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Is 12 rad-in-air an Appropriate Quantity for "Excessive Dose"?

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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

ANS-8.3 (1979), (1986) 12 rad free air, (1997) ED

1991 ICRP 60

1996 Clarifications - “biological segregated from CAAS”

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

2007 10CFR835 amended

Analysis Approach

HEU metal(100) -H_2O 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

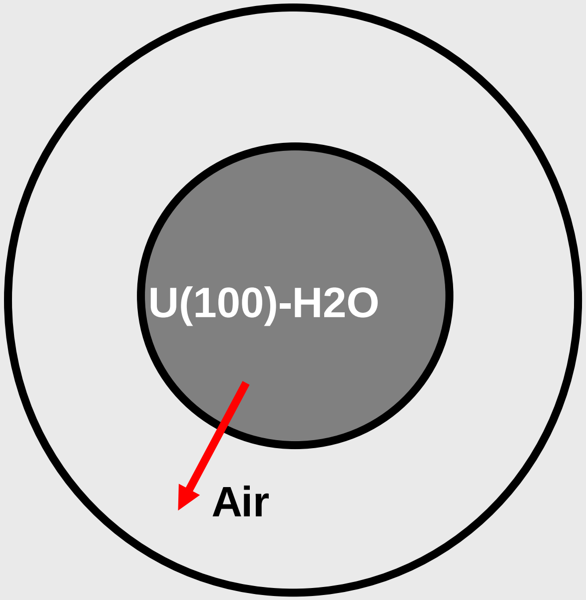
Critical radius from (XSDRN)

