160, 2006

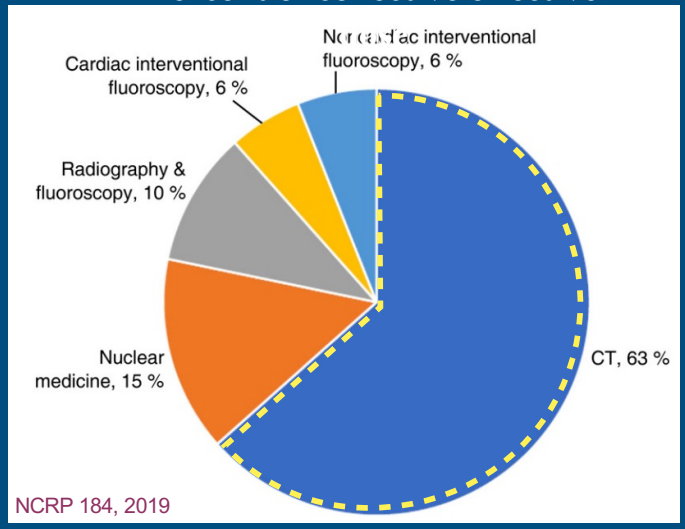



## Number (millions) of medical radiation procedures

**USA**



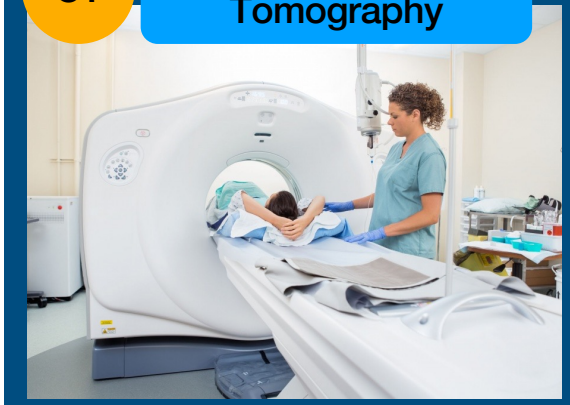

## Percent of collective effective



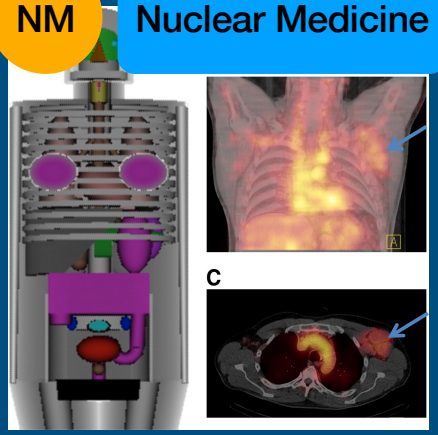

NCRP 184, 2019

# Medical Radiation Exposure of Patients

CT Computed Tomography



NM Nuclear Medicine

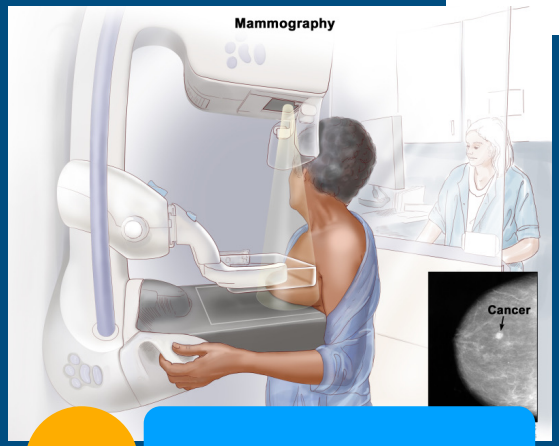



FL Fluoroscopy

CI-FL Cardiac Interventional FL

non-CI-FL Non-Cardiac Interventional FL

Rad. Radiography




MM Mammography

Dent. Dental Radiography

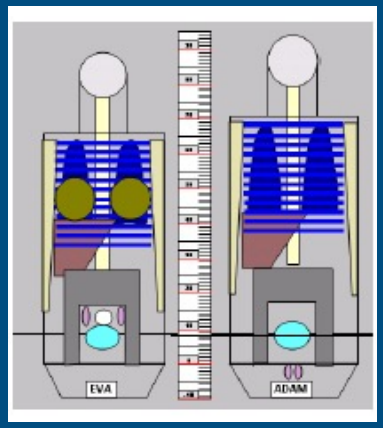
# Dose Index

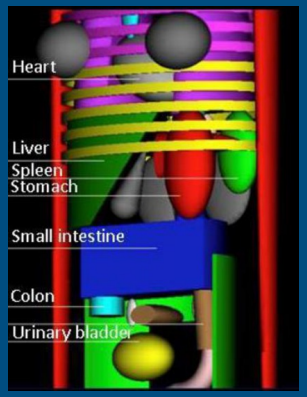


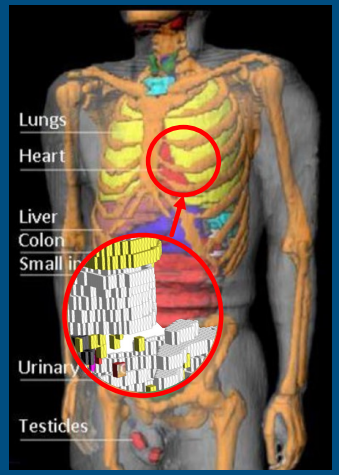

| **Dose Index** | Symbols | Radiography | Mammography | Fluoroscopy Imaging-Guilded FL | CT |
|---|---|---|---|---|---|
| Entrance skin dose | ESD | √ | √ | √ | |
| Average glandular dose | $D_g$ | | √ | | |
| Dose area product | DAP | | | √ | |
| Cumulative dose | CD | | | √ | |
| CT dose index | $CTDI_{vol}$ | | | | √ |
| | DLP | | | | √ |

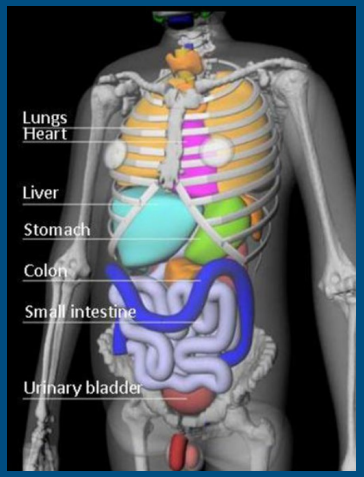
# Anthropomorphic Phantom Used for Simulation

| | Stylized phantoms | Voxel phantoms | Hybrid phantoms |
|---|---|---|---|
| | 1960s | 1980s | 2000s |
| Models | mathematical | tomographic | NURBS/PM |
| Flexible | ✓ | ✗ | ✓ |
| Anatomically realistic | ✗ | ✓ | ✓ |



