Review of NCRP Report #161 (Vol. 1 & 2)
“Management of Persons Contaminated with Radionuclides: Handbook”

Albert L. Wiley, BNE, MD, PhD
albert.wiley@orise.orau.gov
Director & Staff Physician, REAC/TS
Head, WHO Collaborating Center at Oak Ridge
Oak Ridge Institute for Science and Education (ORISE)
NCRP 161 Writing Committee

William J Bair, PhD, Chairman
Wesley E Bolch, PhD (Univ. of Florida)
William E Dickerson, MD (Retired, AFFRI)
Keith F Eckerman, PhD (ORNL)
Ronald E Goans, MD, PhD (MJW Corp.)
P Andrew Karam, PhD (NYC Health Dept.)
Richard W Leggett, PhD (ORNL)
Joyce L Lipsztein, PhD (Univ. of Rio de Janeiro)
Michael G Stabin, PhD (Vanderbilt Univ.)
Albert L Wiley Jr., BNE, MD, PhD (REAC/TS/NNSA)
NCRP Report 161 (Vol. 1&2)

- Executive Summary & Introduction
- Part A: Quick Reference Information
- Part B: Onsite and Pre-Hospital Actions
- Part C: Patient Management at Hospital
- Part D: Patient Management Post-Hospital
- Part E (or Vol. 2)
- Extensive, Useful References in both Vol. 1&2!
NCRP 161 (Vol. 1 & 2)

- Detailed discussions of the rationale and practical clinical examples

- “Purpose...to provide guidance to those who may be called to respond to radionuclide contamination incidents.”

- Primary objective...to facilitate diagnosis and treatment of internal contamination so as to reduce early and delayed health risks”
Part A. Quick Reference Information

- Section 3. Compendium of Radiation Facts & Guidance
- Section 4. Radiation-Safety Guidance for First Responders
- Section 5. Performing Surveys & Controlling Personnel & Area Contamination
NCRP 161 (Vol. 1)

Part B. Onsite & Prehospital Actions

- Section 6. Stage 1: Medical Assessment
  (onsite triage area)
- Section 7. Stage 2: External Contamination Assessment
  (onsite triage area)
- Section 8. Stage 3: External Decontamination
  (onsite decontamination area)
Part C:

Section 10: Internal Contamination, General Discussion


Section 12. Stage 7: Med Management (hospital)
Part D. Patient Management Post-Hospital

- Section 13. Stage 8: Follow-up Medical Care
- Section 14. Stage 9: Contaminated Decedents (hospital & mortuary)
- Section 15. Contamination Control in Medical Facilities
Part A: (Quick Reference Guide)

- On-site emergency check-list
- Identification tag information
- Medical information check-list
- Hospital decontamination procedures
- Tabular review of various radionuclides, their emissions, energies of emissions, half-lives, measurement methods & treatment recommendations (with introduction to CDG).
161: Part A. Quick Reference Information, Section 4: Radiation-Safety Guidance for First Responders

- General instructions
- Guidance for first responders
  - First on scene
  - Immediate goals for protection of exposed individuals
  - Control areas
  - Protection of first responders
Quick (Reference)

161: Part A. Quick Reference Information, Section 5: Performing Surveys & Controlling Personnel & Area Contamination

- Contamination surveys
- Personal protection equipment (PPE)
- Contamination control
NCRP 161 (Vol. 1)

161: Part B. On-site & Prehospital Actions, Section 6: Stage 1 – Medical Assessment (on-site triage)

- Initial actions – medical & rad safety personnel
- Potential life-threatening problems
- ID of exposed &/or contaminated individuals
- Contamination screening of individuals
- On-site treatment for internal contamination
- Priorities in processing exposed persons
161: Part B. Section 8: Stage 3 – External Decontamination Assessment (on-site decon area)

- Decontamination of persons – objectives & procedure
- Decon guidance
- Decon facilities
- Saving contaminated materials
- Management after assessment & decon
NCRP Report No. 161 – Part B
Stage 1 – Medical Assessment (onsite triage area)