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 dcfs

Normalize fissions to total dose



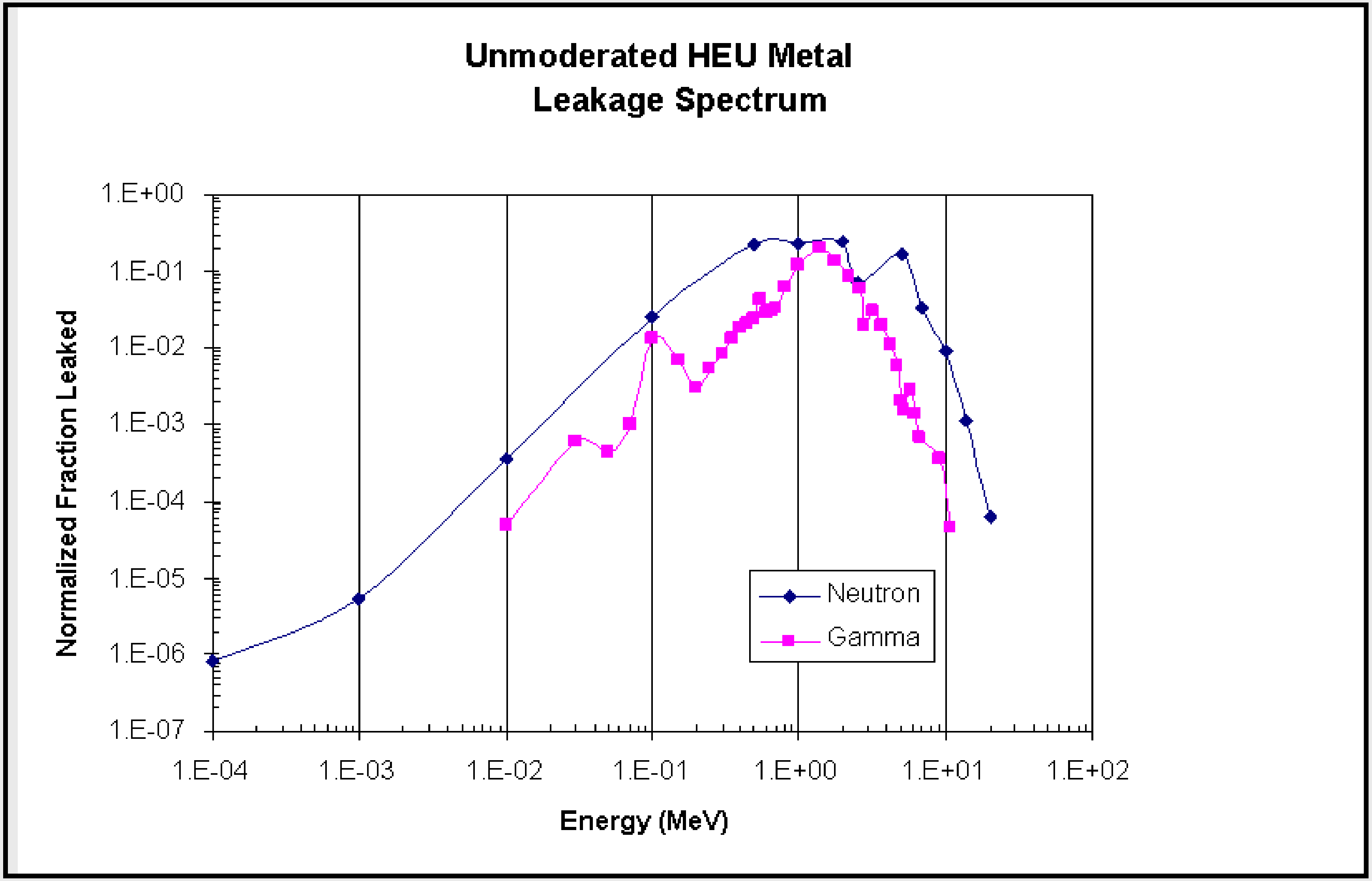
$$D_n = L_n * \nu * \Phi_n * dcf_n$$

$$D_\gamma = L_\gamma * \nu * \Phi_\gamma * dcf_\gamma$$

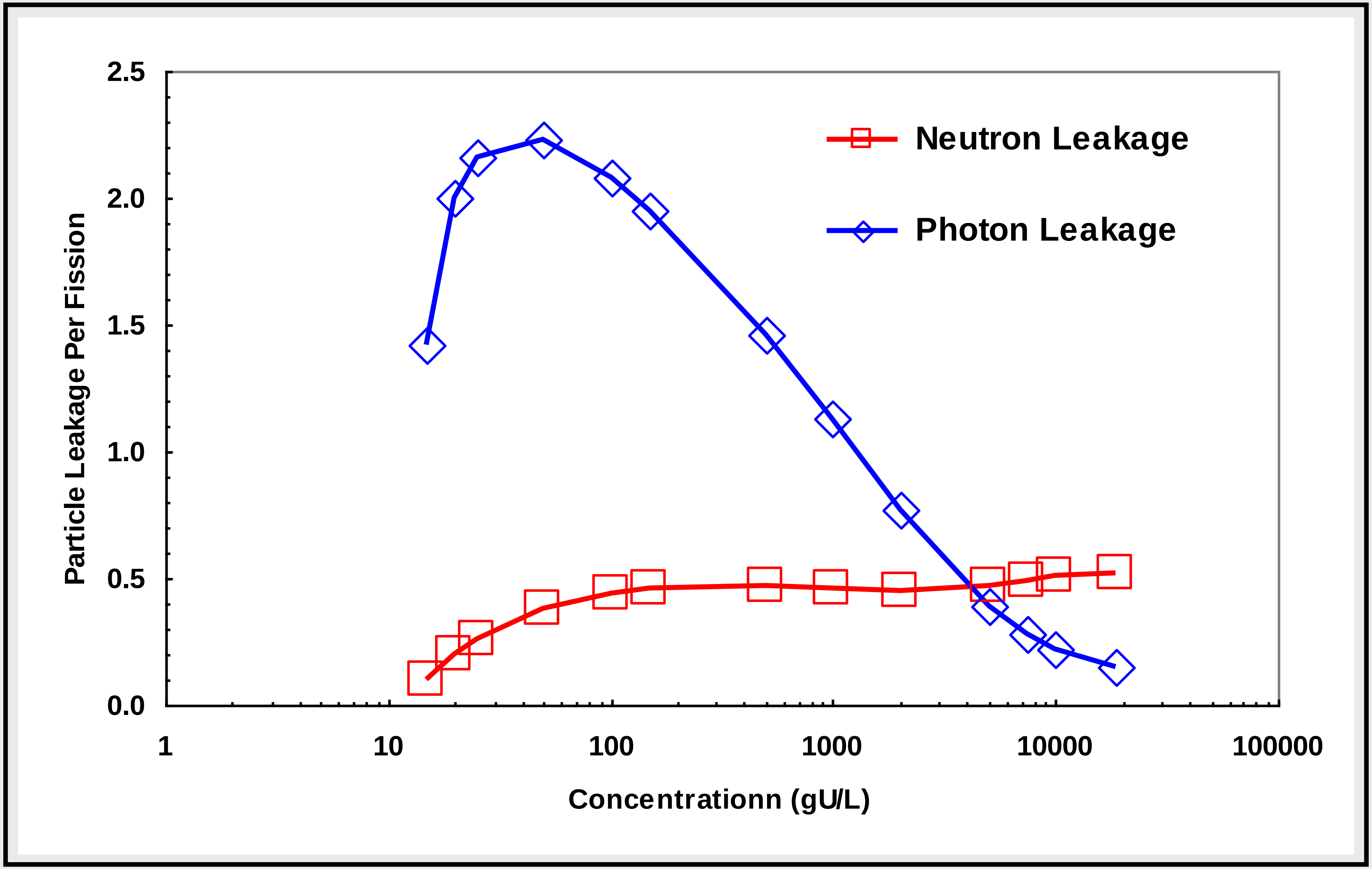
$$F = 12 / [D_n + D_\gamma]$$

Is 12 rad-in-air appropriate?