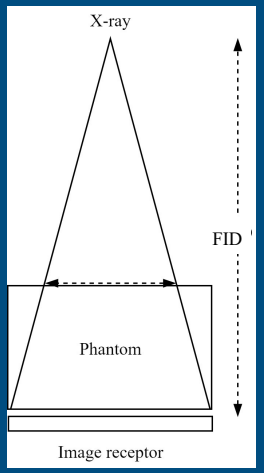



# PCXMC

A Monte Carlo program for calculating patient doses in medical x-ray examinations

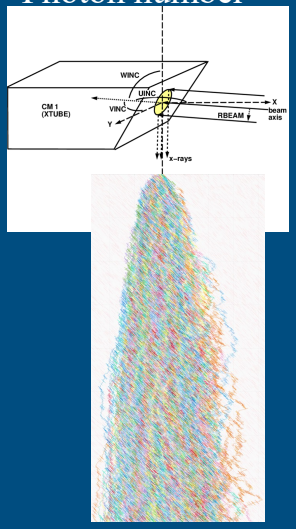
## X ray output

- FID
- Image width
- Image height




## Monte Calo Simulation

- Max energy 150 keV
- Photon number

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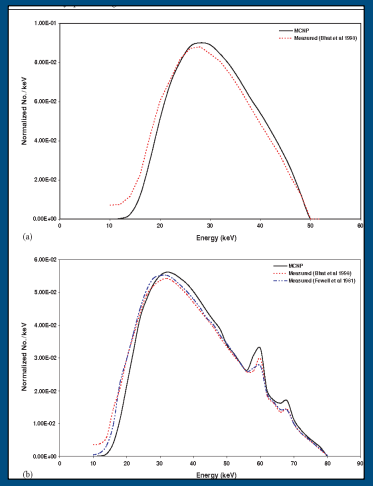
## Spectra

- x-ray tube voltage
- Anode angle
- Total filtration

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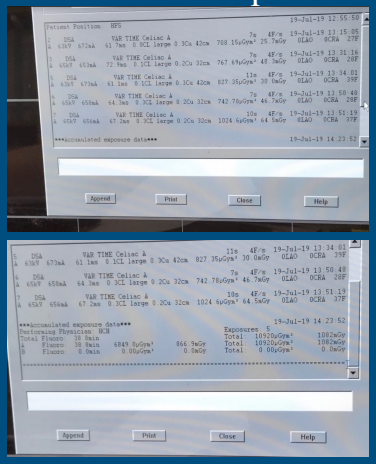
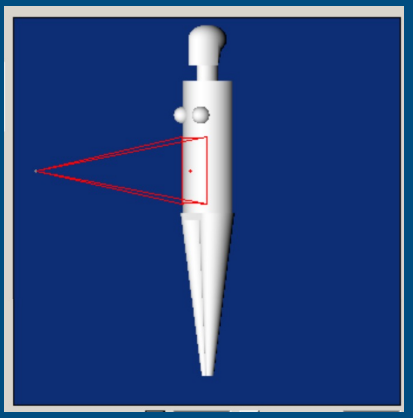
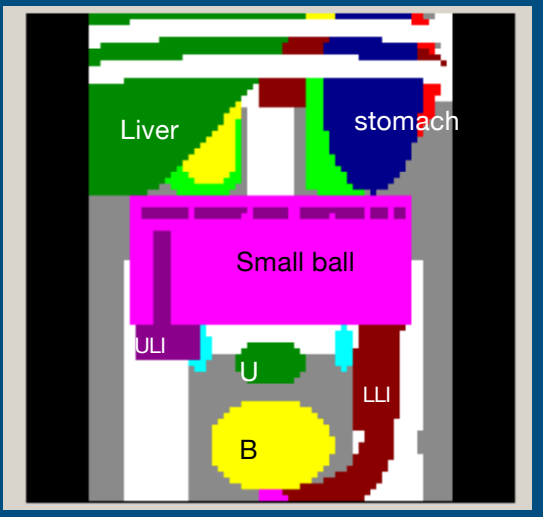
## Parameter input

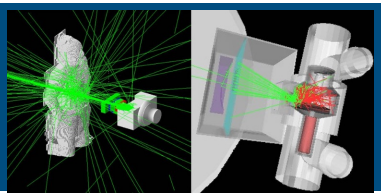
- Incident air kerma
- Entrance exposure
- DAP or KAP
- Exposure-area product
- Current-time product



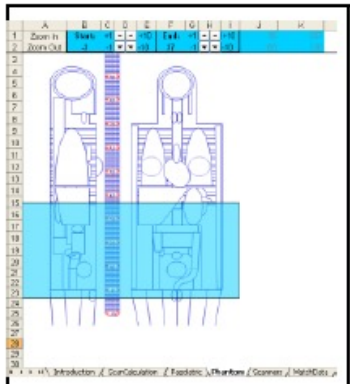




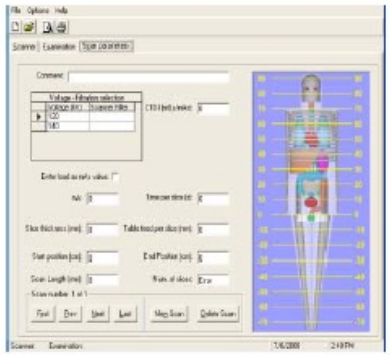
# Dose Assessment in CT
# Existing Software Packages



