



# 방사선비상시 내부피폭선량평가

한국원자력의학원  
국가방사선비상진료센터  
보건물리팀  
하 위 호



한국원자력의학원  
국가방사선비상진료센터

# 목 차

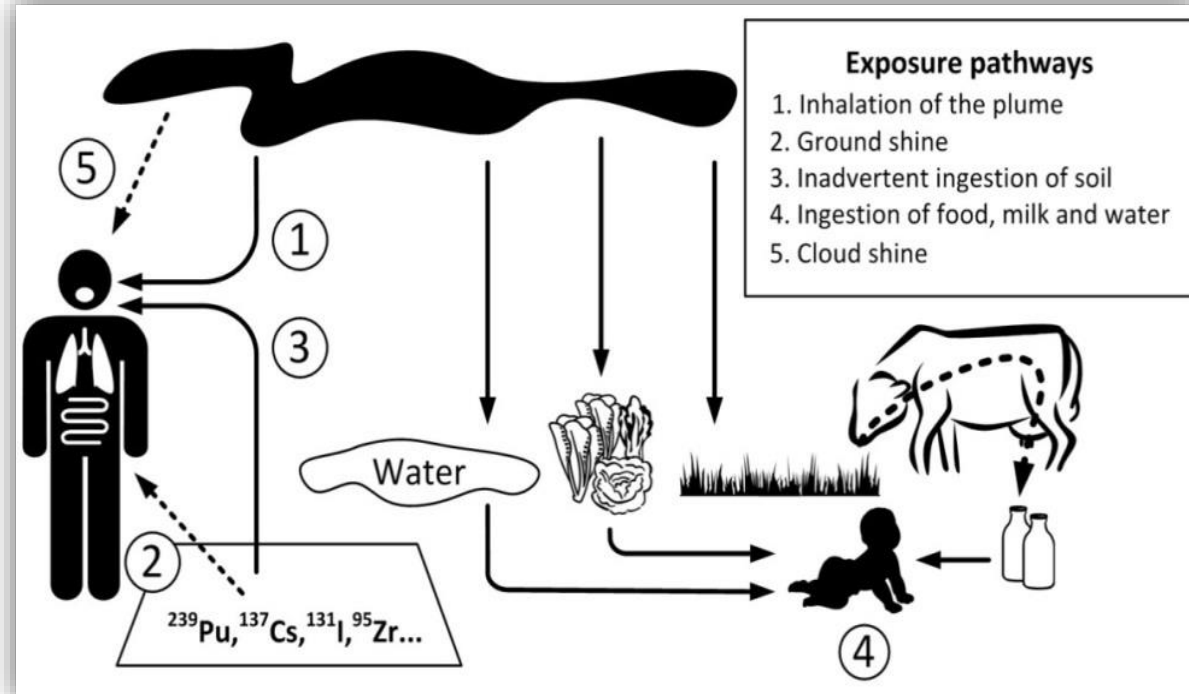
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1. 내부피폭 사고사례
2. 비상시 내부피폭선량평가기술
3. 의학원 내부피폭 평가시스템 소개

# 내부피폭 사고사례

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# 체르노빌/후쿠시마 원전사고





# 영국 Po-210 테러



**Polonium tests at Arsenal FC**  
The Mail on Sunday 3/12/06

**Stop the aircraft scare stories - Hundreds**  
the risk is remote, doctors say **hunted in**

**Moves to allay health fears alert over**  
after radiation **radiation**  
traces found  
Telegraph 25/11/06

**Thousands in stampede for poisoned spy radiation tests**  
Daily Express 26/11/06

**Radiation Poisoned spy:**  
risk in bar **33,000 people**  
may be at risk  
London News 8/12/06  
Daily Express 30/11/06