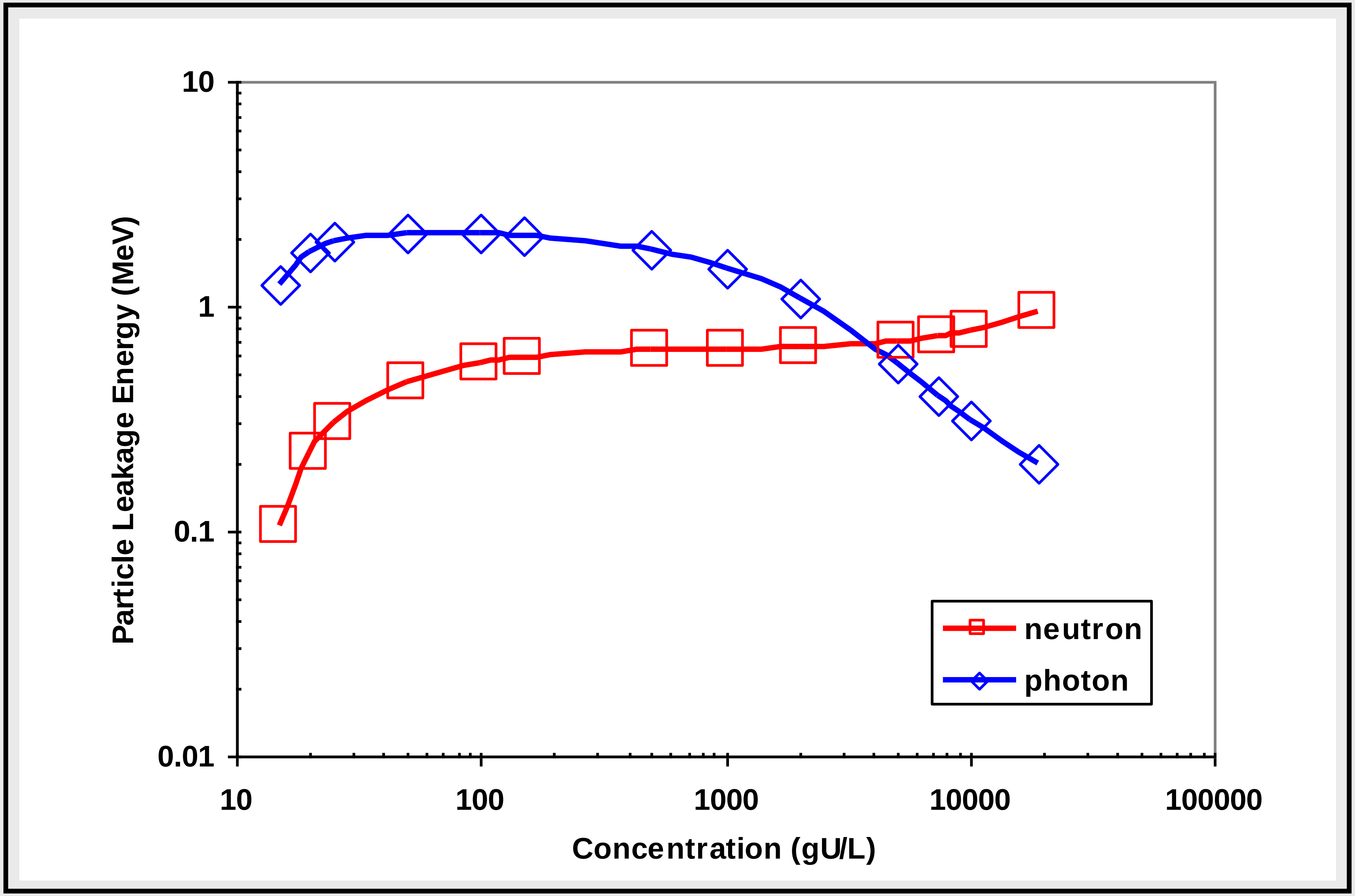
18.9 kg/U HEU Metal Leakage Spectrum



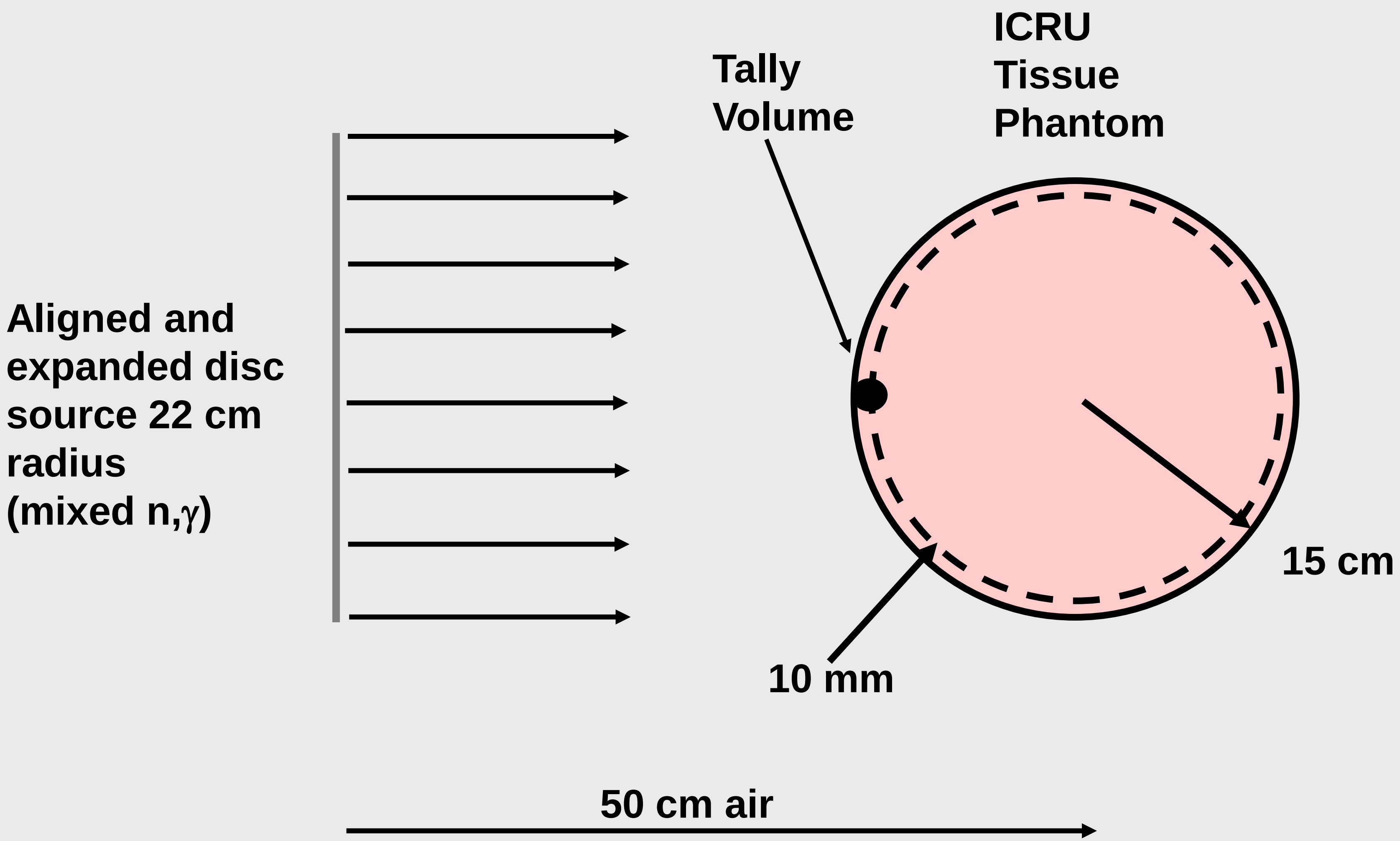
Particle Leakage vs. Fissile Concentration