Flowchart:
- Potential radiation exposure or injury? (Yes/No)
  - Yes: Injury? (Yes/No)
    - Yes: Life threatening? (Yes/No)
      - Yes: Stabilize
      - No: Treat
    - No: Send home
  - No: Send home

- Possible contamination? (Yes/No)
  - Yes: Send home
  - No: Stage 2 (page 107)

Stage 4 (page 123)
### Stage 2 – External Contamination Assessment
(onsite triage area)

| Alpha (Bq cm\(^{-2}\) (nCi cm\(^{-2}\))| Beta/Gamma (Bq cm\(^{-2}\) (nCi cm\(^{-2}\))| Beta/Gamma (low background area\(^a\)) & Actions |
|---|---|---|---|
| <10 (<0.27) (<2.7) [<600] | <100 (<2.7) [<6,000] | Not detectable | None | allow release |
| >10 (>0.27) (>2.7) [6,000] | >100 | Not detectable | Intervention optional | decontaminate or advise to shower and wash clothing |
| >100 (>2.7) (>27) [60,000] | >1,000 (>27) (>60,000) | 0.2 – 0.3 (20 – 30) | Intervention advisable | prevent inadvertent ingestion and inhalation, limit spread of contamination and decontaminate |
| >1,000 (>27) (>270) [600,000] | >10,000 (>270) (>600,000) | 2 – 3 (200 – 300) | Intervention required | prevent inadvertent ingestion and inhalation, limit spread of contamination and decontaminate |

\(^a\) Ambient dose equivalent rate measured at 10 cm from skin surface.
161: Part C. Patient Management at Hospital, Section 9: Stage 4 – Patient Evaluation & Emergency Care

- General issues – medical & psychological
- General instructions for ED personnel
- Emergency medical management – life-threatening injuries, slightly injured or uninjured,
- Initial treatment decisions for contamination
NCRP 161

161: Part C. Patient Management at Hospital, Section 10: Stage 5 – Internal Contamination Assessment (hospital)

- Preliminary assessment activities
- Information gathering
- Bioassay – indirect (in vitro) and direct (in vivo)
161: Part C. Patient Management at Hospital, Section 11: Stage 6 – Clinical Decision Guidance (hospital)

- Objective: “Provide guidance to physicians making treatment decisions.”
- New operational quantity - CDG’s
- CDG = maximum, once-in-a-lifetime intake
Clinical Decision Guidelines (CDG)

CDG = the maximum, once-in-a-lifetime intake of a radionuclide that represents:

✓ “Stochastic risk, as judged by the calculated ED over 50Y for intake by adults and to age 70Y for intake by children, that is in the range of risks associated with guidance on dose limits for emergency situations (DOE, 2008a; FEMA, 2008; ICRP, 1991a; NCRP, 1993; 2005a)”
Clinical Decision Guidelines (CDG)

- CDG = the maximum, once-in-a-lifetime intake of a radionuclide that represents:

  ✓ “Avoidance of deterministic effects as judged by the calculated 30d RBE-weighted absorbed doses to red marrow and lungs, with allowance for the significant uncertainties often involved in an initial evaluation of the chemical and physical form of a radionuclide and the level of activity taken into the body during an incident.”
NCRP 161(Vol.1): Specific Recommendations for Medical Management
1. Reduce &/or inhibit absorption from the GI tract (e.g., induce emesis, gastric lavage, cathartics)

2. Block uptake to the organ of interest (e.g., KI to block uptake of radio-I by the thyroid)
Countermeasure Categories (continued)

3. Isotopic dilution (e.g., increase fluid hydration for internalized $^3$H)

4. Alter chemistry (e.g., prevent deposition of uranium in renal tubules with sodium bicarbonate)
6. Chelators (e.g., DTPA for Pu, Am, Cm, Cf)