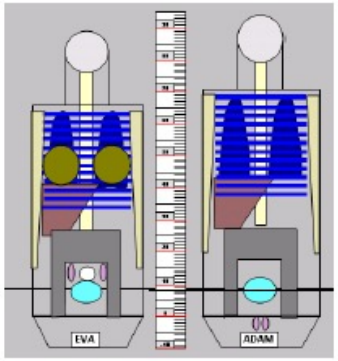




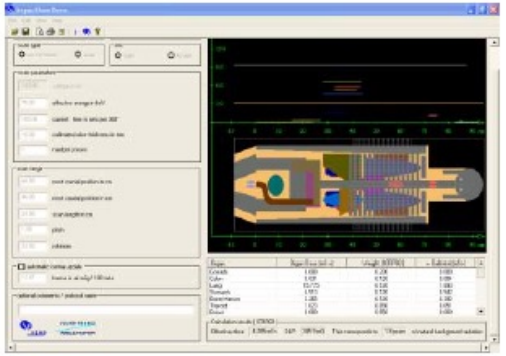
ImPACT



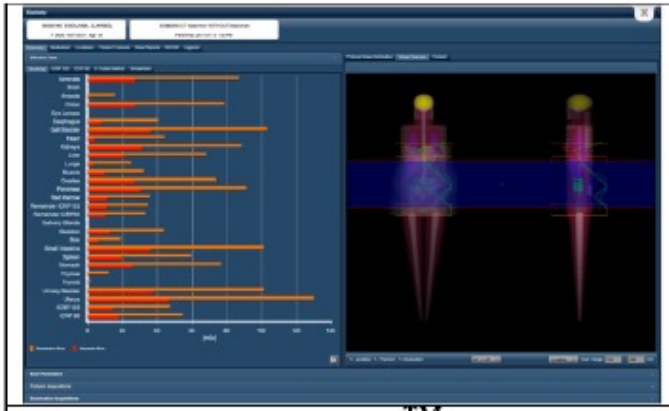
CT Dose



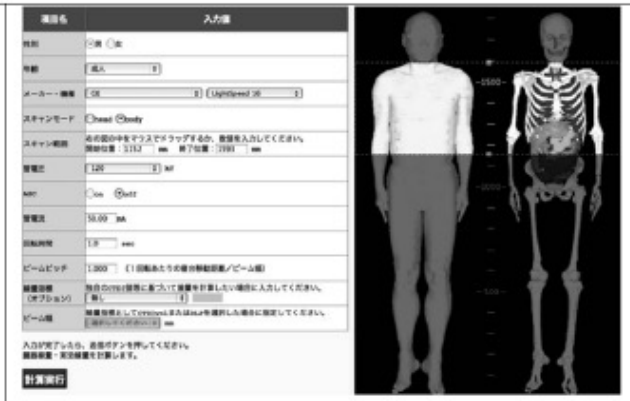

CT-Expo



ImpactDose



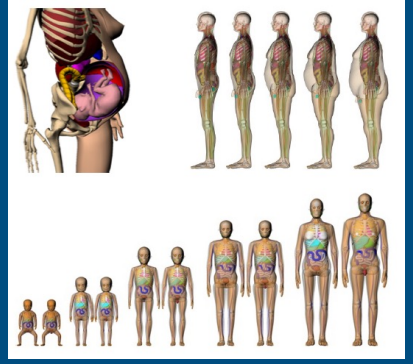
eXposure™



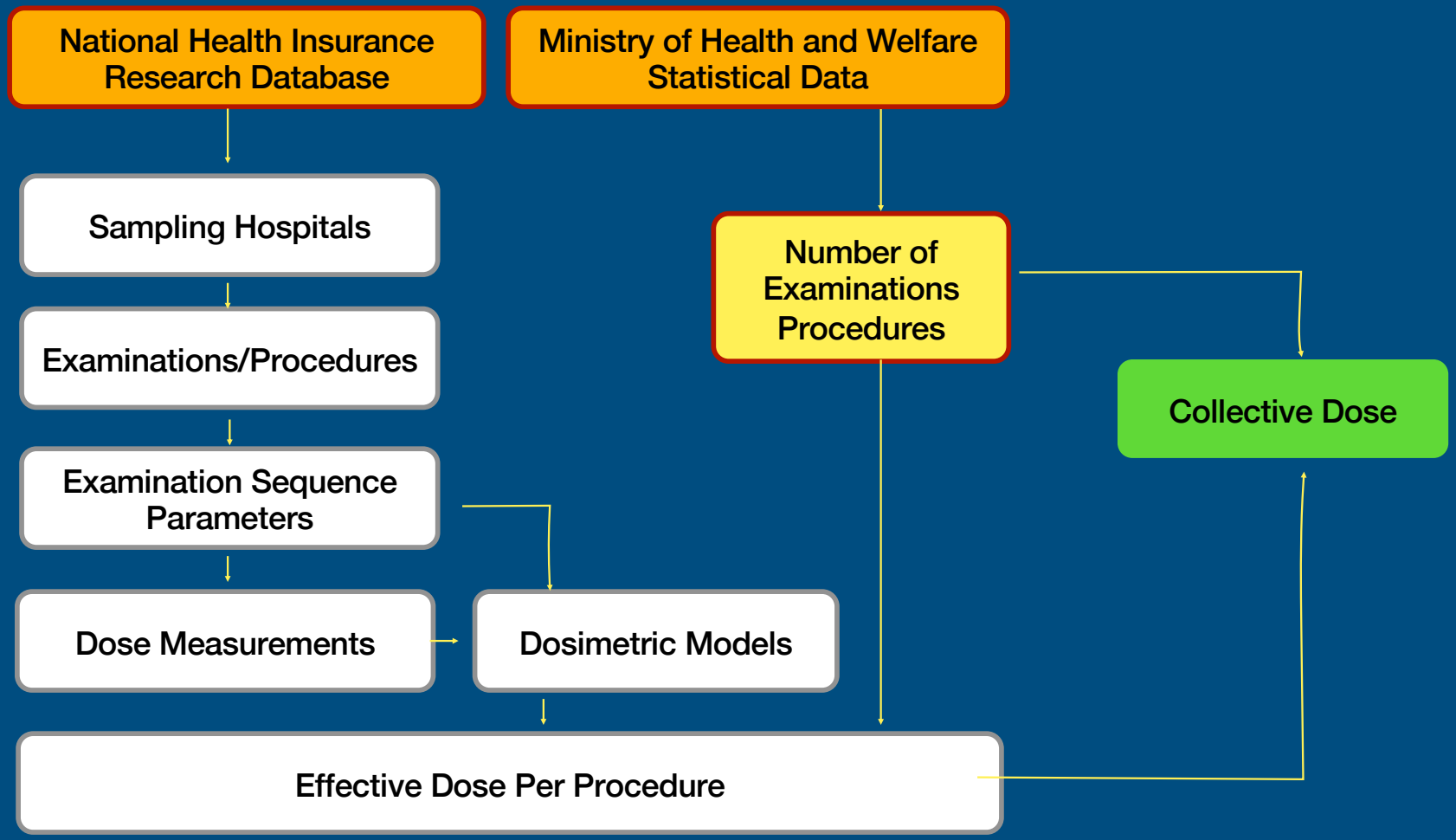
WAZA-ARI

VirtualDose
A product of Virtual Phantoms, Inc.
Monitor Medical Radiation Dose - Increase Patient Safety