Average Leakage Energy vs. Fissile Concentration

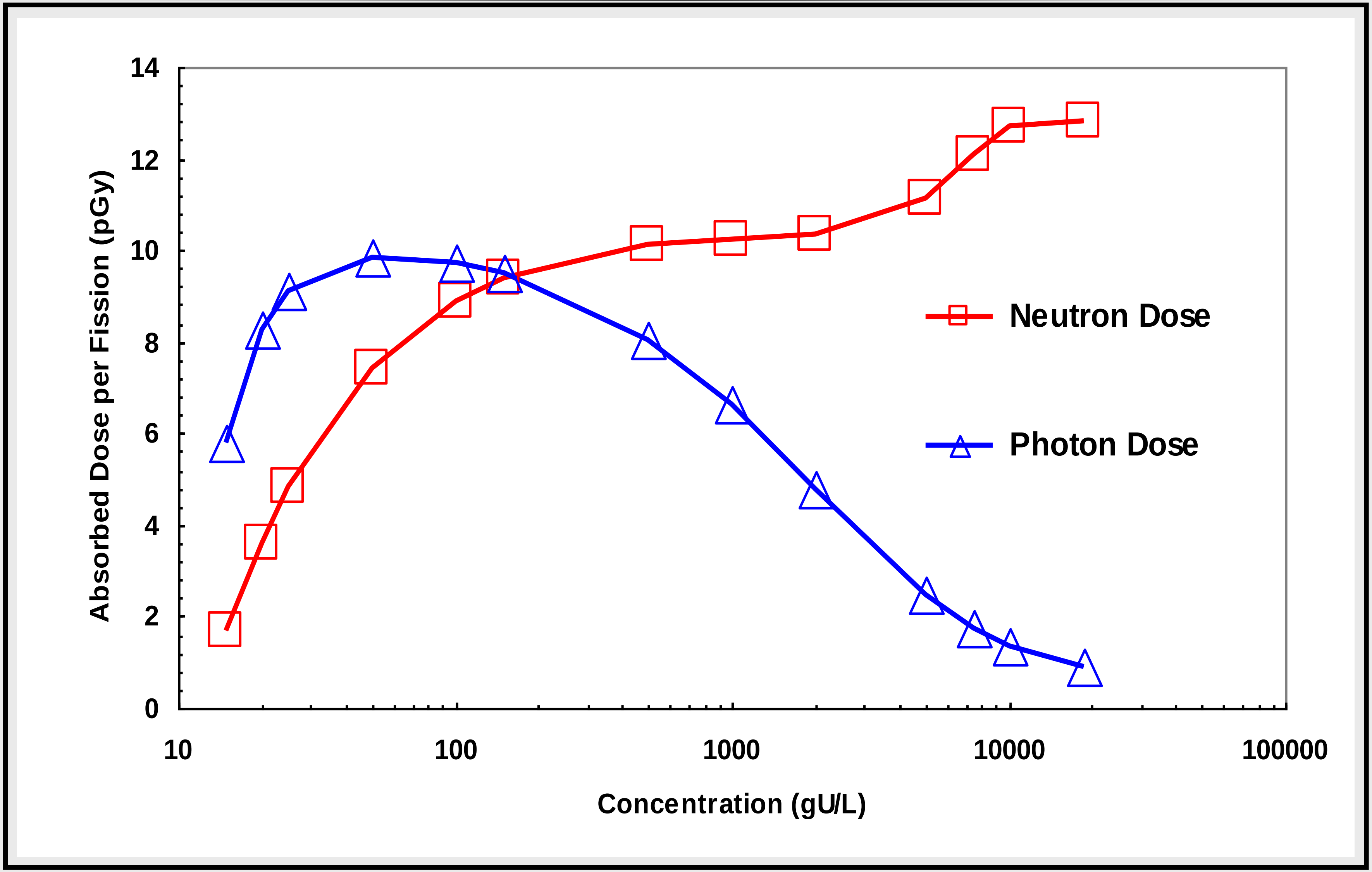


Simplified MCNP Tissue Dose Calculation Model

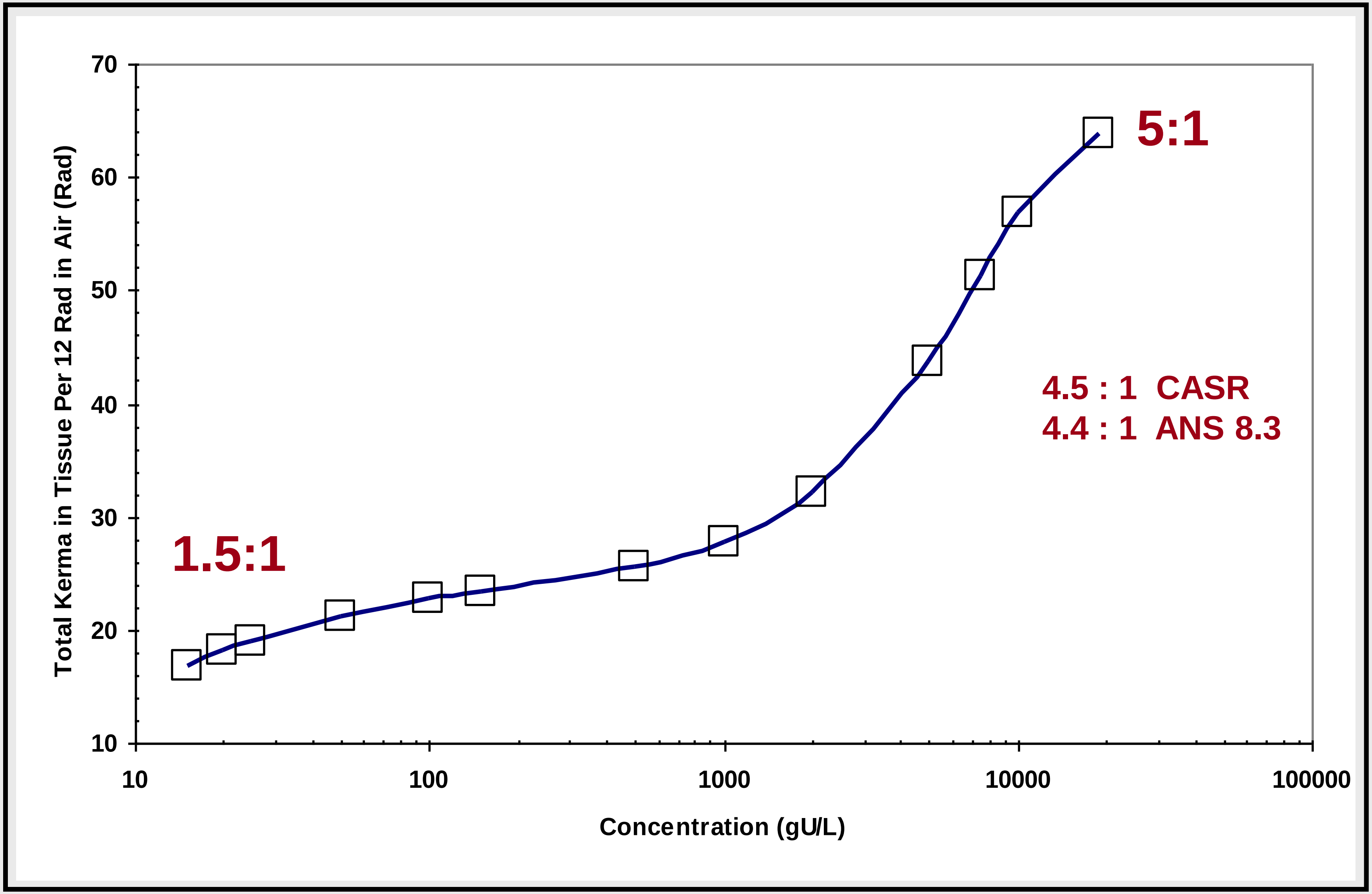


Journal of Radiation Protection Dosimetry 115, 1-4, pp.536-541 (2005)