**100 tested for spy death radiation**  
Sunday Times 26/11/06

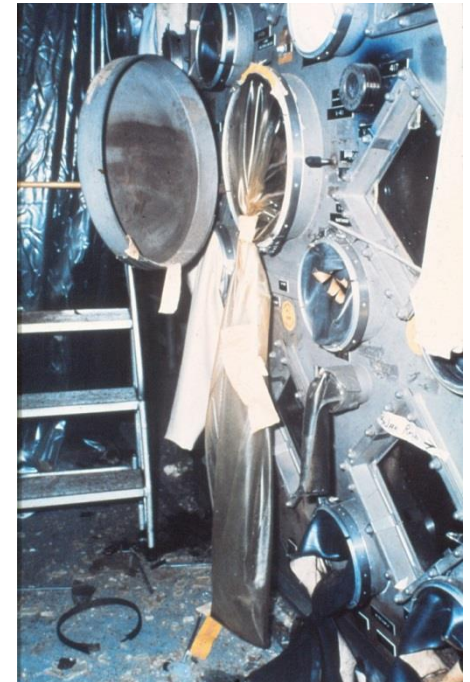
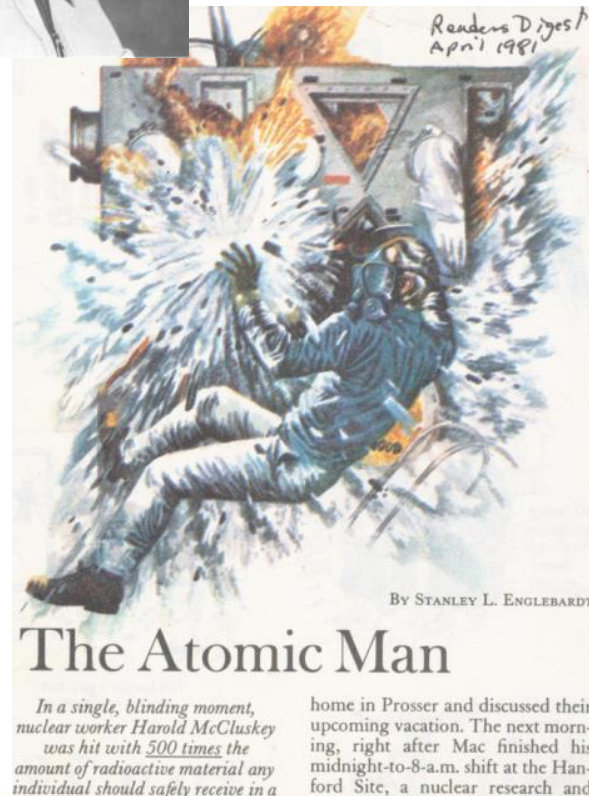
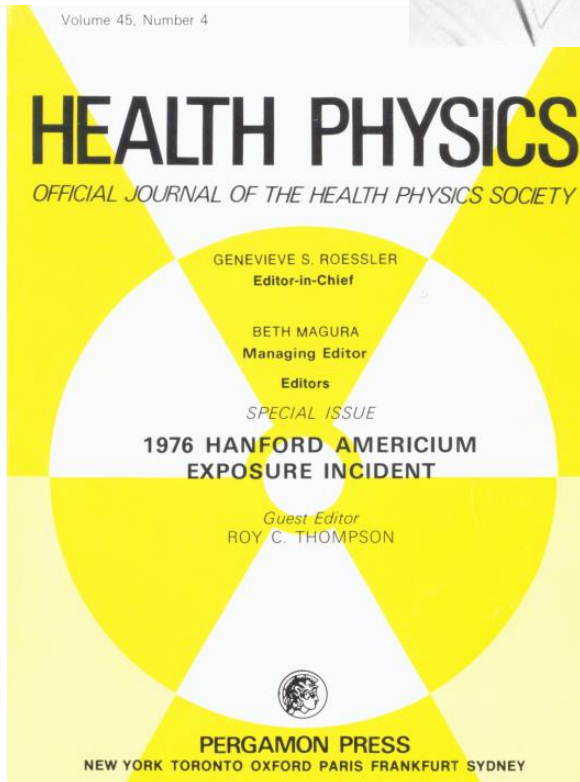
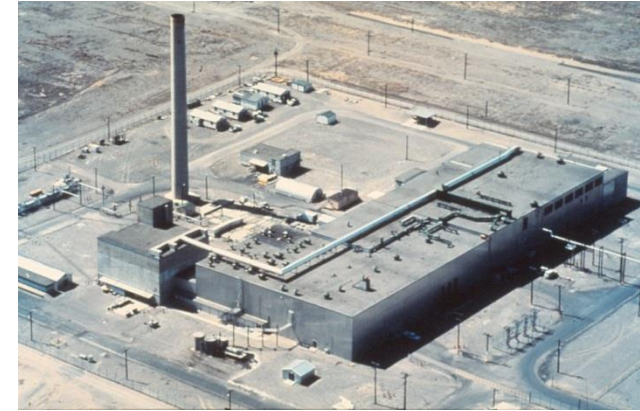
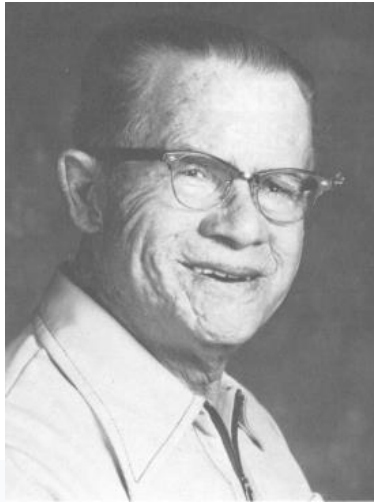
# 고이아니아 방사선사고

| Case age, sex | Death (days after initial exposure) | Cause of death                                 | Cs burden (MBq) | Estimated dose by CA, Gy |
|---------------|-------------------------------------|--|-----------------|--------------------------|
| LNF – 6 y, F  | 29                                  | Diffuse haemorrhage of multiple organs; sepsis | 1677            | 5.0 – 7.3                |
| IBS, 22 y, M  | 34                                  | APE and bilateral bronchopneumonia; sepsis     | 60              | 4.0 – 5.0                |
| MGF, 38 y, F  | 34                                  | Diffuse haemorrhage of multiple organs; sepsis | 34              | 4.8 – 6.8                |
| AAS, 18 y, M  | 35                                  | Lungs collapse and lobar pneumonia; sepsis     | 120             | 4.5 – 6.5                |





# Hanford Am Accident



# 내부피폭 방사선사고 영향

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- ◆ 종사자/일반인 내부피폭 가능
- ◆ 사회혼란 야기 (ex. 식품중 방사능, 방사능비, etc.)
- ◆ 내부피폭 확인시 추적관찰 또는 의료개입 요구
- ◆ 체계적인 사후 내부피폭선량평가 시스템 요구



