Is 12 rad-in-air appropriate?
Is 12 rad-in-air an Appropriate Quantity for “Excessive Dose”?

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Atlanta GA
The Answer

It depends ....
Brief Talk

Reasons for inquiry

Historical timeline

Analysis approach (MCNP models)

12 rad-air $\rightarrow$ rad-tissue $\rightarrow$ rem

CAAS and IEZ “No Man’s Lands”

Conclusions
Reasons for Inquiry

Dose “in free air” versus risk

Standards (ANS-8.3), (ANS-8.23) connected

Legacy 12 rad-air “annunciation zones” and IEZ

Mixed (n,γ) spectrum / dose conversion factors (DCF)

New requirements: 10CFR835 → ICRP 60 by July 2010

New facilities: DOE-STD-1189 (100 rem) → 10CFR835
Historical Timeline

Post 1958 Y-12 accident - 25 rem to muster areas

N16.2 (1969) No CAAS if “dose to man” < 25 rem

NCRP 39 (1971) 25 rem threshold


1991 ICRP 60
1996 Clarifications - “biological segregated from CAAS”

2002 - MCNP F6 for CAAS 12 rad-air (industry practice)

2007 10CFR835 amended

Is 12 rad-in-air appropriate?
Analysis Approach

HEU metal(100) -H2O homogenized critical spheres

15 gU/L (Highly Moderated) to 18.9 kgU/L (metal)

Unshielded critical spectra and particle (n,γ) leakage

MCNP F6 calculation for 12 rad-air kerma

ICRU Phantom for rad-tissue (rad-tissue : rad-air)

ICRP 60 QF (2005) for DE (rem : rad tissue)
Critical Sphere Model

Critical radius from (XSDRN)

n,γ leakage, spectra, ν*Φ, Φ
(MCNP k-code)

F1 - current, F4 – n,γ flux Φ, F14- ν* Φ

Fold flux w/ ICRU air dcf

Normalize fissions to total dose

\[ D_n = L_n \* \nu \* \Phi_n \* dcf_n \]

\[ D_\gamma = L_\gamma \* \nu \* \Phi_\gamma \* dcf_\gamma \]

\[ F = 12 / [D_n + D_\gamma] \]
18.9 kg/U HEU Metal Leakage Spectrum
Particle Leakage vs. Fissile Concentration

- Neutron Leakage
- Photon Leakage

Is 12 rad-in-air appropriate?
Average Leakage Energy vs. Fissile Concentration

![Graph showing average leakage energy vs. fissile concentration. The graph compares neutron and photon leakage energy across different concentrations.](image-url)
Simplified MCNP Tissue Dose Calculation Model

Aligned and expanded disc source 22 cm radius (mixed n,γ)

Tally Volume

ICRU Tissue Phantom

15 cm

10 mm

50 cm air

Absorbed Dose (rad-tissue) per Fission

Is 12 rad-in-air appropriate?
Ratio rad-tissue to 12 rad-air (MCNP F6)

<table>
<thead>
<tr>
<th>Concentration (gU/L)</th>
<th>Total Kerma in Tissue Per 12 Rad in Air (Rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.5:1</td>
</tr>
<tr>
<td>20</td>
<td>4:5 : 1 CASR</td>
</tr>
<tr>
<td>30</td>
<td>4.4 : 1 ANS 8.3</td>
</tr>
<tr>
<td>40</td>
<td>5:1</td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>10000</td>
<td></td>
</tr>
<tr>
<td>100000</td>
<td></td>
</tr>
</tbody>
</table>
Effective Quality Factors for Neutrons (Veinot - Hertel)

Is 12 rad-in-air appropriate?

Ratio rem to rad-tissue (ICRP 60 QF)

\[ QF_n \sim 12 \]

12:1

3.5:1
### Unshielded 12 rad-air, rad-tissue, rem (ICRP 60 DE)

<table>
<thead>
<tr>
<th>Fissile Conc. (gU/L)</th>
<th>Tissue eq. (12 rad air)</th>
<th>ICRP 60 DE (rem)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Highly Moderated</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>17</td>
<td>58</td>
</tr>
<tr>
<td>25</td>
<td>19</td>
<td>93</td>
</tr>
<tr>
<td>50</td>
<td>21</td>
<td>124</td>
</tr>
<tr>
<td>100</td>
<td>23</td>
<td>146</td>
</tr>
<tr>
<td><strong>Poorly Moderated</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>44</td>
<td>467</td>
</tr>
<tr>
<td>7500</td>
<td>51</td>
<td>587</td>
</tr>
<tr>
<td>10000</td>
<td>57</td>
<td>673</td>
</tr>
<tr>
<td><strong>Metal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18900</td>
<td>64</td>
<td>782</td>
</tr>
</tbody>
</table>

- **< 35 gU/l (HM):**
  - > 12 rad-air < 20 rad tissue < 100 rem
- **> 50 gU/l (moderated):**
  - > 12 rad-air > 20 rad-tissue > 120 rem
- **> 5 kgU/L (PM):**
  - > 12 rad-air > 40 rad-tissue; > 450 rem
- 18.9 kg U/L Metal:
  - > 12 rad-air > 60 rad-tissue; > 750 rem
Possible CAAS and IEZ Implications

12 rad-air $\gg$ threshold WB DE / 2 \ (converse of NCRP 1971)

12 rad-air $> 100$ rem over M-UM range
100 rem $> 12$ rad in-air (HM)

CAAS/IEZ “No Man’s Lands” for IEZ MD chosen at 100 rem

NO IEZ where CAAS ? ($< 35$ gU/L)
NO CAAS where IEZ ? ($> 35$ gU/L)

1958 Y-12 Criticality Accident $\sim 38$ gU/L
IEZ “No Man’s Land” – 15 gU/L Solution Accident

IEZ Boundary

CAAS INSTALLED / NO IEZ REQUIRED?