7. Excise radionuclides from wounds

8. Consider bronchoalveolar lavage for insoluble inhaled materials
<table>
<thead>
<tr>
<th>Age Category</th>
<th>Predicted Absorbed Dose to the Thyroid [Gy (rad)]&lt;sup&gt;b&lt;/sup&gt;</th>
<th>KI Dose (mg)&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Number of 130 mg Tablets</th>
<th>Number of 65 mg Tablets</th>
<th>KI Solution 65 mg mL&lt;sup&gt;−1&lt;/sup&gt; (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults &gt;40 y</td>
<td>≥5 (500)</td>
<td>130</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Adults 18 – 40 y</td>
<td>≥0.1 (10)</td>
<td>130</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Pregnant or lactating women</td>
<td>≥0.05 (5)</td>
<td>130</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Adolescents 12 – 18 y&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td>65</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Children 3 – 12 y</td>
<td>≥0.05 (5)</td>
<td>65</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1 month – 3 y</td>
<td>≥0.05 (5)</td>
<td>32</td>
<td>0.25</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Birth – 1 month</td>
<td>≥0.05 (5)</td>
<td>16</td>
<td>0.125</td>
<td>0.25</td>
<td>0.25</td>
</tr>
</tbody>
</table>

<sup>a</sup>The protective effect of KI lasts ~24 h. For optimal prophylaxis, KI should therefore be administered daily, until a risk of significant exposure to radioiodines by either inhalation or ingestion no longer exists.

<sup>b</sup>Without KI treatment.

<sup>c</sup>Adolescents approaching adult size (>70 kg) should receive the full adult dose (130 mg).
The **MAJORITY OF THE DRUGS** listed in the following NCRP 161 tables are **NOT APPROVED BY THE FDA** for the indications listed.

There is limited clinical experience with many of the recommendations in the tables that follow.

See individual drug labels/prescribing information for detailed guidance.
# NCRP 161: Decorporation Therapies

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Possible</th>
<th>Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actinium</td>
<td>Consider DTPA</td>
<td>Consider DTPA</td>
</tr>
<tr>
<td>Americium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Antimony</td>
<td>BAL, penicillamine</td>
<td>BAL</td>
</tr>
<tr>
<td>Barium</td>
<td>Ba, Ca therapy (Section 12.4.1.)</td>
<td>Same</td>
</tr>
<tr>
<td>Berkelium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Bismuth</td>
<td>BAL, penicillamine, <strong>DMSA</strong></td>
<td><strong>DMSA</strong></td>
</tr>
<tr>
<td>Cadmium</td>
<td><strong>DMSA</strong>, DTPA, EDTA</td>
<td><strong>DMSA</strong></td>
</tr>
<tr>
<td>Californium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ba, Ca therapy (Section 12.4.1)</td>
<td>Section 12.4.1.</td>
</tr>
<tr>
<td>Carbon</td>
<td>Consider hydration &amp; non-rad C</td>
<td>Same</td>
</tr>
<tr>
<td>Cerium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
</tbody>
</table>
## 161: Decorporation Therapies

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Possible</th>
<th>Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cesium</td>
<td>Prussian Blue</td>
<td>Prussian Blue</td>
</tr>
<tr>
<td>Chromium</td>
<td>DTPA, EDTA, no antacids</td>
<td>DTPA</td>
</tr>
<tr>
<td>Cobalt</td>
<td><strong>DMSA, DTPA, EDTA, NAC</strong></td>
<td><strong>DMSA</strong></td>
</tr>
<tr>
<td>Copper</td>
<td><strong>EDTA, penicillamine, trientine</strong></td>
<td>Pencillamine</td>
</tr>
<tr>
<td>Curium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Einsteinium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Europium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Mixed fission products</td>
<td>Depends upon predominant radionuclides: early – I; late: Sr, Cs</td>
<td></td>
</tr>
<tr>
<td>Fluorine</td>
<td>Aluminum hydroxide</td>
<td>AIOH</td>
</tr>
<tr>
<td>Gallium</td>
<td>Consider penicillamine</td>
<td>Penicillamine</td>
</tr>
<tr>
<td>Gold</td>
<td>BAL, penicillamine</td>
<td>Penicillamine</td>
</tr>
</tbody>
</table>
### 161: Decorporation Therapies