# 비상시 내부피폭선량 평가기술

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# 내부피폭선량평가 방법



직접측정법



간접측정법

$$I = \frac{M}{m(t)}$$

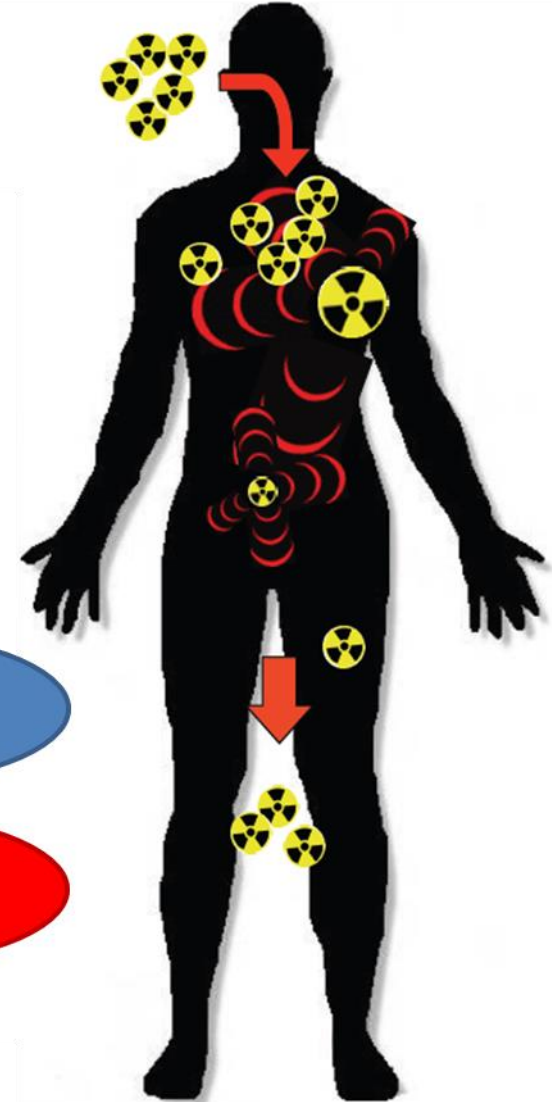
섭취량(Intake) 평가

$$E = I \times e$$

예탁유효선량(E(50)) 평가

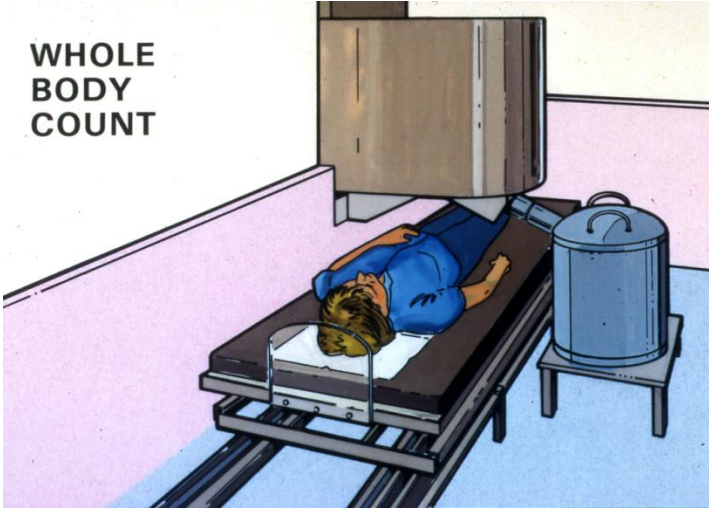
Biokinetic model

Dosimetric model

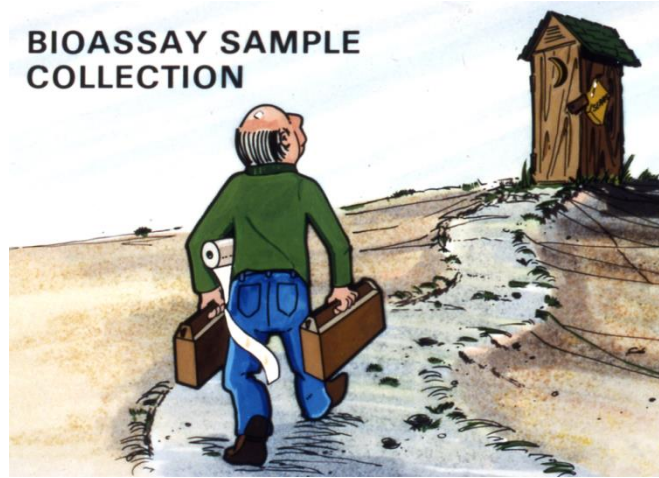


# 내부피폭선량평가 방법

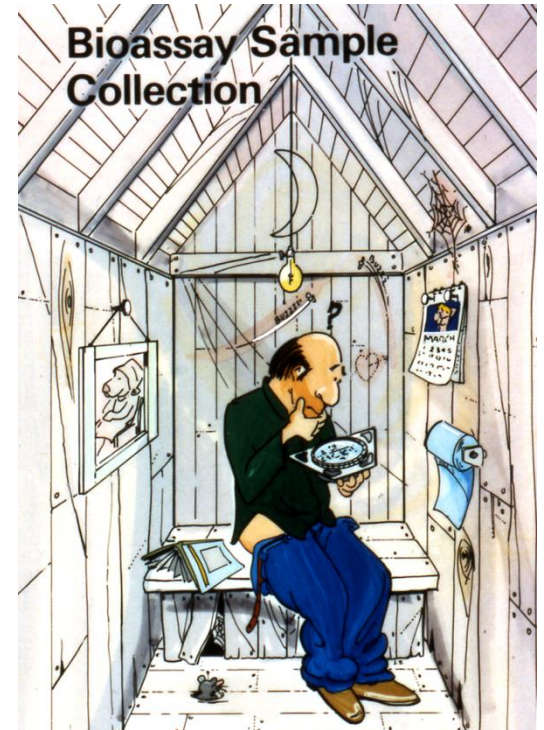
WHOLE  
BODY  
COUNT



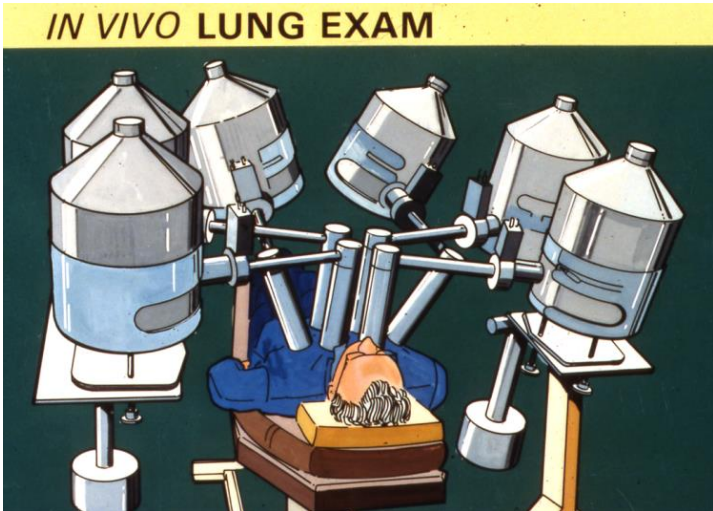
BIOASSAY SAMPLE  
COLLECTION



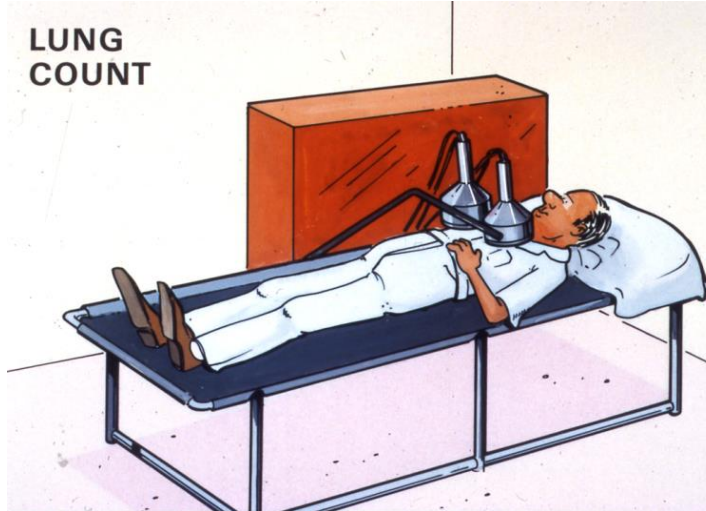
Bioassay Sample  
Collection



IN VIVO LUNG EXAM



LUNG  
COUNT





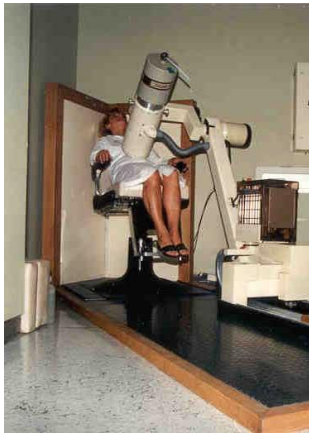
# 방사성 핵종별 측정 방법

| Radionuclide (absorption type) <sup>1</sup> |                   | Radiation type emitted | Rapid screening method                     | Primary monitoring method                            |
|---|-------------------|------------------------|--|--|
| Manganese-54 (F)                            | <sup>54</sup> Mn  | γ (EC)                 | Whole body (rapid)                         | Whole body <sup>4</sup>                              |
| Cobalt-60                                   | <sup>60</sup> Co  | β, γ                   | Whole body (rapid)                         | Lung <sup>5</sup>                                    |
| Strontium-90                                | <sup>90</sup> Sr  | β                      | Nose blow/nasal swab <sup>6</sup>          | Urine  |
| Selenium-75                                 | <sup>75</sup> Se  | γ (EC)                 | Whole body (rapid)                         | Whole body   |
| Silver-110m                                 | <sup>110</sup> Ag | β, γ                   | Whole body (rapid)                         | Whole body   |
| Cadmium-109                                 | <sup>109</sup> Cd | γ (EC)                 | Whole body (rapid)<br>Nose blow/nasal swab | Whole body, urine                                    |
| Iodine-131                                  | <sup>131</sup> I  | β, γ                   | Thyroid (rapid)                            | Thyroid  |
| Barium-133                                  | <sup>133</sup> Ba | γ (EC)                 | Whole body (rapid)                         | Whole body   |