VirtualDose™ CT



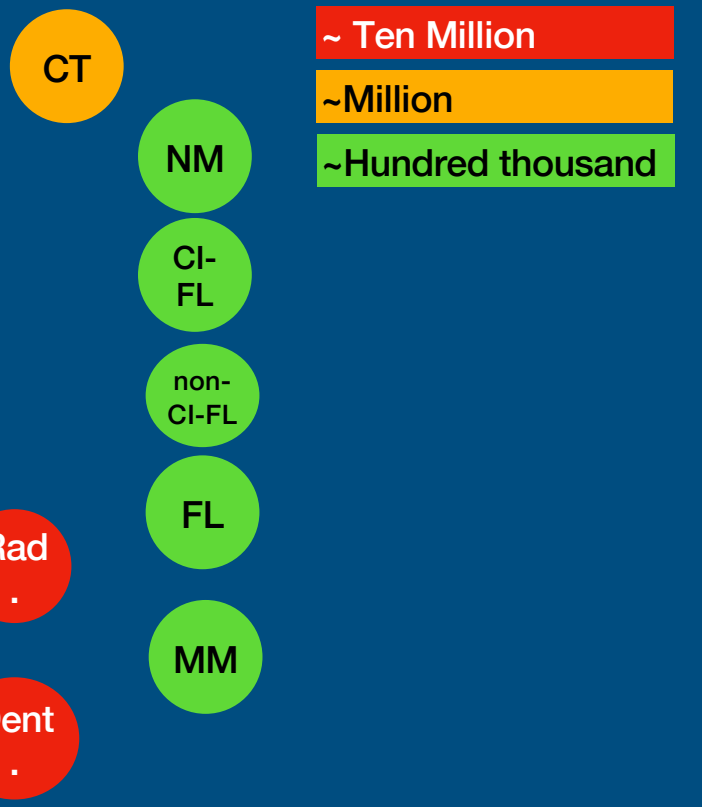
# Study Design



# Medical Exposure Population

National Health Insurance Research Database

| Category | Number of people |
|---|---|
| 1. CT | 2,376,604 |
| 2. Nuclear medicine | 615,285 |
| 3. Cardiac interventional fluoroscopy | 242,859 |
| 4. Non-cardiac interventional fluoroscopy | 237,972 |
| 5. Conventional fluoroscopy | 375,269 |
| 6. Radiography | 27,482,404 |
| 7. Mammography | 239,099 |
| 8. Dental radiography | 12,070,505 |
| Total | 43,639,997 |



# Category-Examination-Sequence-Model-Health Insurance Code

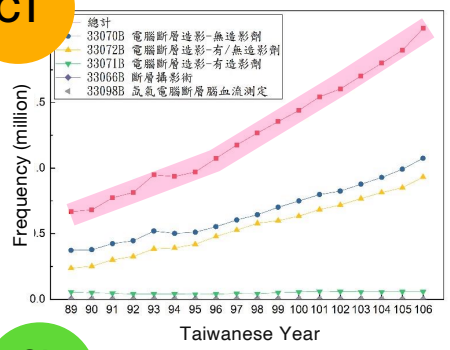
National Health Insurance Research Database

| Category | Number of Examination | Number of Sequence | Dosimetric Models | Health Insurance Codes |
|---|---|---|---|---|
| 1. CT | 11 | 23 | 23 | 105 |
| 2. Nuclear medicine | 6 | 12 | 12 | 70 |
| 3. Cardiac interventional fluoroscopy | 6 | 26 | 6 | 26 |
| 4. Non-cardiac interventional fluoroscopy | 6 | 13 | 11 | 57 |
| 5. Fluoroscopy | 7 | 10 | 8 | 46 |
| 6. Radiography | 7 | 35 | 69 | 25 |
| 7. Mammography | 2 | 4 | 4 | 2 |
| 8. Dental radiography | 6 | 17 | 22 | 61 |
| **Subtotal** | **51** | **140** | **155** | **392** |

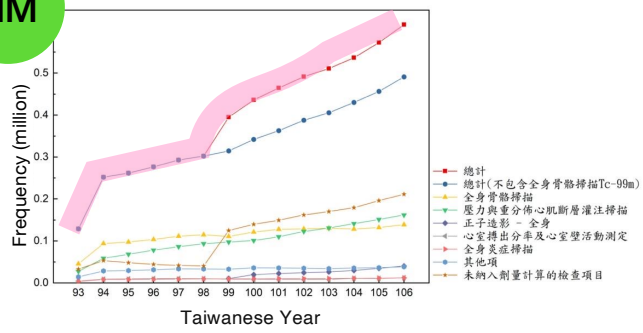
# National Health Insurance Database Data

| Category | Duration | Annual Growth Rate |
|---|---|---|
| 1. CT | 2000~2017 | 6.9 |
| 2. Nuclear medicine | 2004~2017 | 7.9 |
| 3. Cardiac interventional fluoroscopy | 2004~2017 | 3.8 |
| 4. Non-cardiac interventional fluoroscopy | 2000~2017 | 8.2 |
| 5. Conventional fluoroscopy | 2000~2017 | 0.1 |
| 6. Radiography | 2000~2017 | 4.2 |
| 7. Mammography | 2000~2017 | 3.4 |
| 8. Dental radiography | 2000~2017 | 3.3 |

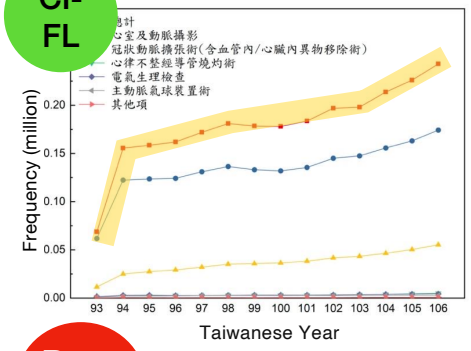
CT



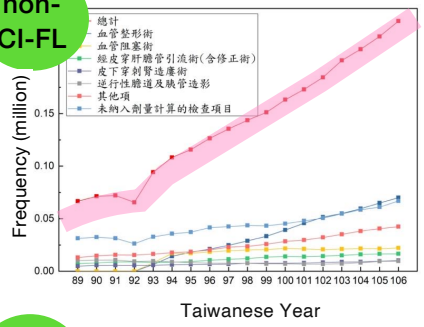

NM



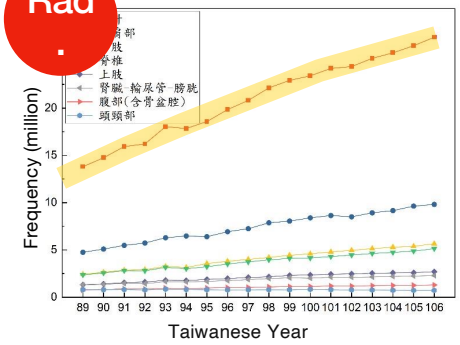

CI-FL



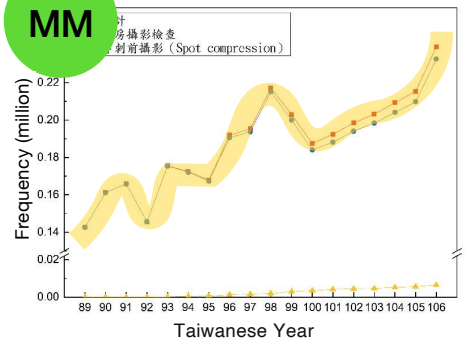

non-CI-FL



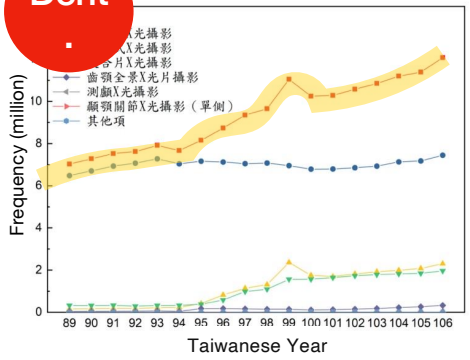

Rad.