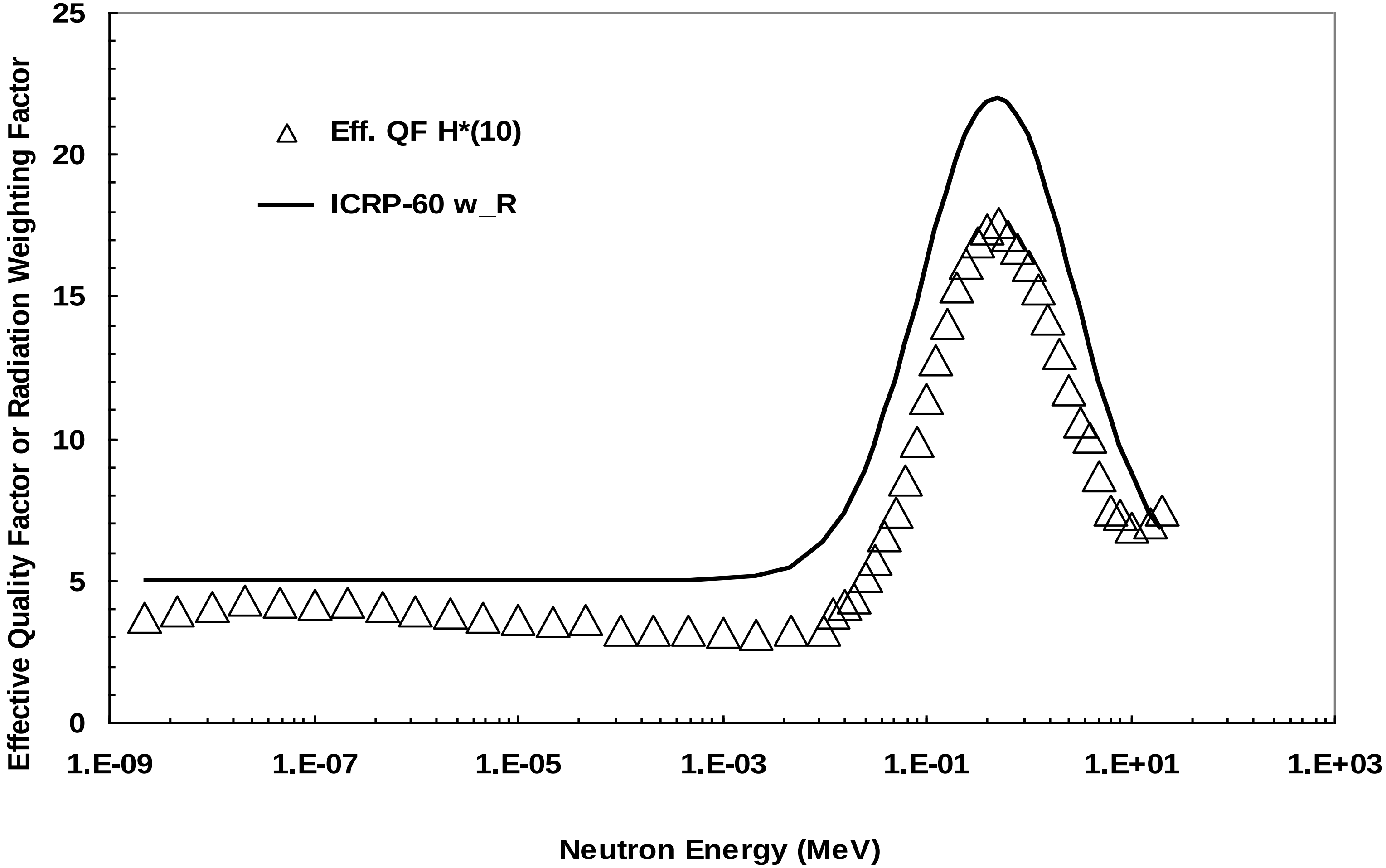
Absorbed Dose (rad-tissue) per Fission



Ratio rad-tissue to 12 rad-air (MCNP F6)