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Possible</th>
<th>Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Iodine</td>
<td>KI, consider SSKI, propylthiouracil, methimazole or potassiumiodate</td>
<td>KI</td>
</tr>
<tr>
<td>Iridium</td>
<td>Consider DTPA, EDTA</td>
<td>Consider DTPA</td>
</tr>
<tr>
<td>Iron</td>
<td>Deferoxamine (DFOA), deferasirox, DTPA, or DOFA + DTPA</td>
<td>DFOA</td>
</tr>
<tr>
<td>Lanthanum</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Lead</td>
<td><strong>DMSA, EDTA, EDTA + BAL</strong></td>
<td><strong>DMSA</strong></td>
</tr>
<tr>
<td>Manganese</td>
<td>DFOA, DTPA, EDTA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Consider Sr (Section 12.4.5)</td>
<td>Section 12.4.5.</td>
</tr>
<tr>
<td>Mercury</td>
<td>BAL; EDTA; penicillamine; DMSA</td>
<td>BAL</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Limited clinical experience</td>
<td></td>
</tr>
</tbody>
</table>
### 161: Decorporation Therapies

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Possible</th>
<th>Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neptunium</td>
<td>Consider DFOA &amp;/or DTPA</td>
<td>⇣Same</td>
</tr>
<tr>
<td>Nickel</td>
<td>BAL, EDTA</td>
<td>BAL</td>
</tr>
<tr>
<td>Niobium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Palladium</td>
<td>Penicillamine, DTPA</td>
<td>Penicillamine</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Phosphorus therapy</td>
<td>⇣Same</td>
</tr>
<tr>
<td>Plutonium</td>
<td>DTPA, DFOA, EDTA, DTPA + DFOA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Polonium</td>
<td>BAL, DMSA, penicillamine</td>
<td>BAL</td>
</tr>
<tr>
<td>Potassium</td>
<td>Diuretics</td>
<td>Diuretics</td>
</tr>
<tr>
<td>Promethium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Radium</td>
<td>AlPO₄ gel, BaSO₄</td>
<td>⇣Same</td>
</tr>
<tr>
<td>Rubidium</td>
<td>Prussian Blue</td>
<td>Prussian Blue</td>
</tr>
</tbody>
</table>
## 161: Decorporation Therapies

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Possible</th>
<th>Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruthenium</td>
<td>DTPA, EDTA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Scandium</td>
<td>DTPA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Silver</td>
<td>No specific therapy</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>Diuretics &amp; isotopic dilution with 0.9% NaCl</td>
<td>Same</td>
</tr>
<tr>
<td>Strontium</td>
<td>Multiple therapies (Section 12.4.5)</td>
<td>Same</td>
</tr>
<tr>
<td>Sulfur</td>
<td>Consider sodium thiosulfate</td>
<td>Same</td>
</tr>
<tr>
<td>Technetium</td>
<td>Potassium perchorolate</td>
<td>Same</td>
</tr>
<tr>
<td>Thallium</td>
<td>Prussian Blue</td>
<td>Prussian Blue</td>
</tr>
<tr>
<td>Thorium</td>
<td>Consider DTPA</td>
<td>Consider DTPA</td>
</tr>
<tr>
<td>Uranium</td>
<td>Sodium bicarbonate to alkalinize urine; consider dialysis</td>
<td>Bicarbonate</td>
</tr>
</tbody>
</table>
## 161: Decorporation Therapies

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Possible</th>
<th>Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yttrium</td>
<td>DTPA, EDTA</td>
<td>DTPA</td>
</tr>
<tr>
<td>Zinc</td>
<td>DTPA, EDTA, Zn Sulfate as diluting agent</td>
<td>DTPA</td>
</tr>
<tr>
<td>Zirconium</td>
<td>DTPA, EDTA</td>
<td>DTPA</td>
</tr>
</tbody>
</table>
Management of the Actinides

- Actinides = heavy elements at the bottom of the Periodic Table beginning with Actinium (Z = 89) & ending with Lawrencium (Z = 103)

- Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No and Lr

- DTPA recommended for all except for Th, U, and Np (Differs from NCRP 65)
DTPA

- More information of its use for wound irrigation, per NCRP 156.
- For lanthanides and actinides
- Recommendations on Ca vs Zn-DTPA
Penicillamine Therapy

