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Review of Dangerous Radioisotopes: What is Available in Practice, What Should We be Concerned About?

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About This Publication

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- The author has no fiscal affiliation with any private company that may be affected by this research.
- The analysis reflected in this presentation was performed by the Institute for Defense Analyses (IDA), under contract number HQ0034-14-D-0001 as amended for the Joint Staff, Joint Requirements Office (JRO) for Chemical, Biological, Radiological and Nuclear (CBRN) Defense (J-8/JRO) and the U.S. Army Office of The Surgeon General (OTSG), under Task Order CA-6-3079.
- The views expressed in this presentation are those of the author and do not reflect the official policy or position of the Department of Defense of the U.S. Government.

Objective

- Describe a mechanism for considering radioactive isotopes as credible candidates for use as radiation exposure devices (RED) or radiation dispersal devices (RDD).
  - This allows for the consideration of the credibility of a radioactive material as a radiological weapon to be applied to specific scenarios.
  - This does not replace the IAEA “A/D” ratios, but more precisely applies this concept to assessments of interest.

Radiological Weapons

- This analysis identified the radioisotopes of interest from within the full spectrum of radiological threats. Thirty one radioisotopes were evaluated for their credibility as radiological weapons under seven different routes of exposure (or types of radiological weapons), including external irradiation from a point source or contaminated ground; aerosol exposure by inhalation, ingestion, contamination, and submersion in contaminated air; and immersion in a radioactive gas.

IDA | Radiological Weapons

- 31 isotopes evaluated for credibility as radiological weapons
  - Identified from IAEA/NRC publications
  - Represent full spectrum of radiological threats
- Different routes of exposure (or types of radiological weapons)
  - Radiation Exposure Device
  - Explosive Radiological Dispersal Device
  - Aerosol Radiological Dispersal Device
    - Submersion – Dose to skin or whole body from particles in air
    - Inhalation – Dose to lungs or whole body from breathing contaminated air
    - Skin Deposition – dose from contamination settling out of the air
  - Ingestion Radiological Dispersal Device
  - Immersion Radiological Dispersal Device

Isotopes Considered as Potential Radiological Weapons

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- Hydrogen-3
- Phosphorus-32
- Iron-55
- Cobalt-57
- Cobalt-60
- Nickel-63
- Germanium-68
- Selenium-75
- Krypton-85
- Strontium-90
- Molybdenum-99
- Palladium-103
- Ruthenium-106/ Rhodium
- Cadmium-109
- Iodine-125
- Iodine-131
- Caesium-137
- Promethium-147
- Gadolinium-153
- Ytterbium-169
- Thulium-170
- Iridium-192
- Gold-198
- Polonium-210
- Radium-226
- Plutonium-238
- Plutonium-239/ Beryllium
- Americium-241
- Americium-241/ Beryllium
- Curium-244
- Californium-252

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- 31 radioisotopes
- Derived from
  - International Atomic Energy Agency (IAEA), TECDOC 1344 *Categorization of Radioactive Sources*, 2003
  - International Atomic Energy Agency (IAEA), *Dangerous Quantities of Radioactive Materials*, 2006
  - NRC, *Radionuclides of Concern*, Appendix A, 10CFR73