| Caesium-137                                 | <sup>137</sup> Cs | β, γ                   | Whole body (rapid)                         | Whole body   |
| Europium-152                                | <sup>152</sup> Eu | β, γ                   | Whole body (rapid)                         | Whole body   |
| Europium-154                                | <sup>154</sup> Eu | β, γ                   | Whole body (rapid)                         | Whole body   |
| Iridium-192 (F)                             | <sup>192</sup> Ir | β, γ                   | Whole body (rapid)                         | Whole body <sup>4</sup>                              |
| Polonium-210                                | <sup>210</sup> Po | α                      | None                                       | Urine  |
| Radium-226                                  | <sup>226</sup> Ra | α                      | Nose blow/nasal swab                       | Lung <sup>5</sup> , Urine                            |
| Plutonium-238                               | <sup>238</sup> Pu | α                      | Nose blow/nasal swab                       | Urine, Faeces <sup>2</sup><br>(Lung <sup>3,5</sup> ) |
| Americium-241                               | <sup>241</sup> Am | α, γ                   | Nose blow/nasal swab                       | Lung <sup>5</sup>                                    |
| Californium-252                             | <sup>252</sup> Cf | α                      | Nose blow/nasal swab                       | Urine, Faeces <sup>2</sup><br>(Lung <sup>3,5</sup> ) |

α – alpha emitter    β – beta emitter    γ – gamma emitter    EC – electron capture

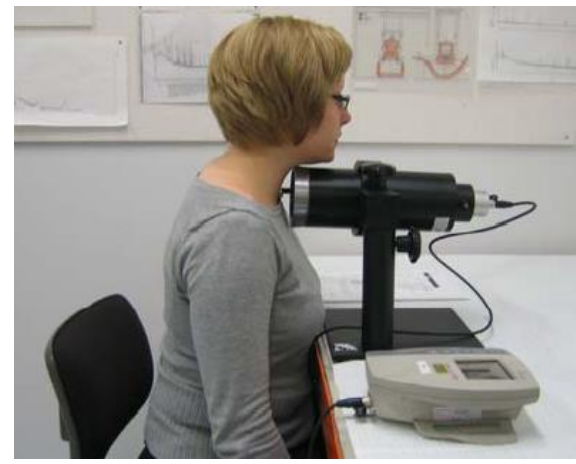
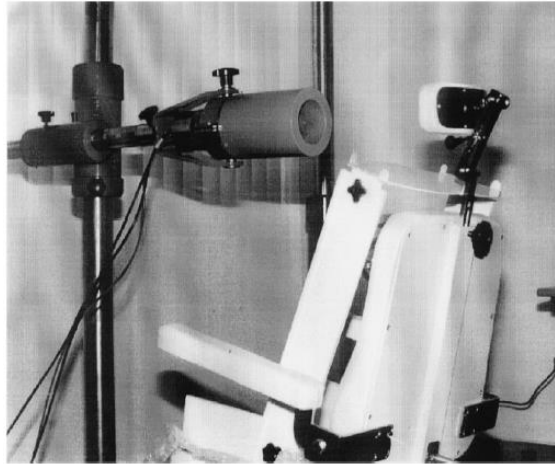
※ TMT Handbook (2009)

# 전신계수기





# 갑상선계수기





# 비상시 내부피폭 평가

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## ◆ 현장 기반의 내부피폭 신속분류

- Mobile bioassay lab
- Screening of internal contamination with hand-held instruments

## ◆ 실험실 기반의 대량시료 신속분석 및 내부피폭 평가

- Whole body counting
- Urine bioassay

※ 의료적 개입은 연간섭취한도의 10배(=200 mSv) 이상에서 권고됨. (ICRP, TMT handbook)

# 비상시 내부피폭 관리

## ◆ 내부피폭선량 평가결과에 따른 관리 조치

- 1 mSv 미만 : 추가 조치 불필요
- 1 ~ 20 mSv : 정밀한 선량평가는 요구되나 의료개입은 불필요
- 20 ~ 200 mSv : 지속적인 내부피폭 모니터링을 통한 정밀한 선량평가 요구, 의료개입은 환자 상태에 따라 결정
- 200 mSv 이상 : 정밀 선량평가 요구, 의료개입 권고

※ TMT Handbook (2009)