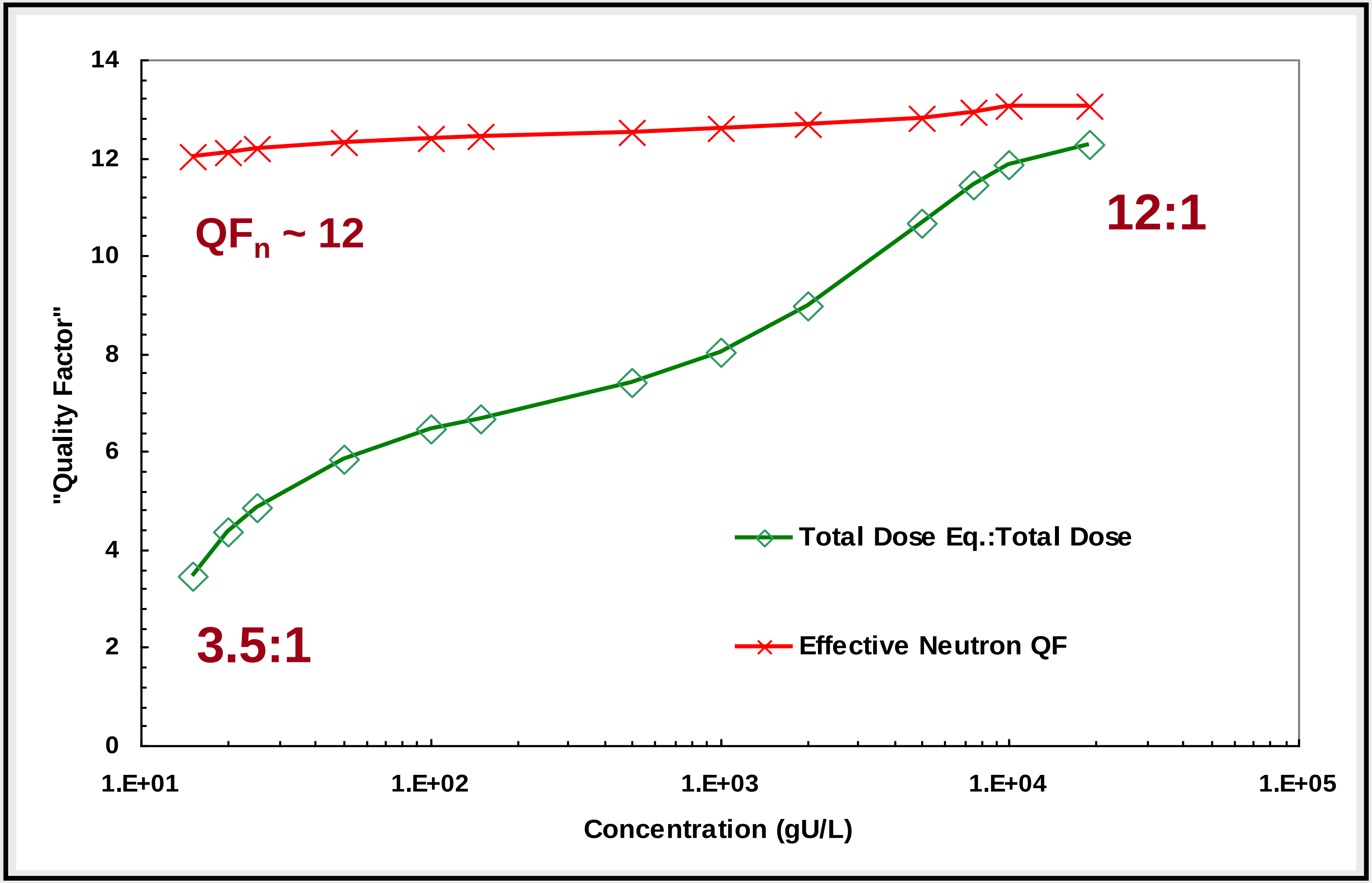


Effective Quality Factors for Neutrons (Veinot - Hertel)



Journal of Radiation Protection Dosimetry 115, 1-4, pp.536-541 (2005)

Ratio rem to rad-tissue (ICRP 60 QF)



Unshielded 12 rad-air, rad-tissue, rem (ICRP 60 DE)