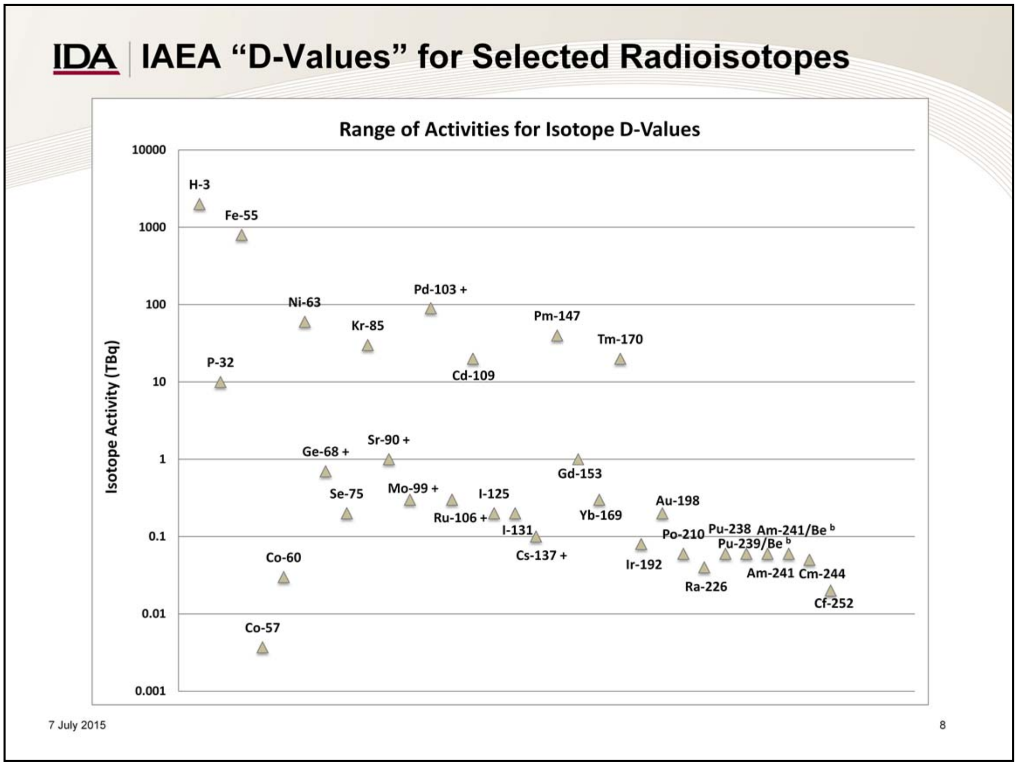
IDA | Data Sources

- International Atomic Energy Agency (IAEA), *Dangerous Quantities of Radioactive Materials*, 2006
- International Atomic Energy Agency (IAEA), TECDOC 1344 *Categorization of Radioactive Sources*, 2003
- NRC, *Radionuclides of Concern*, Appendix A, 10CFR73
- Keith F. Eckerman and Jeffrey C. Ryman, *External Exposure to Radionuclides in Air, Water, and Soil*, Federal Guidance Report No. 12, US EPA, Washington, DC, 1993