NO CAAS INSTALLED

< 100 rem

72 ft

< 12 rad-air

100 rem MD
29 rad-tissue
21 rad-air
100 ft

58 rem
17 rad-tissue
12 rad-air
172 ft

“This Standard assumes an alarm system.. is in place” - ANS- 8.23 Forward
CAAS “No Man’s Land” – Metal Accident

Is 12 rad-in-air appropriate?

CAAS INSTALLED

IEZ REQUIRED/ NO CAAS INSTALLED?

IEZ Boundary

< 12 rad-air

150 ft

< 100 rem

782 rem
64 rad-tissue
12 rad-air
81 ft

100 rem MD
8 rad-tissue
1.5 rad-air
231 ft

“Criticality alarm signals shall be for prompt evacuation” - ANS-8.3
Conclusions

10CFR835 - ICRP 60 DE results for unshielded mixed spectrum (10CFR835 – no explicit value defines “excessive” rad)

12 rad-air as “universal” ED definition? (depends)
CAAS/IEZ disconnect for 12 rad-air ED, 100 rem MD

Dose value as sole criteria needs further examination
Risk acceptance/ risk reduction in overall decision making

No alternate ED definition recommended
Responsibility to define ED same as MD – facility management
The specified 12 rad threshold is loosely based on one half the whole body dose at which temporary changes to whole blood cells were barely detectable using techniques available by the year 1971. Improved technology and changes in recommendations do not invalidate this threshold because it is significantly less than exposures expected to cause severe radiation sickness in adults.


e. David R. Smith, personal communication to ANS-8.3 work group, 1990.

“Consensus Standard Requirements and Guidance”
1995 Criticality Accident Alarm System Workshop, (available at OSTI)
Is 12 rad in air appropriate?

New NCRP Data on Acute Symptoms (2006)

**The Decision Dose**
(related information)

<table>
<thead>
<tr>
<th>Short-term a Whole-Body Dose [rad (Gy)]</th>
<th>Acute Symptoms (nausea and vomiting within 4 h) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 (0.5)</td>
<td>0</td>
</tr>
<tr>
<td>100 (1)</td>
<td>5 – 30</td>
</tr>
<tr>
<td>150 (1.5)</td>
<td>40</td>
</tr>
<tr>
<td>300 (3)</td>
<td>75</td>
</tr>
<tr>
<td>600 (6)</td>
<td>100</td>
</tr>
</tbody>
</table>

*a* Short-term refers to the radiation exposure during the initial response to the incident. The acute effects listed are likely to be reduced by about one-half if radiation exposure occurs over weeks.

NCRP/ICRP 1 Gy, 1 Sv threshold for acute symptoms

NCRP Commentary No. 19, Key Elements of Preparing Emergency Responders for Radiological Emergencies...
**Response:** This is specified as the dose in free air because biological dose equivalents are dependent on many undefinable factors. For example, the quality factor is sensitive to the magnitude of the dose, the age of the recipient, the organ or portion of the body being irradiated, and other less significant considerations. The dose in free air is a physical quantity subject to unambiguous definition.

Also, the criterion of Paragraph 4.2.2 is stated to indicate that the issue of whether an alarm system is needed is segregated from the issue as to what the currently accepted conversion factors are for flux to biological dose conversion.

- “in free air” - kerma or energy deposition to air
- Biological dose equivalent - “protection quantity” (wR factors)
- Ambient dose equivalent – “operational quantity” (Quality Factors)
1. "Why does Paragraph 4.2.2 specify absorbed dose in free air? The apparent intent of this paragraph is to determine whether criticality accident systems (CASs) are needed based on potential radiation levels. If the concern is life-threatening radiation doses, the phrases absorbed dose in human tissue or whole body absorbed dose seems to be more appropriate. The phrase absorbed dose in free air is more applicable to the radiation level that a detector would experience, which is appropriate for detector sensitivity calculations (Paragraph 5.6)."

**Response:** The primary intent of the standard is to address required criticality alarm characteristics. The criterion of Paragraph 4.2.2 was therefore intentionally written in terms of detector capability, although as correctly noted, the overall goal is to provide personnel protection.
750 rem Short-term WBD and Acute Death (2006)

The Decision Dose (related information)

<table>
<thead>
<tr>
<th>Short-term Whole-Body Dose [rad (Gy)]</th>
<th>Acute Death from Radiation without Medical Treatment (%)</th>
<th>Acute Death from Radiation with Medical Treatment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 (0.5)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100 (1)</td>
<td>&lt;5</td>
<td>0</td>
</tr>
<tr>
<td>150 (1.5)</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>300 (3)</td>
<td>30 – 50</td>
<td>15 – 30</td>
</tr>
<tr>
<td>600 (6)</td>
<td>95 – 100</td>
<td>50</td>
</tr>
<tr>
<td>1,000 (10)</td>
<td>100</td>
<td>&gt;90</td>
</tr>
</tbody>
</table>

\(\gamma\)-only 750 rad or rem DE

LD 50/50

600 rad

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NCRP Commentary No. 19, Key Elements of Preparing Emergency Responders for Radiological Emergencies...