# Mobile Bioassay Lab





# Screening of internal contamination

## ◆ TMT Guideline

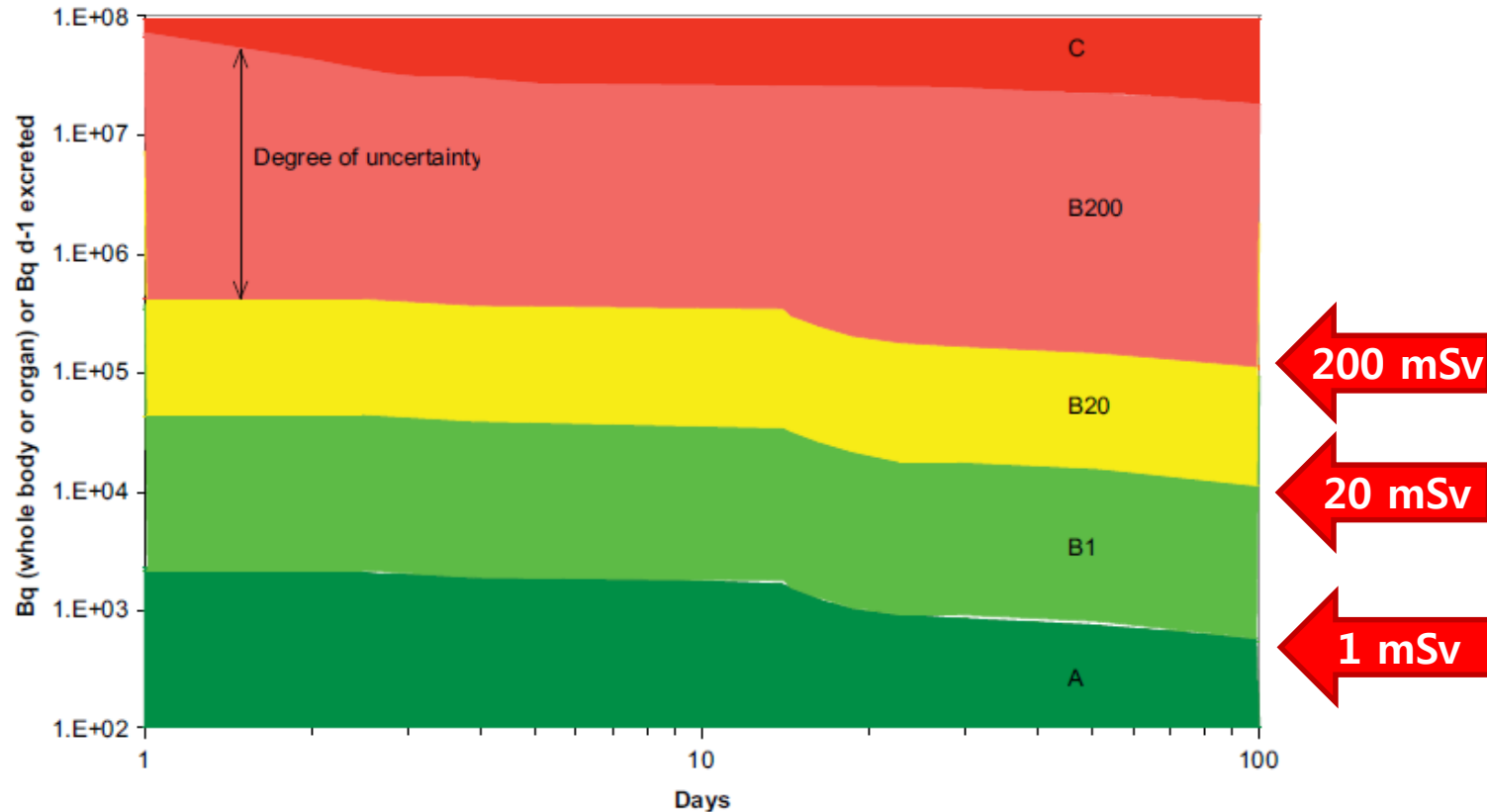


### **Monitoring with hand-held instruments**

The minimum detectable amount (MDA) in this type of measurement is about 1–2 kBq for  $^{137}\text{Cs}$  ( $\pm 50\%$ ) (Zvonova et al, 1995). The uncertainty depends partly on the position of the person and partly on the background to some degree shielded by the body of the person. Since the measurements often are performed in environments with enhanced background the actual background in the person measurement might be difficult to estimate. Comparisons with regular whole body counting measurements have shown satisfactory agreement and the method is useful when remembering the corrections that have to be made and the limitations involved.

# Screening of internal contamination

## ◆ TMT Guideline



### Notes

1. The y-axis shows the measured amount of the radionuclide in whole body or organ of the body, expressed in Bq, or the measured amount of the radionuclide excreted in urine or faeces per day, expressed in Bq d<sup>-1</sup>.
2. The x-axis shows the elapsed time of the measurement or sample after intake.
3. This example is for whole-body measurements of <sup>137</sup>Cs.

# Urine Bioassay

## ◆ Urine analysis method of US CDC

### Radionuclide Analytical Methods (typical in DOE / DOD facilities)

- Requires a **24 hour** Urine Collection
- Most results available in **3-21 days**
- **Limited** radionuclide analytical methods
- Sample throughput of **5-20 samples/day/lab**