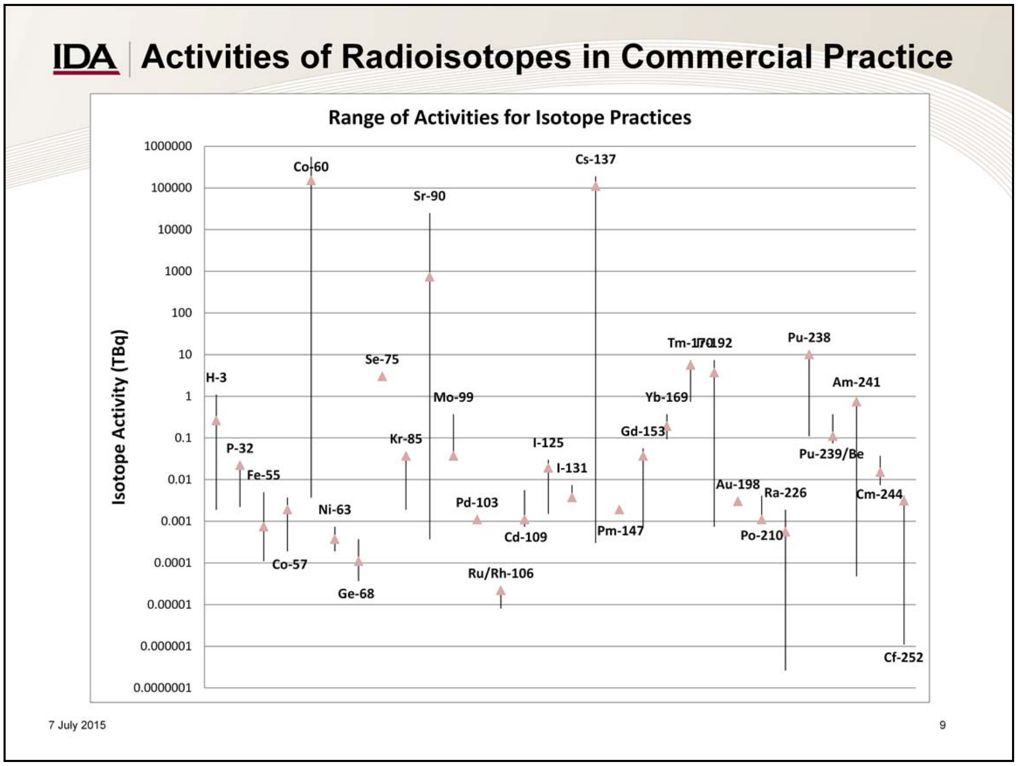
IDA | IAEA Categorization of Sources

Categories of Radioactive Sources	Definitions	Activity Ratio (A/D)
Category 1	These sources "if not safely managed or securely protected would be likely to cause permanent injury to a person who handled [them], or were otherwise in contact with [them] for more than a few minutes. It would probably be fatal to be close to this amount of unshielded material for a period of a few minutes to an hour.	$A/D \geq 1000$
Category 2	These sources "if not safely managed or securely protected could cause permanent injury to a person who handled [them], or were otherwise in contact with [them] for a short time (minutes to hours. It would probably be fatal to be close to this amount of unshielded material for a period of hours to days.	$1000 > A/D \geq 10$
Category 3	These sources "if not safely managed or securely protected could cause permanent injury to a person who handled [them], or were otherwise in contact with [them] for some hours. It would probably be fatal to be close to this amount of unshielded material for a period of days to weeks.	$10 > A/D \geq 1$
Categories 4 and 5	The sources in these categories contain relatively low activity materials and thus are generally not considered dangerous in the context of most radiological weapons unless a large enough aggregate amount of these sources were collected and used.	$1 > A/D$

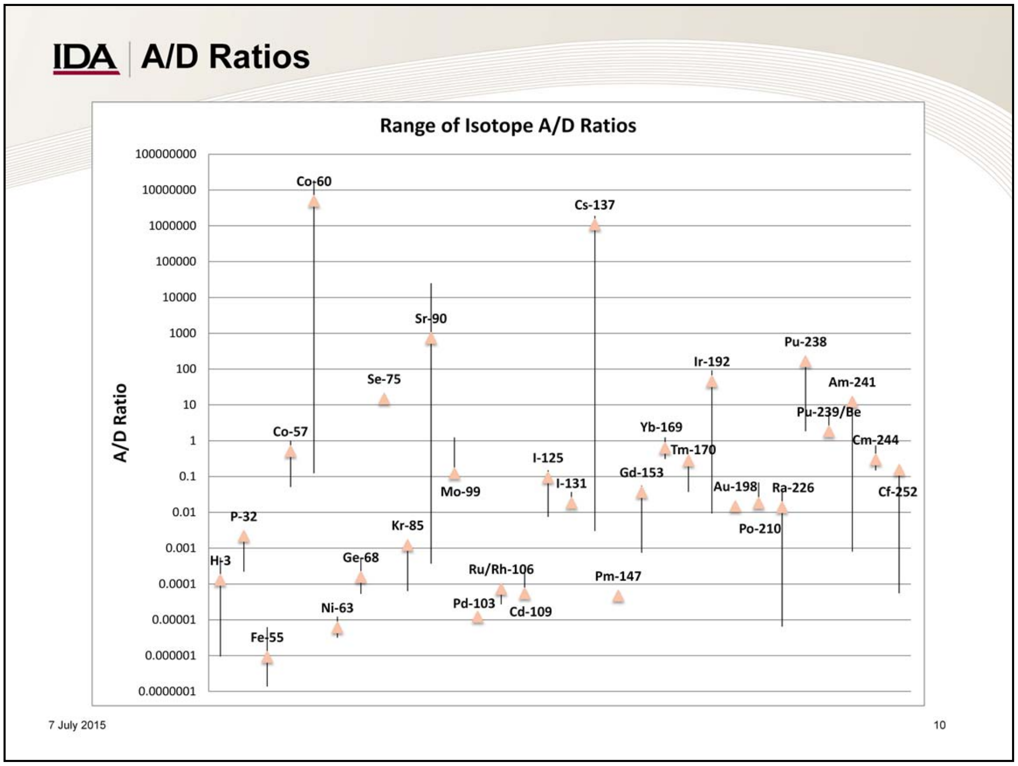
International Atomic Energy Agency (IAEA), TECDOC 1344 *Categorization of Radioactive Sources*, 2003