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

< 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 **>>** threshold WB DE / **2** (converse of NCRP 1971)

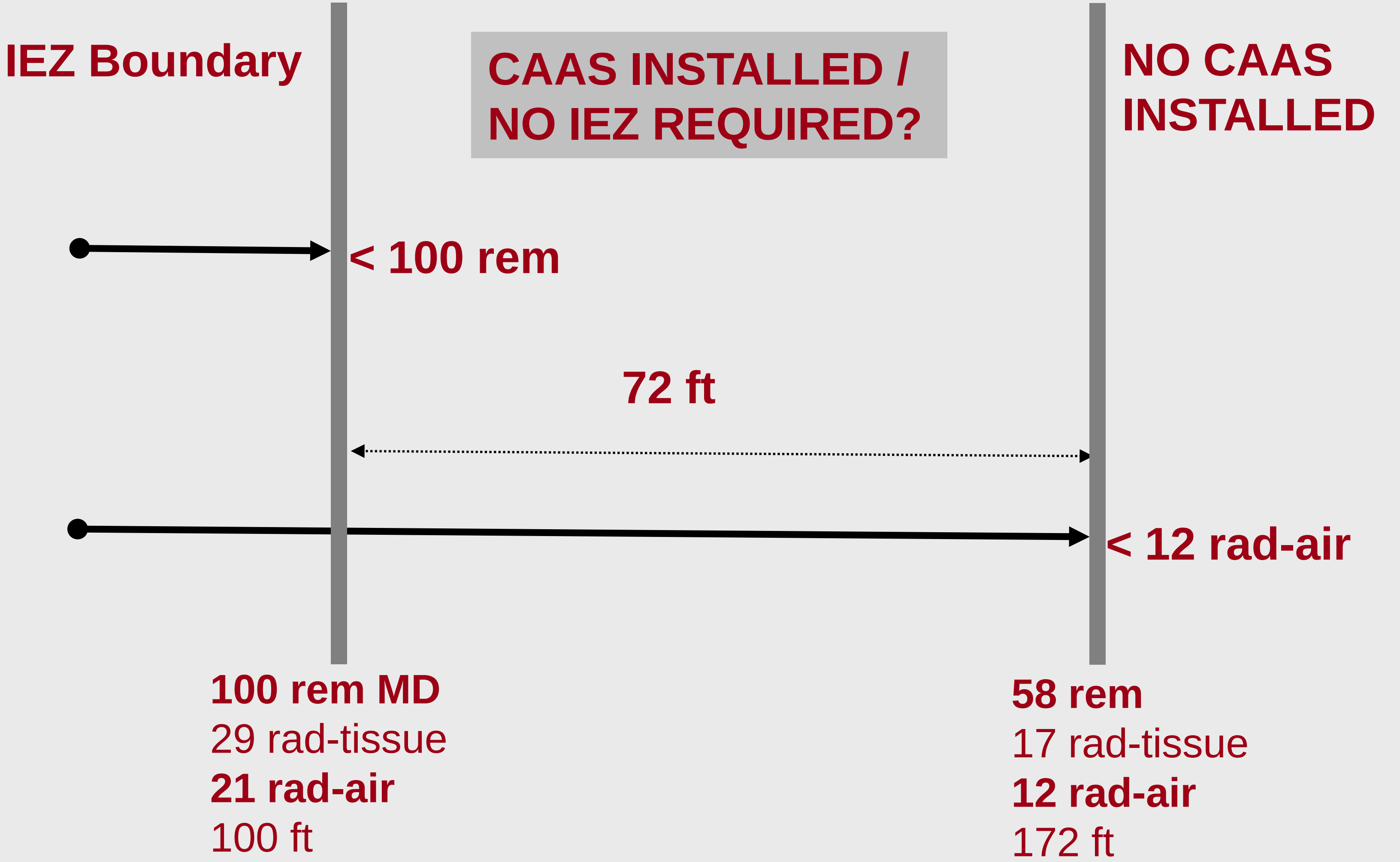
12 rad-air > 100 rem over M-UM range
100 rem > 12 rad in-air (HM)