- Penicillamine = D-3-mercaptovaline = Cuprimine®

- 161: FDA approved to treat genetic copper storage disorder (Wilson’s disease, cystinuria), failures of conventional therapies for rheumatoid arthritis
**Penicillamine Therapy**

- **NCRP 65 Administration:** 250 mg qid, may increase up to 4-5 gm in divided doses

- **NCRP 161 Administration:** 0.75-1.5 g daily for adults, 30 mg/kg/d for pediatrics – in divided doses

- **Dosage form:** 250 mg capsules

- **See package insert; pregnancy cat D**
Prussian Blue Therapy

- Prussian blue insoluble = ferric III hexacyanoferrate II = Radiogardase®
- FDA approved for radiocesium, radiothallium and non-radioactive thallium.
- 161 Adult dosage: start with 3 g po qd
- Titrate using radiobioassay results
DMSA – Dimercaptosuccinic acid or dimerecaptosuccinate ("succimer" or Chemet®)

FDA approved for lead poisoning in children with Pb levels >45μg/dL

Not approved by FDA but considered by other authors for arsenic, cadmium, cobalt, mercury, polonium
DMSA Recommendations

- Dosage form: 100 mg capsules
- Dosage: start at 10 mg/kg or 350 kg/m$^2$ po q8h X 5d then reduce
- Safety & efficacy for children <12MOA have not been established
Uranium

- In acidic urine, uranyl ion complex with tubule surface proteins

- Some of the bound $\text{UO}_2^{2+}$ is retained in the kidney

- Kidney is the first organ to show chemical damage in the form of nephritis and proteinuria

- Oral doses or infusions of sodium bicarbonate are the treatment of choice and should be dosed to keep the urine alkaline by frequent pH measurements
MORE DETAILS on CDG and EXAMPLE of USE: The Guidebook for the Treatment of Accidental Internal Radionuclide Contamination of Workers, a joint publication for CDC and DOE, recommended that treatment be considered for internal radionuclide depositions that would result effective doses in the range of 20 to 200 mSv (2 to 20 rem) or higher (Bhattacharyya et al., 1992). ICRP has judged that no tissues are expected to express clinically-relevant functional impairment from internally-deposited radionuclides at absorbed doses up to ~ 100 mGy (10 rad), low or high linear energy transfer LET), with threshold doses for deterministic effects in most tissues in the 1Gy (100 rad) or higher range (ICRP, 2007).
Based upon the recommendations and limits for emergency situations and knowledge of deterministic effects, the numerical values of dose used as a basis in this Report for computing the CDG intake values for different radionuclides, excluding isotopes of iodine, in adults are 0.25 Sv (25 rem) (50 y effective dose) for consideration of stochastic effects [based on the population–averaged nominal cancer fatality risk coefficient of 5% Sv\(^{-1}\) derived from epidemiological data (ICRP, 2007), this represents about a 1.3\%lifetime risk of fatal cancer attributable to the radiation dose]; a 30 d RBE – weighted absorbed-dose value of 0.25 Gy-Eq (25 rad-Eq) for consideration of deterministic effects to bone marrow; and a 30 d RBE- weighted absorbed-dose value of 1 Gy-Eq (100 rad-Eq) for consideration of deterministic effects to the lungs. Thus, for intake of a radionuclide (other than iodine) the CDG for an adult is the maximum intake satisfying these dose constraints for both stochastic and deterministic effects:
CDG =

\[
MIN\left[ \frac{0.25 \text{ Sv}}{e(\text{Sv Bq}^{-1})}, \frac{0.25 \text{ Gy-Eq}}{d_{\text{Red Marrow}}(\text{Gy-Eq Bq}^{-1})}, \frac{1.0}{d_{\text{Lung}}(\text{Gy-Eq Bq}^{-1})} \right]
\] (11.1)

where:

- \( e \) = effective dose coefficient for the radionuclide
- \( d_{\text{Red Marrow}} \) and \( d_{\text{Lung}} \) = RBE-weighted absorbed-dose coefficients for red marrow and lung, respectively
- \( MIN \) = minimum value of the three arguments
The CDG for an adult is the intake that satisfies the constraint on the effective dose and the 30d absorbed dose to the red marrow and lungs.