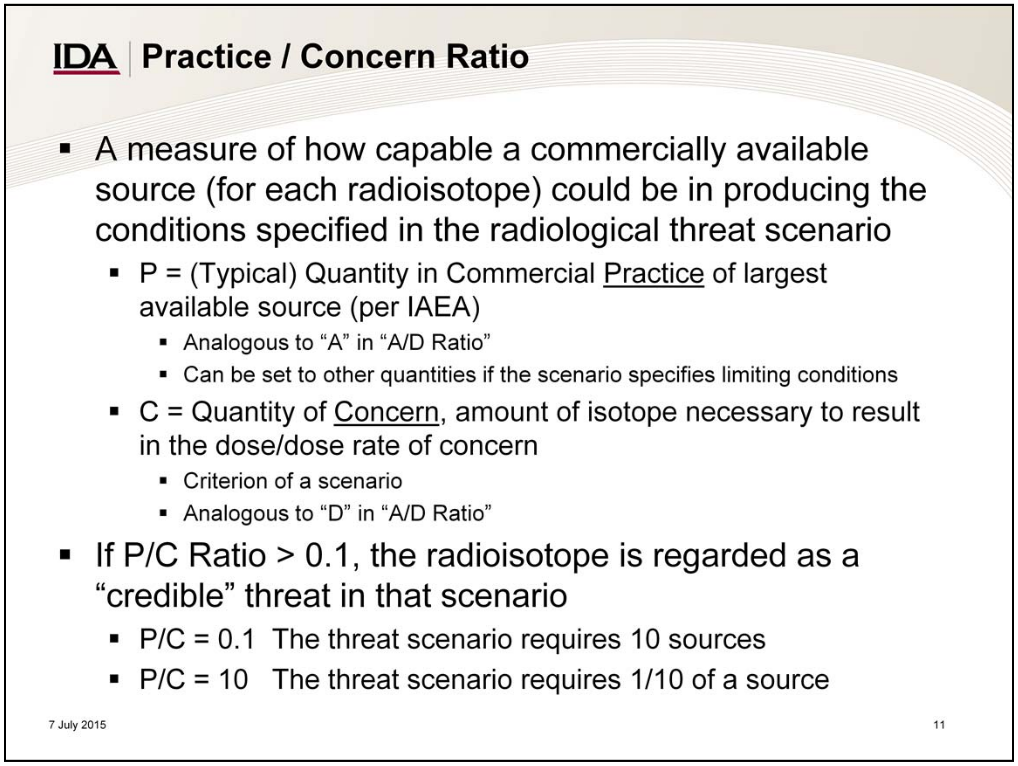
- D-Values identify "dangerous" amounts of specified radioisotopes
    - International Atomic Energy Agency (IAEA), *Dangerous Quantities of Radioactive Materials*, 2006



- Wide range of commercial applications ("practice")
  - International Atomic Energy Agency (IAEA), TECDOC 1344 *Categorization of Radioactive Sources*, 2003
- Note that the range includes the minimum and maximum values as identified on IAEA 2003 for all commercial practices
- The "triangle" is the "typical" activity of the largest commercial practice, as identified in IAEA 2003



- Range of activity used in practices (“A”) results in wide range A/D ratios
    - International Atomic Energy Agency (IAEA), TECDOC 1344 *Categorization of Radioactive Sources*, 2003
- *One method of categorizing the threat from radioactive materials as radiological weapons*
    - *High A/D (>1?) means there are sources that include a “dangerous” amount of radioactivity*



- A different method of categorizing the threat from radioactive materials as radiological weapons
- P/C is not "politically correct"
- "P" comes from IAEA 2003
- "C" is a different way of representing the "D-Value"
    - Specific to radiological weapon planning scenarios.
- P/C indicates the fraction of the activity (present in a practice) needed to result in a scenario of concern

RED Scenario

- Placement of a radioactive source near or under a seat

- Dose rate of concern
  - 1.25 Sv/hr at 1 m
    - 1.25 Sv is the threshold for casualty estimation from whole body irradiation in the NATO CBRN casualty estimation methodology
    - 1 hour is a reasonable, but arbitrary, exposure time
  - *This value may be set as a function of the scenario, base upon the objective of the analysis*

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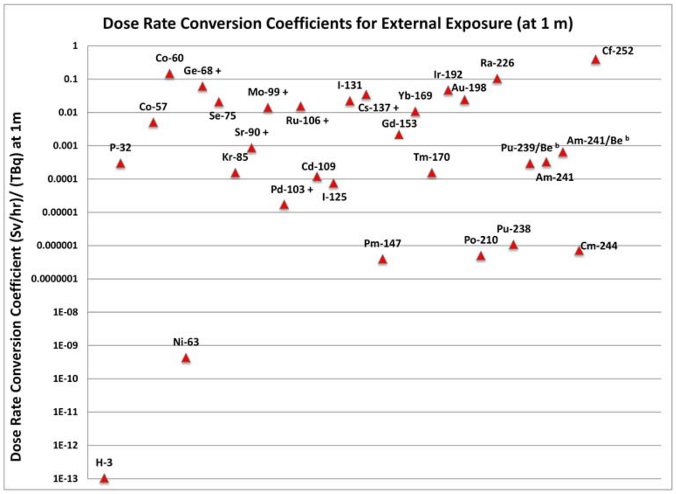
Dose Equivalent Rate Conversion Factors (Sv/hr)/ (TBq) (RED Scenario)