### Urgent Needs for Evaluation of a Population Exposed to an IND / RDD (Future Rad Lab Requirements)

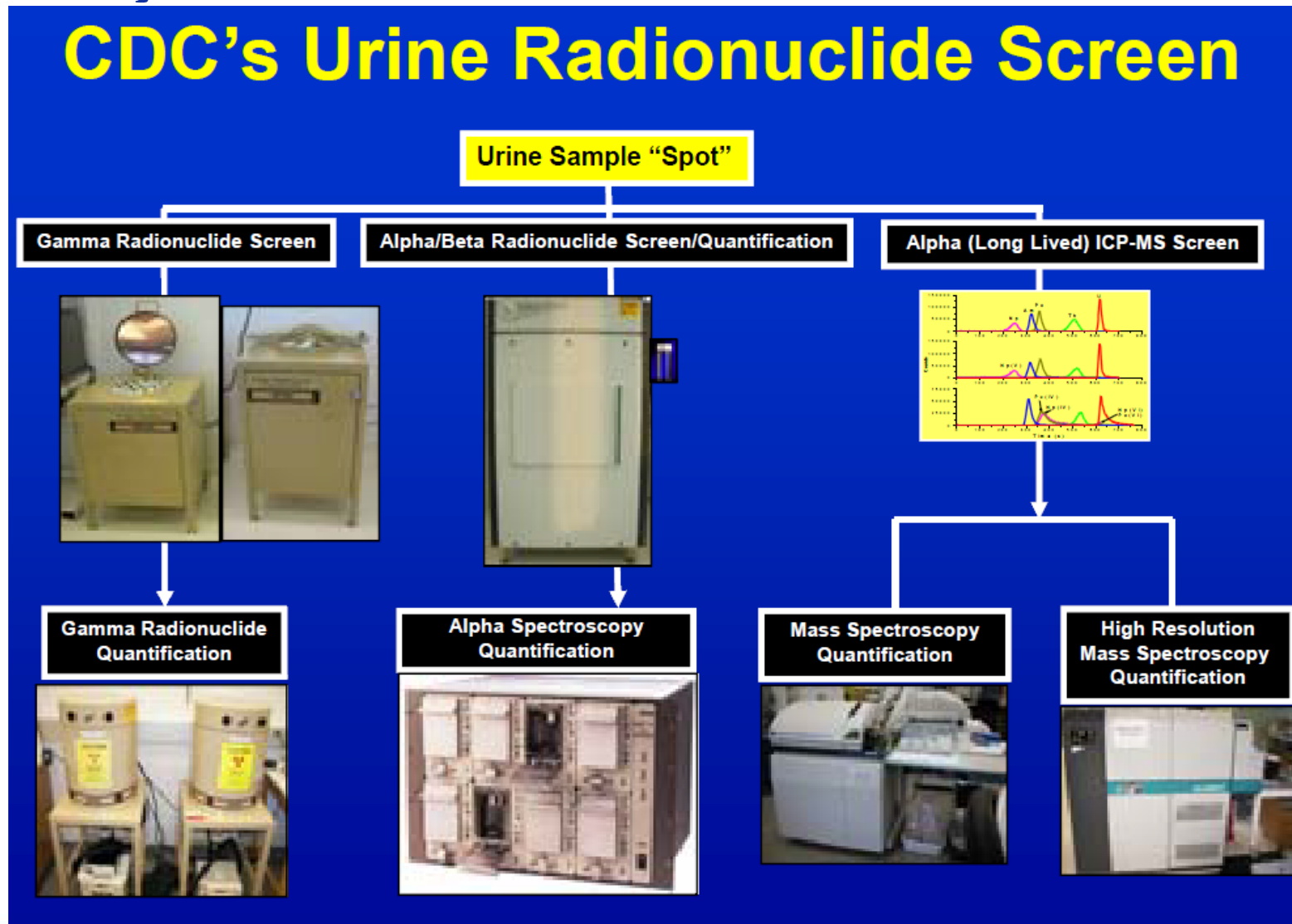
- Analytical methods that require only **5-50 mL of urine**
- Analytical methods for a **wide variety** of radionuclides
- Results available in **4-36 hours**
- Sample throughput of **100-2000+ samples/day/lab**

**This will provide the decision makers essential exposure data in the shortest possible time**



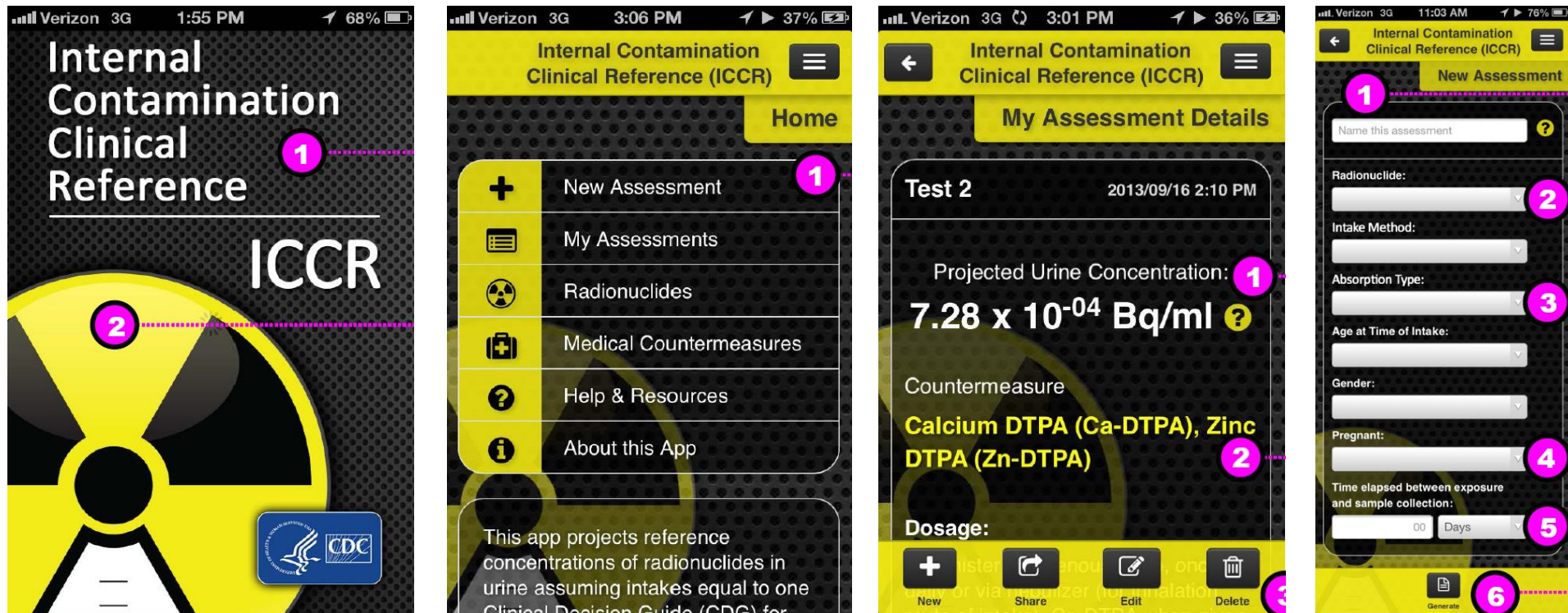
# Urine Bioassay

## ◆ Urine analysis method of US CDC



# Clinical Reference

## ◆ ICCR App from US CDC



$$CDG = \text{MIN} \left[ \frac{0.25 \text{ Sv}}{e(\text{Sv Bq}^{-1})}, \frac{0.25 \text{ Gy} \cdot \text{Eq}}{d_{\text{Red Marrow}}(\text{Gy} \cdot \text{Eq Bq}^{-1})}, \frac{1.0 \text{ Gy} \cdot \text{Eq}}{d_{\text{Lung}}(\text{Gy} \cdot \text{Eq Bq}^{-1})} \right]$$