For radionuclides (other than isotopes of iodine), the CDGs for children (age 0 to 18 y) and pregnant women are defined as one-fifth the adult value, reflecting the increased vulnerabilities during development and maturation (AAP, 2003). Children weighing >70kg should be considered as adults.

From: NCRP161
Over 300 people including several children and a pregnant woman are potentially exposed to airborne $^{137}$Cs in a RDD incident in a indoor shopping mall. None of them receive cuts or have other immediate medical issues. During the first 24 h after the incident they are screened for signs of $^{137}$Cs contamination. Over 100 persons show potentially significant contamination levels. They are admitted to an emergency unit and decontamination externally. A spot urine sample is collected from each person during one of the next 3 d days (two, three and four) and analyzed for $^{137}$Cs. The measured $^{137}$Cs activity in each sample is extrapolated to a 24 h excretion value based on the age and gender matched reference 24h urine volume listed in Table 11.4. Solubility measurements made on radioactive material collected at the shopping mall indicate that the released $^{137}$Cs was in highly –soluble form (Type F).
Table 11.1 of NCRP 161 lists a CDG of $5.8 \times 10^7$ Bq for inhalation of $^{137}$Cs of type F by an adult. Table 20.27 of Section 20, lists predicted 24 h urinary $^{137}$Cs values of 0.71, 0.51, and 0.36% of inhaled material on days two, three and five, respectively following acute inhalation of $^{137}$Cs of Type F (5 µm AMAD) by a reference adult. A urinary $^{137}$Cs value of 0.44% for day four is estimated by averaging the values for days three and five. Therefore, for adults, 24 h urinary $^{137}$Cs corresponding 1CDG is:

- $0.0071 \times 5.8 \times 10^7$ Bq = $4.1 \times 10^5$ Bq = $2.5 \times 10^7$ dpm for day two;
- $0.0051 \times 5.8 \times 10^7$ Bq = $3.0 \times 10^5$ Bq = $1.8 \times 10^7$ dpm for day three; and
- $0.0044 \times 5.8 \times 10^7$ Bq = $2.6 \times 10^5$ Bq = $1.6 \times 10^7$ dpm for day four.
For the children and pregnant women, the 24 h urinary $^{137}\text{Cs}$ for day two, three or four corresponding to 1CDG is one-fifth the value for the adult for that day:

- $2.5 \times 10^7 \text{ dpm} / 5 = 5.0 \times 10^6 \text{ dpm}$ for day two;
- $1.8 \times 10^7 \text{ dpm} / 5 = 3.6 \times 10^6 \text{ dpm}$ for day three; and
- $1.6 \times 10^7 \text{ dpm} / 5 = 3.2 \times 10^6 \text{ dpm}$ for day four.

From: NCRP 161
NCRP 161 (Vol.2)

- NCRP 161 (Vol.2 or Part E) is a 1031 page document (pdf downloadable from NCRP) and is a very comprehensive, excellent review of the existing health physics data, providing the rationale and calculations used to justify those clinical management strategies discussed in NCRP 161, Vol. 1.
• Case 4: Wood and Sheehan (1971) reported follow-up measurements on five workers exposed to an accidental release of $^{239}\text{Pu}$ oxide. The assay of initial urine samples revealed some uptake of $^{239}\text{Pu}$ but when interpreted on the basis of available models did not indicate that any of the intakes had exceeded 10% of the allowable intake. The rate of excretion of $^{239}\text{Pu}$ in urine continued to increase over a period of six to eight months in all five workers and then declined with a half-time of about eight months. It then became apparent that intake limits had been exceeded in some of the workers. The nonmonotonic pattern of dissolution and absorption of $^{239}\text{Pu}$ indicated in this and the previous case studies above, as well as studies on rats and dogs (Bair et al., 1973; Mewhinney and Diel, 1983; NCRP, 2001c; Park et al., 1969; Stuart et al., 1968), appear to be associated with the relatively-high specific activity of $^{238}\text{Pu}$. It has been proposed that the high specific activity causes spallation from the surface of the particles, resulting in much smaller, relatively unstable particles of increased solubility in tissue fluids (Bair et al., 1973).