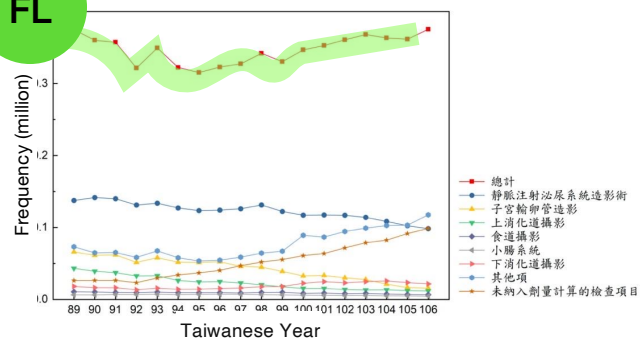

MM




Dent.




FL



# Examination Items: 51

| Category | Ordering of Examination Items | # |
|---|---|---|
| 1. CT | Body Part | 11 |
| 2. Nuclear medicine | Estimated Collective Effective Dose Total from High to Low | 6 |
| 3. Cardiac interventional fluoroscopy | Technical Difficulty Level | 6 |
| 4. Non-cardiac interventional fluoroscopy | Estimated Collective Effective Dose Total from High to Low | 6 |
| 5. Fluoroscopy | Estimated Collective Effective Dose Total from High to Low | 7 |
| 6. Radiography | Body Part | 7 |
| 7. Mammography | Technical Difficulty Level | 2 |
| 8. Dental radiography | Technical Difficulty Level | 6 |

**Category 1: CT**

1. Head
2. Neck
3. Chest
4. Upper Abdomen
5. Abdomen (including pelvis)
6. Chest and Upper Abdomen
7. Chest and Abdomen (including pelvis)
8. Pelvis
9. Lower Extremities
10. Spine
11. Cardiovascular System

**Category 2: Nuclear Medicine**

12. Myocardial Perfusion Imaging with Stress Test
13. Whole-body Bone Scan
14. Whole-body Inflammation Scan
15. Cardiac Function Imaging and Heart Wall Motion Measurement
16. PET Scan - Whole-body
17. Others:
    - Whole-body Tumor Imaging
    - Cardiac Function Testing
    - Parathyroid Imaging
    - I-131 Cancer Follow-up Test
    - Thyroid Scan
    - Renal Function Imaging (dynamic)
    - Renal Function Imaging (99mTc)
    - Parathyroid Imaging

**Category 3: Cardiac Interventional Fluoroscopy**

18. Cardiac Catheterization
19. Coronary Angiography (including stent/heart valve replacement)
20. Endovascular Aneurysm Repair (EVAR)
21. Electrophysiology Study and Ablation
22. Electrical Physiology Testing
23. Others: Whole-body

**Category 4: Non-Cardiac Interventional Fluoroscopy**

24. Percutaneous Angioplasty
25. Vascular Embolization
26. Percutaneous Biliary Drainage (including stenting)
27. Percutaneous Nephrostomy
28. Retrograde Ureteropyelography
29. Others:
    - Percutaneous Vertebroplasty (single level)
    - Four-limb Venography
    - Carotid Angiography (one side)
    - Spinal Venography
    - Percutaneous Vertebroplasty (two or more levels, each additional level)
    - Portal Venography and Embolization

**Category 5. Fluoroscopy**

30. Intravenous Pyelography
31. Lower Gastrointestinal Series
32. Upper Gastrointestinal Series
33. Esophagram
34. Small Bowel Series
35. Hysterosalpingography
36. Others:
    - Barium Swallow
    - Voiding Cystourethrography

**Category 6. Radiography**

37. Head
38. Chest
39. Abdomen (including pelvis)
40. Kidney-ureter-bladder (KUB)
41. Spine
42. Upper Extremities
43. Lower Extremities

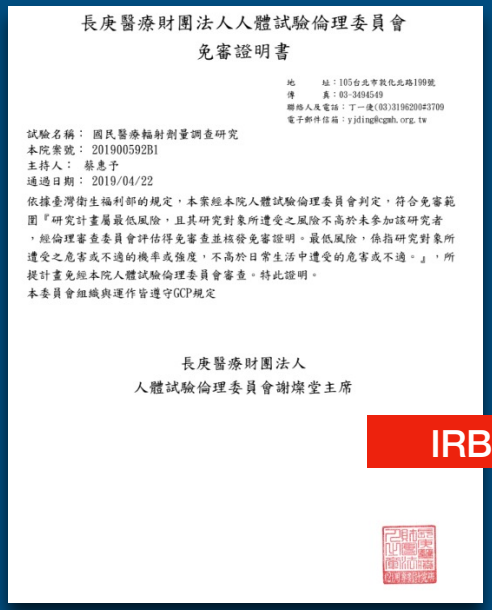
**Category 7. Mammography**

44. Routine Mammography
45. Mammography-guided Stereotactic Biopsy

**Category 8. Dental Radiography**

46. Periapical
47. Bitewing
48. Occlusal
49. Panoramic
50. Cephalometric
51. Temporomandibular Joint (TMJ)

# Data Acquisition/ On-site Measurement



長庚醫療財團法人人體試驗倫理委員會
免審證明書

地　　址：105台北市敦化北路199號
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試驗名稱： 國民醫療輻射劑量調查研究
本院案號： 201900592B1
主持人： 蔡惠予
通過日期： 2019/04/22

依據臺灣衛生福利部的規定，本案經本院人體試驗倫理委員會判定，符合免審範圍『研究計畫屬最低風險，且其研究對象所遭受之風險不高於未參加該研究者，經倫理審查委員會評估得免審查並核發免審證明。最低風險，係指研究對象所遭受之危害或不適的機率或強度，不高於日常生活中遭受的危害或不適。』，所提計畫免經本院人體試驗倫理委員會審查。特此證明。
本委員會組織與運作皆遵守GCP規定

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人體試驗倫理委員會謝燦堂主席

奇美醫療財團法人奇美醫院人體試驗委員會
臨床試驗/研究核准函（新案）

計畫編號：無 / IRB編號: 11005-012
試驗機構：奇美醫療財團法人奇美醫院
計畫主持人：黃美娟/ 協同主持人：蔡惠予
計畫名稱：國民醫療輻射劑量調查研究計畫
計畫書：Version 4, 2021-06-03
受試者同意書: 免除知情同意程序

上述計畫業經本院人體試驗委員會於 2021 年 06 月 10 日審查通過，核准執行期限為一年(自 2021 年 06 月 11 日至 2022 年 06 月 10 日)，應接受本會之監督，主持人於研究期間所獲得受試者的資料應負保密責任。如試驗無法於核准期限內完成，請於屆期前 2 個月繳交期中報告並申請展延試驗期限，經本會審查核准後方可繼續進行。