# 의학원 내부피폭 평가시스템 소개

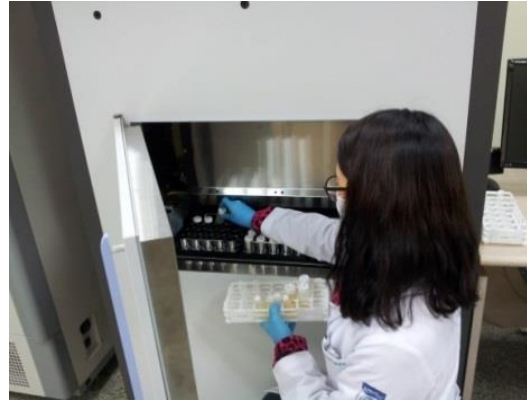
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# KIRAMS monitoring procedure



**External  
contamination  
monitoring**



**Urine bioassay  
for gross alpha/beta analysis**



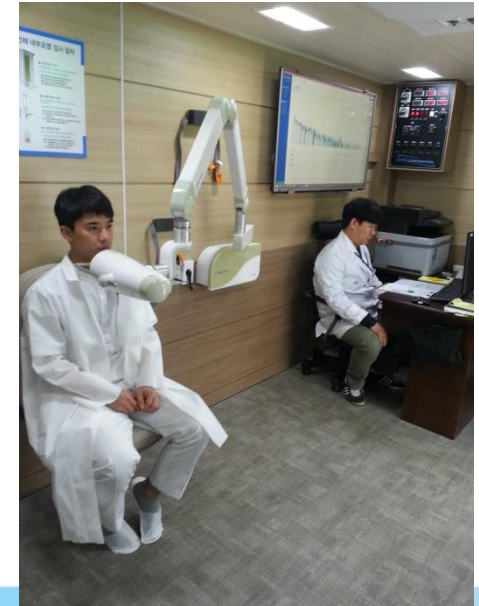
**Whole body counting  
for gamma-emitting radionuclide monitoring**



**Radionuclide  
identification  
& quantification**



# KIRAMS mobile laboratory





# Bioassay Intercomparison

## ◆ US LLNL (2015~)



Actual result provided by LLNL:  
I-131  $1.65 \times 10^4$  Bq, EMU  $5.9 \times 10^2$  Bq

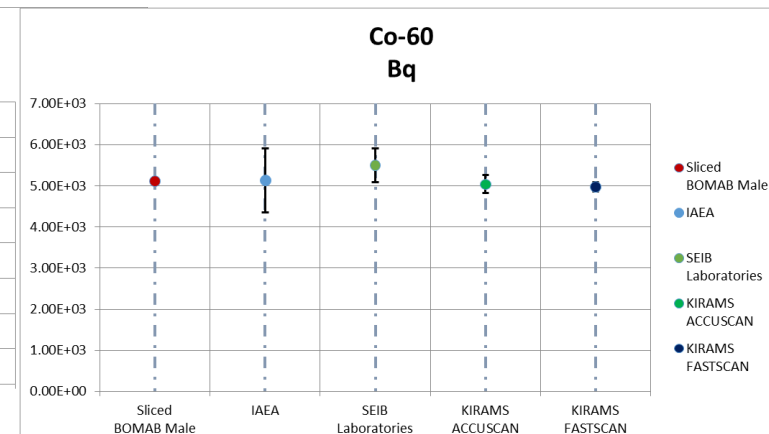
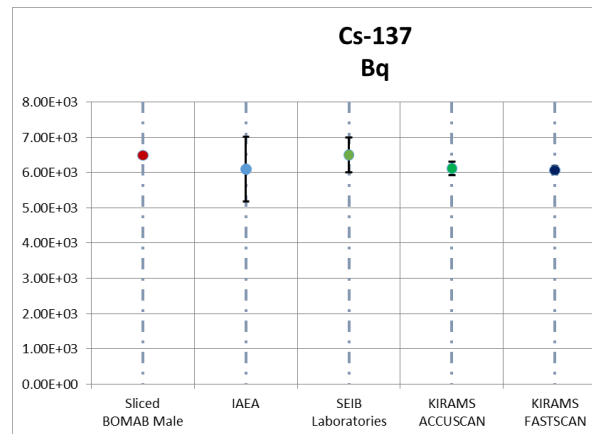
Reported result of KIRAMS:  
I-131  $1.77 \times 10^4$  Bq, EMU  $1.7 \times 10^3$  Bq  
( $1.60 \times 10^4 \sim 1.94 \times 10^4$  Bq, 99% CI)

Relative Bias = 7.0% (Criteria = -25% ~ 50%)

Relative Precision = 4.0% (Criteria <40%)

RMSE (Root Mean Squared Error) = 9.0% (Criteria <25%)

## ◆ IAEA (2015)





# Bioassay Intercomparison

## ◆ US NIST (2012~)

NRIP: **NIST**

**R**adiochemistry

**I**ntercomparison


**P**rogram

| Category       | Radionuclides<br>(potentially present)  | Maximum Activity<br>(Bq/Sample) |           |
|----------------|---|---------------------------------|-----------|
|                |   | Routine                         | Emergency |
| Gamma-emitters | $^{54}\text{Mn}$ , $^{57,58,60}\text{Co}$ , $^{65}\text{Zn}$ , $^{133}\text{Ba}$ ,<br>$^{134,137}\text{Cs}$ , $^{134,137}\text{Cs}$ , $^{152}\text{Eu}$ , $^{192}\text{Ir}$ | 250                             | 250       |
| Beta-emitters  | $^{89}\text{Sr}$ , $^{210}\text{Pb}$ , $^{228}\text{Ra}$  | 1                               | 10        |
|                | $^{90}\text{Sr}$  | 4                               | 10        |
| Alpha-emitters | $^{210}\text{Po}$ , $^{226}\text{Ra}$ , $^{234,235,238}\text{U}$ , $^{237}\text{Np}$ ,<br>$^{238,239,240}\text{Pu}$ , $^{241}\text{Am}$ , $^{244}\text{Cm}$                 | 1                               | 10        |
|                | $^{228,230,232}\text{Th}$   | 2                               | 20        |
| Gross Alpha    |   | 60                              | 550       |
| Gross Beta     |   | 3000                            | 3000      |