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 ~ 38 gU/L

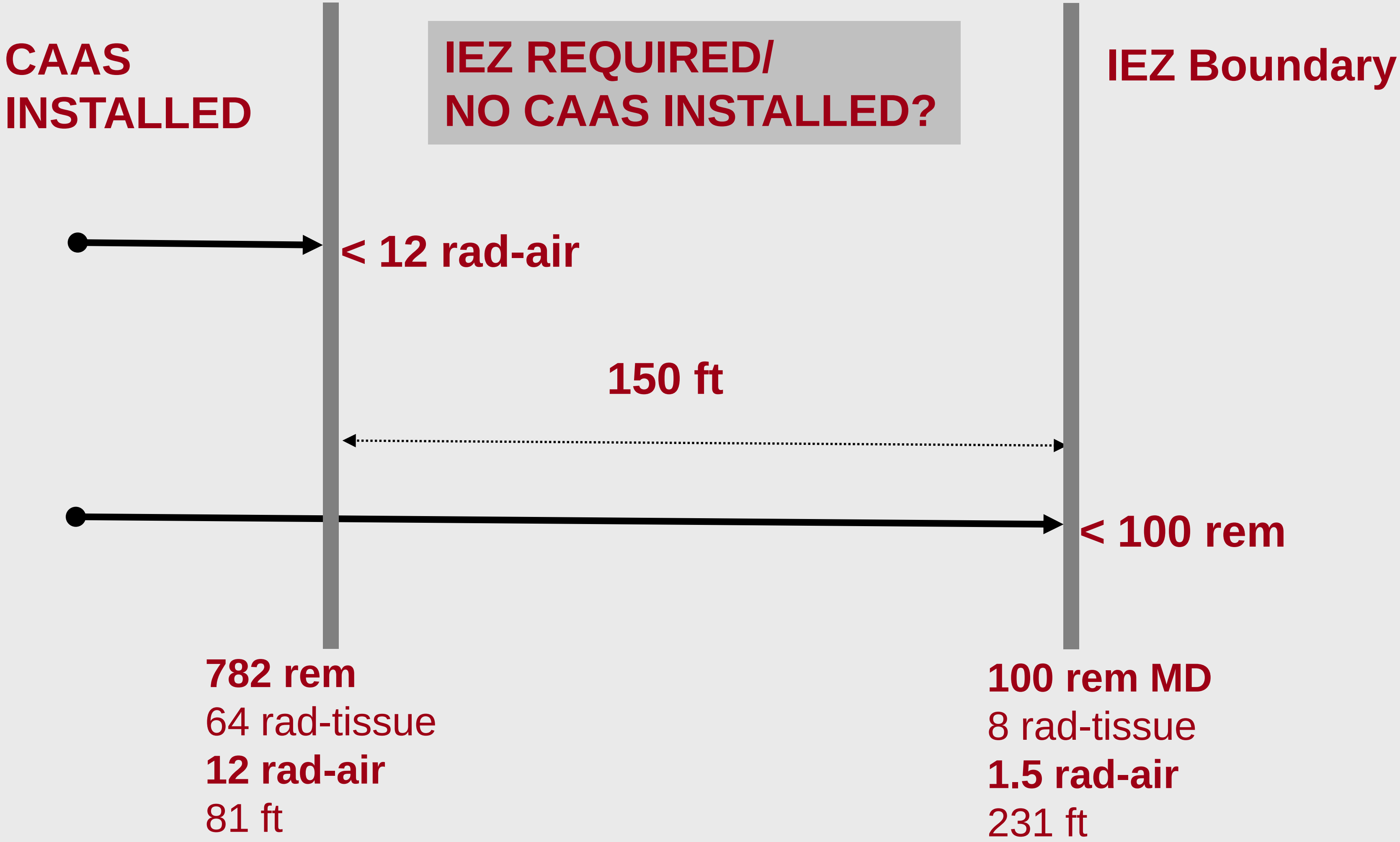
IEZ "No Man's Land" – 15 gU/L Solution Accident



"This Standard assumes an alarm system.. is in place" - ANS- 8.23 Forward

Is 12 rad-in-air appropriate?

CAAS "No Man's Land" – Metal Accident



"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

12 rad WBD threshold explained - 1995

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.[d,e] 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.

d. "Basic Radiation Protection Criteria," NCRP Report No. 39 (Bethesda, Maryland USA: National Council on Radiation Protection and Measurements, issued January 15, 1971).

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)**

New NCRP Data on Acute Symptoms (2006)

NCRP

The Decision Dose
(related information)

γ –only 12 rad WBD

Mixed (n,γ) 12 rad-air?

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

[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…*

(1996) ANS-8.3 Clarification Rad-air and QF

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" (w_R factors)
- Ambient dose equivalent – "operational quantity" (Quality Factors)

Overall Goal - Provide Personnel Protection

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.

When can 12, 10, 8 rad-air become life threatening?

750 rem Short-term WBD and Acute Death (2006)

NCRP

The Decision Dose

(related information)

Short-term[a] Whole-Body Dose [rad (Gy)]	Acute Death[b] from Radiation without Medical Treatment (%)	Acute Death from Radiation with Medical Treatment (%)
50 (0.5)	0	0
100 (1)	<5	0
150 (1.5)	<5	<5
300 (3)	30 – 50	15 – 30
600 (6)	95 – 100	50
1,000 (10)	100	>90

[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.
[b] Acute deaths are likely to occur from 30 to 180 d after exposure and few if any after that time. Estimates are for healthy adults. Persons with other injuries, and children, will be at greater risk.

(γ-only) 750 rad or rem DE →

← **LD 50/50 600 rad**

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