**Clinical Trial/Research Approval Letter (New Application)**

Protocol No.: None / IRB Serial No.: 11005-012
Institute: Chi Mei Medical Center
Principal Investigator: Mei-Lan Huang / Co- Investigator(s): Hui-Yu Tsai
Protocol Title: Investigation on Medical Radiation Exposure of the Taiwan Population
Protocol Version and Date: Version 4, 2021-06-03
Informed Consent Form: Exemption from informed consent process

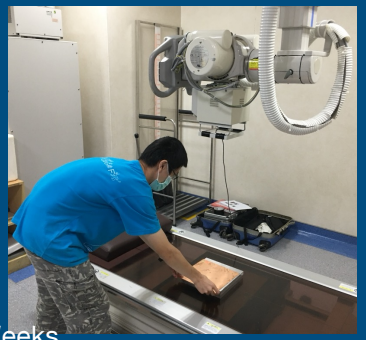
The study was approved by the Institutional Review Board of the Chi Mei Medical Center on 10 Jun 2021 and will be monitored by the IRB. The duration of this approval is one year (from 11 Jun 2021 until 10 Jun 2022). Investigators are responsible for keeping the subject information ... required to submit an Annual Report 2 months before ... roval in order for the research to proceed.

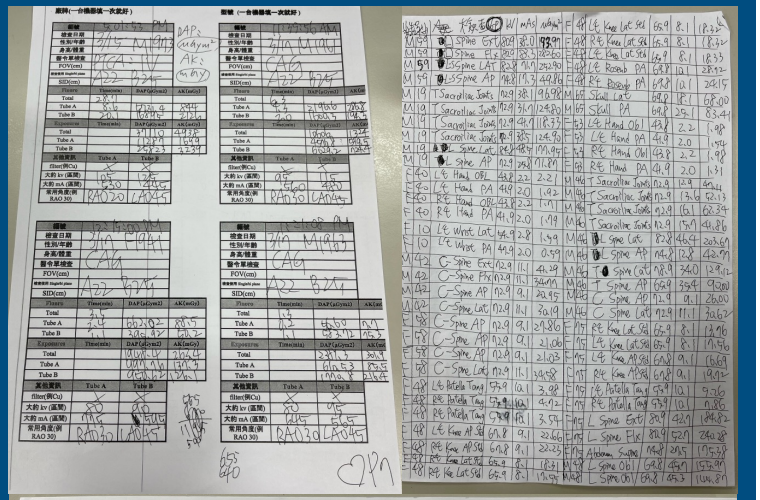
人體試驗委員會
主任委員：邢 中 熹

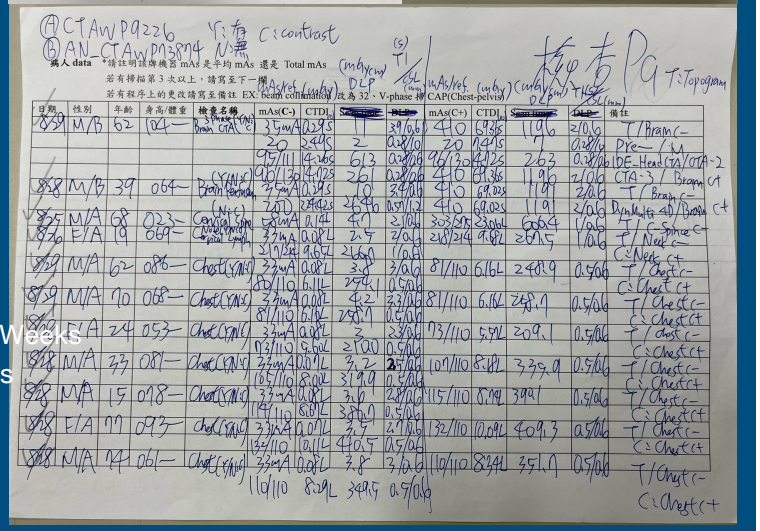
Yours sincerely,
Hsing, Chung-Hsi
Hsing, Chung-Hsi M.D.
Chairman
Institutional Review Board,
Chi Mei Medical Center, Tainan, Taiwan

2021 年 06 月 10 日

IRB Approval







(1) Determining Target Hospitals
(2) Contacting and Visiting to Explain the Project Details, Taking 2 to 3 Weeks
(3) Completing the Administrative Process for Hospital Sampling Consent, Taking 4 to 8 Weeks
（4）Data acquisition at the Hospital, Taking 3 to 4 Weeks

| Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 |
|---|---|---|---|---|---|

# Sampling Hospitals' Levels and Regional Distribution

| Hospital Level | Area Distribution | | | | Subtoal |
|---|---|---|---|---|---|
| | Northern | Central | Southern | Eastern | |
| 1) Medical Center | 4 | 3 | 2 | 0 | 9 |
| 2) Regional Hospital | 4 | 1 | 2 | 1 | 8 |
| 3) District Hospital | 1 | 5 | 1 | 0 | 7 |
| 4) Primary Care Clinic | 1 | 0 | 0 | 0 | 1 |
| Subtotal | 10 | 9 | 5 | 1 | 25 |
| Percentage | 40% | 36% | 20% | 4% | |

| Taiwan | Northern | Central | Southern | Eastern |
|---|---|---|---|---|
| Hospital Regional Distribution | 33% | 29% | 34% | 4% |

| Code | Hospital level | Region |
|---|---|---|
| A | Regional | Northern |
| B | District | Central |
| C | Regional | Southern |
| D | Primary Care Clinic | Northern |
| E | District | Central |
| F | Medical Center | Northern |
| G | Regional | Northern |
| H | Regional | Eastern |
| I | Regional | Northern |
| J | Regional | Southern |
| K | Medical Center | Central |
| L | Regional | Central |
| M | Medical Center | Northern |
| N | District | Northern |
| O | District | Southern |
| P | Medical Center | Central |
| Q | Medical Center | Southern |
| R | Medical Center | Southern |
| S | Medical Center | Central |
| T | District | Central |
| U | Regional | Northern |
| V | Medical Center | Northern |
| W | Medical Center | Central |
| X | Medical Center | Central |
| Y | District | Central Central |