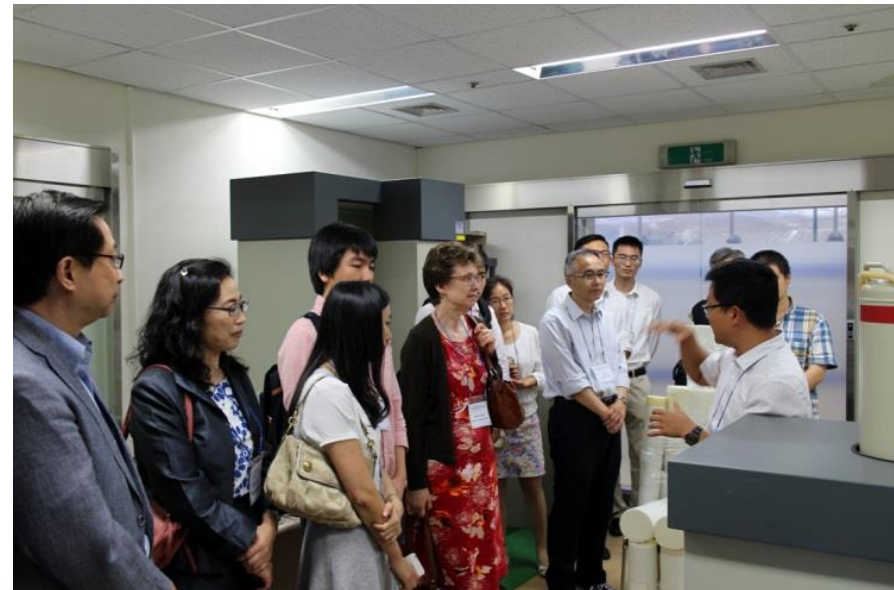
| Measurement Results   |   |   |                                       |   |                                      |
|-----------------------|---|---|---------------------------------------|---|--------------------------------------|
| Nuclide               | NIST Value <sup>2,3</sup>                         |   | Reported Value <sup>4</sup>           |   | Difference <sup>5</sup><br>(±% Bias) |
|                       | Massic Activity<br>Bq·g <sup>-1</sup>             | Relative Expanded<br>Uncertainty (%; k=2) | Massic Activity<br>Bq·g <sup>-1</sup> | Relative Expanded<br>Uncertainty (%; k=2) |                                      |
| $^{243}\text{Cm}$     | 0.850   | 0.94                                      | 0.870                                 | 34.3                                      | 2.2                                  |
| $^{241}\text{Am}$     | 2.268   | 0.90                                      | 2.264                                 | 22.4                                      | -0.2                                 |
| $^{240}\text{Pu}$     | 0.972   | 0.79                                      | 1.086                                 | 29.3                                      | 12                                   |
| $^{238}\text{Pu}$     | 0.746   | 0.71                                      | 0.712                                 | 35.9                                      | -4.5                                 |
| $^{238}\text{U}$      | 2.585   | 0.63                                      | 2.470                                 | 30.3                                      | -4.5                                 |
| $^{235}\text{U}$      | 0.119   | 0.80                                      | 0.122                                 | 119                                       | 2.6                                  |
| $^{234}\text{U}$      | 2.490   | 1.00                                      | 2.481                                 | 30.1                                      | -0.4                                 |
| $^{230}\text{Th}$     | 1.180   | 0.61                                      | 1.225                                 | 32.2                                      | 3.9                                  |
| $^{210}\text{Po}$     | 8.272   | 2.50                                      | 9.062                                 | 60.2                                      | 9.6                                  |
| $^{90}\text{Sr}$      | 18.55   | 0.81                                      | 16.62                                 | 66.8                                      | -10                                  |
| $^{137}\text{Cs}$     | 384.6   | 0.72                                      | 376.9                                 | 10.0                                      | -2.0                                 |
| $^{60}\text{Co}$      | 228.6   | 0.56                                      | 217.4                                 | 17.1                                      | -4.9                                 |
| Methods               |   |   |                                       |   |                                      |
| Activity Measurements | NIST <sup>6</sup>                                 |   |                                       | Reporting Laboratory <sup>7</sup>         |                                      |
|                       | Alpha- and Beta-Spectrometry<br>Mass Spectrometry |   |                                       | Alpha, Beta, and Gamma Spectrometry       |                                      |

| Evaluation (per ANSI N42.22 and N13.30) |                          |                                    |   |                                  |                             |
|---|--------------------------|------------------------------------|---|----------------------------------|-----------------------------|
| Nuclide                                 | N42.22 <sup>1</sup>      |                                    | N13.30 <sup>9</sup>                                   |                                  |                             |
|   | ANSI N42.22<br>Traceable | Traceability<br>Limit<br>(Percent) | Results Acceptable per N13.30 Criteria<br>(Pass/Fail) |                                  |                             |
|   |                          |                                    | Relative Bias<br>(±Percent)                           | Relative Precision<br>(±Percent) | Radiobioassay<br>acceptance |
| $^{243}\text{Cm}$                       | Yes                      | 53                                 | 2.2   | 8.0                              | Pass                        |
| $^{241}\text{Am}$                       | Yes                      | 34                                 | -0.2  | 5.0                              | Pass                        |
| $^{240}\text{Pu}$                       | Yes                      | 49                                 | 12  | 9.4                              | Pass                        |
| $^{238}\text{Pu}$                       | Yes                      | 51                                 | -4.5  | 8.9                              | Pass                        |
| $^{238}\text{U}$                        | Yes                      | 43                                 | -4.5  | 8.3                              | Pass                        |
| $^{235}\text{U}$                        | Yes                      | 184                                | 2.6   | 26                               | Pass                        |
| $^{234}\text{U}$                        | Yes                      | 45                                 | -0.4  | 7.0                              | Pass                        |
| $^{230}\text{Th}$                       | Yes                      | 50                                 | 3.9   | 9.4                              | Pass                        |
| $^{210}\text{Po}$                       | Yes                      | 99                                 | -10   | 11                               | Pass                        |
| $^{90}\text{Sr}$                        | Yes                      | 90                                 | -10   | 22                               | Pass                        |
| $^{137}\text{Cs}$                       | Yes                      | 15                                 | -2.0  | 1.4                              | Pass                        |
| $^{60}\text{Co}$                        | Yes                      | 24                                 | -4.9  | 2.7                              | Pass                        |

Samples Distributed<sup>8</sup> August 11, 2014  
Reporting Data Received October 6, 2014

For the Director  
  
Michael Unterwiesing,  
Group Leader  
Radioactivity Group  
Physical Measurement Laboratory  
(Continued)

# National/Asian Network



# 맺음말

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- ◆ 사후 피폭선량평가는 방호관점에서 중요한 핵심정보
- ◆ 개인의 인체특성 (연령, 신체조건 등)을 반영한 개인  
맞춤형 피폭선량평가 기술 개발
- ◆ 주기적인 교차 분석 및 기술 교류 필요



국가방사선비상진료센터

국민의 건강을 방사능으로부터 지켜드리는데 최선을 다하고 있습니다.

# 감사합니다.