• Case 5: At the Mayak plutonium production plant in the Russian Federation, exposure to $^{239}\text{Pu}$ and other plutonium isotopes was substantial, with post-mortem measurements indicating body burdens >3 kBq in many cases. Some workers developed pulmonary sclerosis, a condition reported previously only in animals administered large quantities of plutonium by inhalation (Claycamp et al., 2000). Increased risks for cancers of the lung, liver and bone (predominantly osteosarcoma) have been observed in the Mayak workers (Gilbert et al., 2000; 2004; Koshurnikova et al., 2000; Shilnikova et al., 2003). Few workers in the United States or the United Kingdom are estimated to have plutonium body burdens >1 kBq.

• Case 6: While working in a glove box in a production plutonium plant, a worker received a puncture wound to the right hand that was contaminated with an estimated 520 kBq of plutonium (Schofield and Dolphin, 1974; Schofield et al., 1974). The material in the glove box was plutonium oxide. Analyses of wound swabs and a blood sample indicated that the primary plutonium isotopes present were $^{239}\text{Pu}$ (~50% of total activity), $^{240}\text{Pu}$ (~38%), and $^{238}\text{Pu}$ (~12%). Surgical excisions on days 1 and 14 reduced the activity in the wound to ~67 kBq. Systemic Ca-DTPA therapy was estimated to have diverted about half of the total absorbed plutonium (~22 kBq) into the urine. The Ca-DTPA IV administrations were usually given as 0.25 g d$^{-1}$ with an upper dose of 1 g d$^{-1}$ at the time of the second incision.

• Case 7: A worker sprayed with an acid solution of PuCl$_3$, PuCl$_3$, and Pu(NO$_3$)$_4$ received inhalation and ingestion exposure as well as skin and burn contamination (Lagerquist et al., 1965). The solution contained 70% $^{239}\text{Pu}$, 14% $^{240}\text{Pu}$, and 16% $^{241}\text{Am}$ by alpha activity. The worker was contaminated over most of his body with 2.5 to 13 Bq cm$^{-2}$, and some areas on the face showed >120 Bq cm$^{-2}$. Except for burned areas, the skin was decontaminated with dilute sodium hypochlorite solution. The patient received 11 g doses of DTPA by IV injection, starting 1 h after the accident and at intervals through day 17. Burn eschars were removed two weeks after the accident and were judged to contain most of the plutonium. The treatments used in this case were considered quite effective.

• Case 8: Norwood (1960; 1962) demonstrated at least a modest therapeutic effect of giving Ca-DTPA to seven persons starting several years after inhalation exposure to plutonium. The rate of elimination of $^{239}\text{Pu}$ in urine increased by a factor of 45 to 120 and fecal excretion increased sixfold. Long-term administration of Ca-DTPA in one case showed a gradually decreasing effectiveness. At the end of 50 weeks of therapy, treatments were only 20% as effective as at the beginning of therapy. About 20% of the estimated body burden of plutonium was removed by this long-term therapy when started 5 y after deposition.

• Case 9: A technician in a metallurgical development laboratory received skin contamination and a puncture wound to the arm when an explosion during compression of a plutonium specimen ejected fragments of plutonium from the jaws of the press (Larson et al., 1968). Initial decontamination efforts were effective except at the wound site. The technician was sent to the occupational physician for examination and treatment. An initial measurement with a wound counter indicated that $-1.3 \times 10^6$ Bq (36 $\mu$Ci) remained in the wound, but this proved to be a substantial underestimate. A series of excisions at the wound site eventually resulted in removal of a piece of plutonium metal with an activity of $-2.6 \times 10^8$ Bq (7,100 $\mu$Ci). After the last excision the wound was flushed repeatedly with DTPA in a normal saline solution. Each flushing was analyzed for plutonium. The flushing was continued until little activity could be removed. The
Thank you!

QUESTIONS

note: Most of these slides taken directly from NCRP161