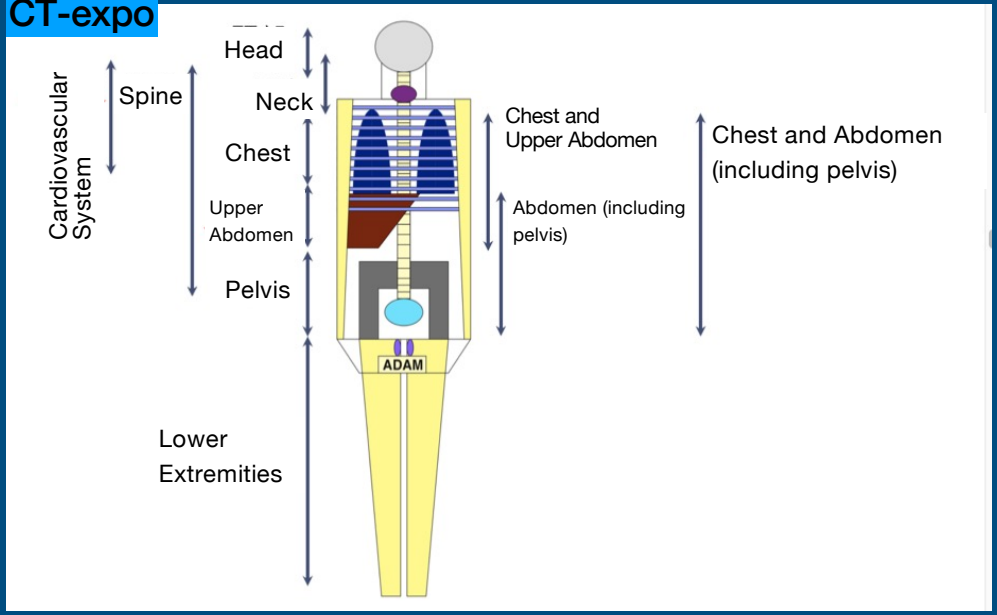
# Distribution of Hospitals Sampled for Medical Radiation Categories

| Category | Number of Hospitals | Hospital Codes | Area Distribution | | | |
|---|---|---|---|---|---|---|
| | | | Northern | Central | Southern | Eastern |
| 1. CT | 13 | A.B.F.G.H.I.J.L.N.O.P.U.V | 7 | 3 | 2 | 1 |
| 2. Nuclear medicine | 7 | A.G.I.J.P.Q.S | 3 | 2 | 2 | |
| 3. Cardiac interventional fluoroscopy | 8 | A.B.G.J.P. Q.U.W | 4 | 2 | 2 | |
| 4. Non-cardiac interventional fluoroscopy | 11 | A.B.G.H.I.J.O.P.R.S.U | 4 | 3 | 3 | 1 |
| 5. Fluoroscopy | 15 | A.B.E.F.G.H.I.J.L.M.O.P.R.S.U | 6 | 5 | 3 | 1 |
| 6. Radiography | 13 | A.B.G.H.I.J.K.L.N.O.P.R.U | 5 | 4 | 3 | 1 |
| 7. Mammography | 21 | A.B.C.E.G.H.I.J.K.L.M.N.O.P.R.Q.R.S.T.U.X.Y | 6 | 9 | 5 | 1 |
| 8. Dental radiography | 8 | B.D.F.I.J.M.P.U | 5 | 2 | 1 | |

# Dosimetric Models

| Category | Items / Parts | Sequence | Dosimetric Models | Methods | |
|---|---|---|---|---|---|
| 1. CT | 11 | 23 | 23 | MC software | CT-expo |
| 2. Nuclear medicine | 6 | 12 | 12 | Dose coefficient | ICRP 106 |
| 3. Cardiac interventional fluoroscopy | 6 | 26 | 6 | MC software | PCXMC |
| 4. Non-cardiac interventional fluoroscopy | 6 | 13 | 11 | MC software | PCXMC |
| 5. Conventional fluoroscopy | 7 | 10 | 8 | MC software | PCXMC |
| 6. Radiography | 7 | 35 | 69 | MC software | PCXMC |
| 7. Mammography | 2 | 4 | 4 | Acquisition data | |
| 8. Dental radiography | 6 | 17 | 22 | MC software | PCXMC |
| Subtotal | 51 | 140 | 155 | | |

**CT-expo**




| Tissue | Publication 26 (ICRP 1977) | Publication 60 (ICRP 1990) | Publication 103 (ICRP 2007) |
|---|---|---|---|
| Active marrow | 0.12 | 0.12 | 0.12 |
| Breast | 0.15 | 0.05 | 0.12 |
| Colon wall | | 0.12 | 0.12 |
| Lungs | 0.12 | 0.12 | 0.12 |
| Stomach wall | | 0.12 | 0.12 |
| Remainder tissues | 0.30 | 0.05 | 0.12 |
| Gonads | 0.25 | 0.20 | 0.08 |
| Thyroid | 0.03 | 0.05 | 0.04 |
| Esophageal wall | | 0.05 | 0.04 |
| Liver | | 0.05 | 0.04 |
| Urinary bladder wall | | 0.05 | 0.04 |
| Skeletal endosteum | 0.03 | 0.01 | 0.01 |
| Brain | | | 0.01 |
| Salivary glands | | | 0.01 |
| Skin | | 0.01 | 0.01 |
| Total | 1.00 | 1.00 | 1.00 |

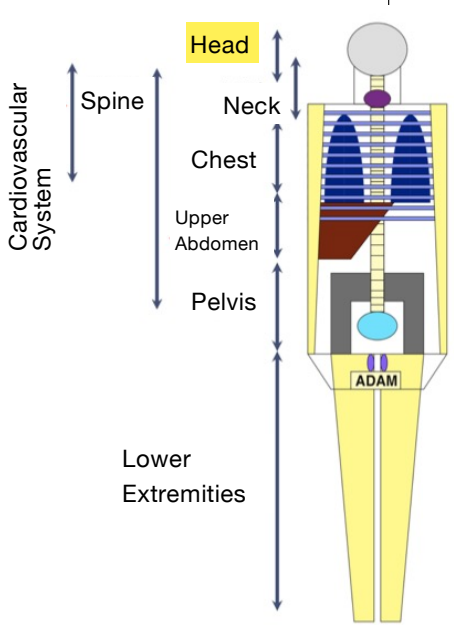
**Equivalent dose**

$$H_T = \sum_R w_R D_{T,R}$$

**Effective dose**

$$E = \sum_T w_T H_T$$

# Effective dose & Collective dose

| Parameters | Vriables |
|---|---|
| $n$ : Number of examinations in a hospital<br>$N$ : Number of examinations in the National Health Insurance database<br>$E$ : Effective dose<br>$S$ : Collective effective dose<br>$R$ : Proportion of total collective effective dose<br>$P$ : Total population of Taiwan<br>$E_{TW}$ : Average annual dose per capita in Taiwan | $i$ Sampling hospital<br>$j$  <br>$k$ Head's Examination sequence<br>• brain<br>• sinus<br>• facial bone<br>• Temporal bones |