- RBE-weighted dose rate in the red marrow at a distance of 1 meter from the source



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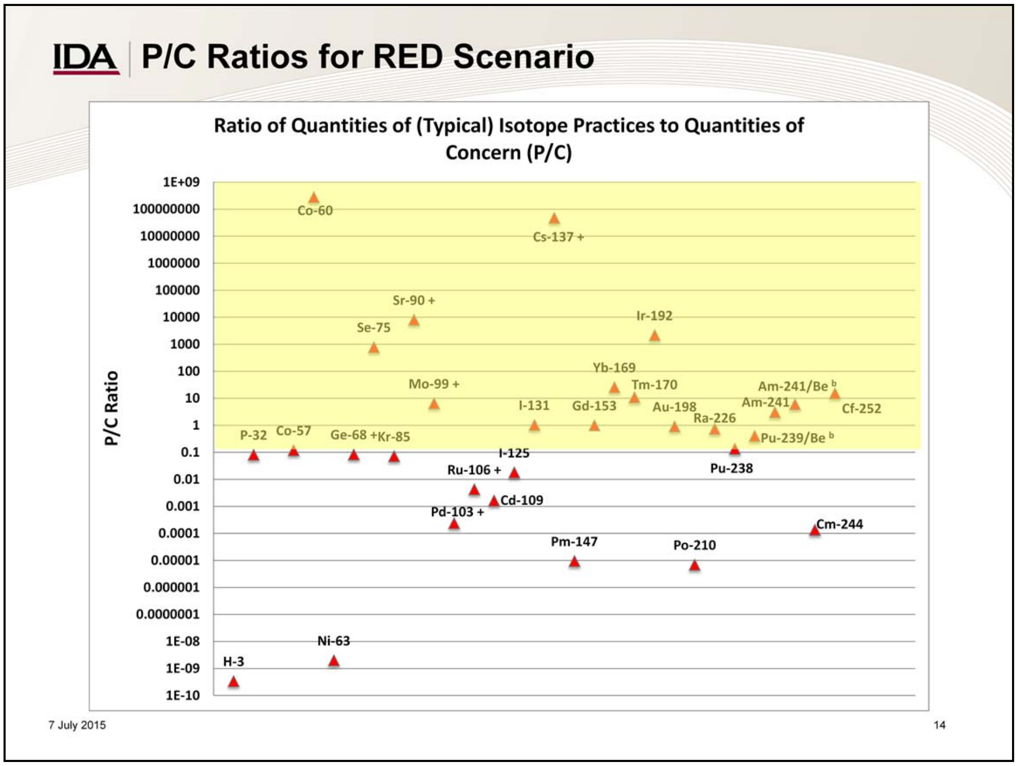
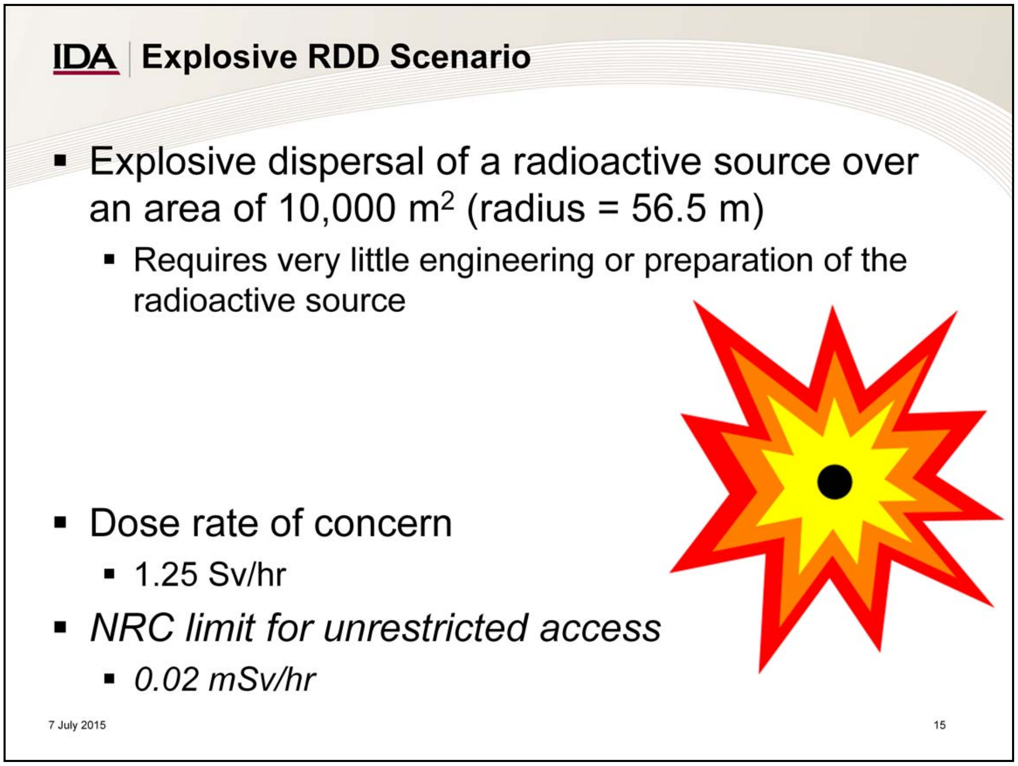
RBE-weighted dose rate in the red marrow at a distance of 1 meter from the source.