$$E_{ij} = \frac{\sum_k n_{ijk} E_{ijk}}{\sum_k n_{ijk}}$$

$$E_j = \frac{\sum_i n_{ij} E_{ij}}{\sum_i n_{ij}} \qquad N_j = \sum_k N_{jk}$$

$$S = \frac{\sum_j N_j E_j}{R}$$

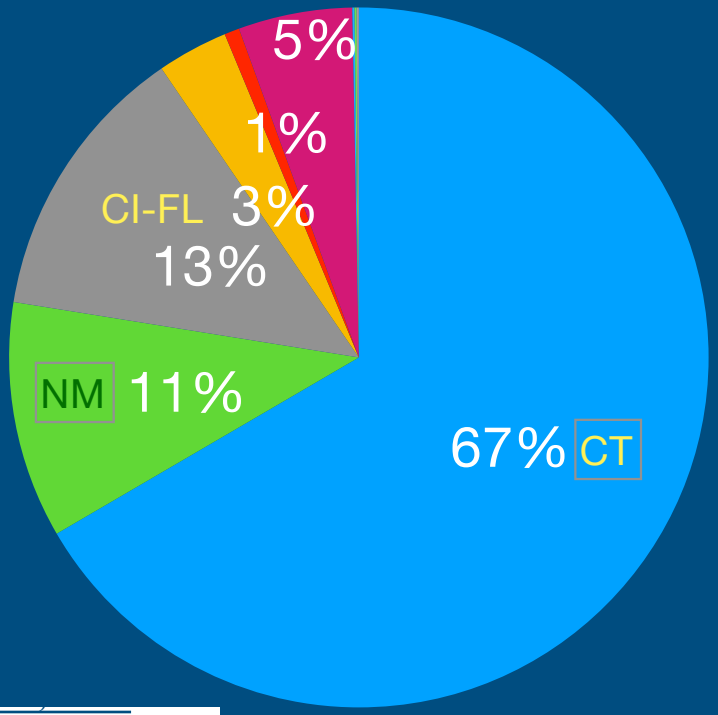
$$E_{TW} = \frac{S}{P}$$

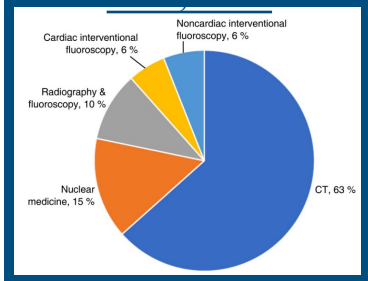
# Effective Dose for CT Examination

CT

| CT examinations | Hospital # | Sampling # | E (60) | E (103) | Medical Radiation population | S (60) | S (103) |
|---|---|---|---|---|---|---|---|
| Head | 13 | 4,510 | 2.07 | 1.63 | 814,810 | 1,687 | 1,328 |
| Neck | 11 | 717 | 7.43 | 8.18 | 139,308 | 1,035 | 1,140 |
| Chest | 12 | 2,971 | 7.4 | 8.01 | 354,363 | 2,622 | 2,838 |
| Upper Abdomen | 11 | 3,761 | 15.96 | 15.92 | 232,225 | 3,706 | 3,697 |
| Abdomen (including pelvis) | 8 | 1,408 | 22.01 | 19.43 | 492,793 | 10,846 | 9,575 |
| Chest and Upper Abdomen | 2 | 260 | 13.4 | 15.37 | 125,268 | 1,679 | 1,925 |
| Chest and Abdomen (including pelvis) | 4 | 183 | 24.54 | 22.89 | 22,187 | 544 | 508 |
| Pelvis | 6 | 344 | 18.3 | 16.38 | 30,945 | 566 | 507 |
| Lower Extremities | 4 | 72 | 7.2 | 8.1 | 35,989 | 259 | 292 |
| Spine | 9 | 224 | 4.48 | 5.13 | 47,022 | 211 | 241 |
| Cardiovascular System | 5 | 246 | 7.88 | 10.27 | 26.474 | 209 | 272 |
| | | | | | Sub-total | 23,364 | 22,323 |

# Medical Radiation Dose of Taiwan's Population




| Category | Annual Effective Dose Per Capita# (mSv) | | |
|---|---|---|---|
| | ICRP 60 | (%) | ICRP 103 |
| 1. CT | 1.02 | 67% | 0.98 |
| 2. Nuclear medicine | 0.16 | 11% | — |
| 3. Cardiac interventional fluoroscopy | 0.19 | 13% | 0.20 |
| 4. Non-cardiac interventional fluoroscopy | 0.05 | 3.3% | 0.05 |
| 5. Fluoroscopy | 0.01 | 0.7% | 0.01 |
| 6. Radiography | 0.08 | 5.3% | 0.08 |
| 7. Mammography | 0.0014 | 0.1% | 0.003 |
| 8. Dental radiography | 0.0012 | 0.1% | 0.005 |
| | 1.51 | 100% | |

# Based on the estimate of the collective effective dose divided by the total population of Taiwan (23,571,227)

(ver. 2022Jun)

# Comparison of Effective Dose per Capita

| Examination | Taiwan | NCRP- 184 | NCRP 160 |
|---|---|---|---|
| | 2017 | 2016 | 2006 |
| CT | 1.02 | 1.45 | 1.46 |
| Nuclear Medicine | 0.16 | 0.41 | 0.73 |
| Cardiac Interventional Fluoroscopy | 0.19 | 0.13 | 0.23 |
| Non-Cardiac Interventional Fluoroscopy | 0.05 | 0.12 | 0.2 |
| Fluoroscopy | 0.01 | 0.2 | 0.3 |
| Radiography | 0.08 | | |
| Mammography | 0.001 | | |
| Dental Radiography | 0.001 | | |
| Effective dose (mSv) | **1.51** | **2.33** | **2.92** |

# Conclusion

Taiwan population: 23.57 million
Effective dose per capital: 1.51 mSv

392

National Health Insurance Research Database

Ministry of Health and Welfare Statistical Data

14.45 million

25

Sampling Hospitals

140

Examinations/Procedures

Examination Sequence Parameters

Number of Examinations Procedures

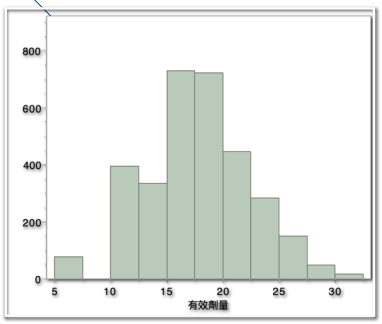
Collective Dose

155

Dose Measurements

Dosimetric Models

Effective Dose Per Procedure

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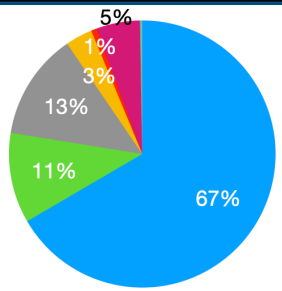
| | 1.51 | 100% | |



# Research Team

4 PIs
23 members

# Comprehensive Assessment of Medical Radiation Dose in Taiwan: Trends and Implications

## Thank you.

**Hui-Yu Tsai, PhD**

**Professor**
**Dept. of Nuclear Engineering and Science**
**National Tsing Hua University**

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