International Atomic Energy Agency (IAEA), *Dangerous Quantities of Radioactive Materials*, 2006, Tables 14 & 15, pp 71-78

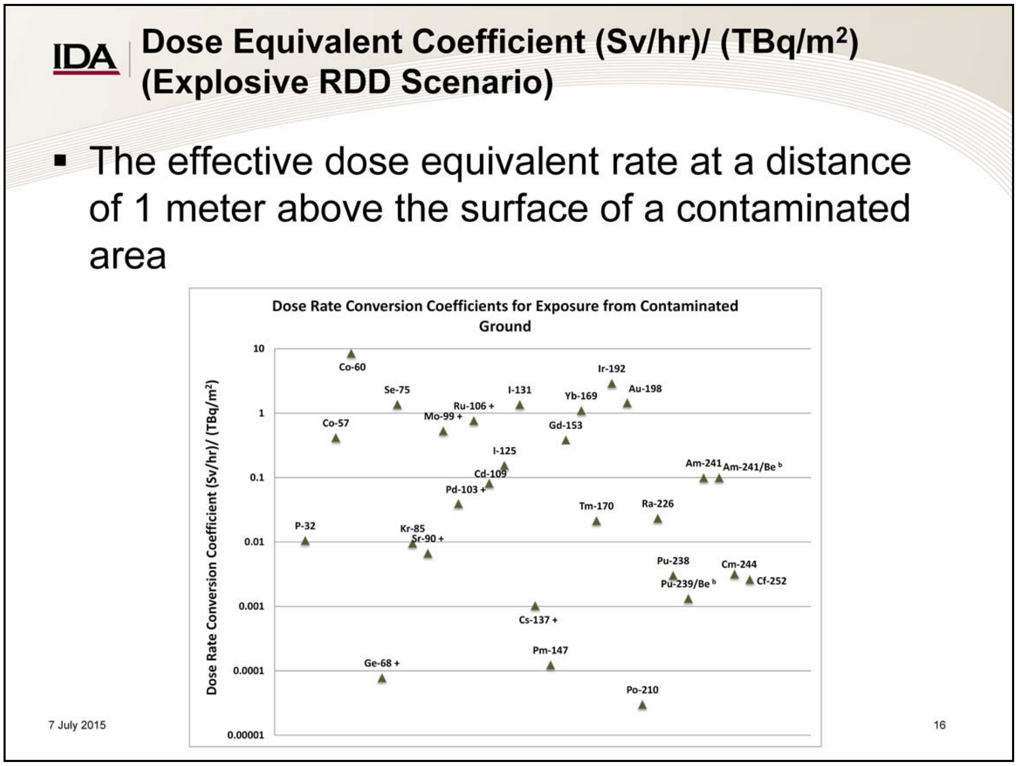


Yellow highlight is the radioisotopes with P/C >0.1

^{60}Co, ^{75}Se, ^{90}Sr, ^{99}Mo, ^{131}I, ^{137}Cs, ^{153}Gd, ^{169}Yb, ^{170}Tm, ^{192}Ir, ^{198}Au, ^{226}Ra, ^{238}Pu, ^{239}Pu/Be, ^{241}Am, ^{241}Am/Be, and ^{252}Cf



- Different standard for area denial than for casualty production

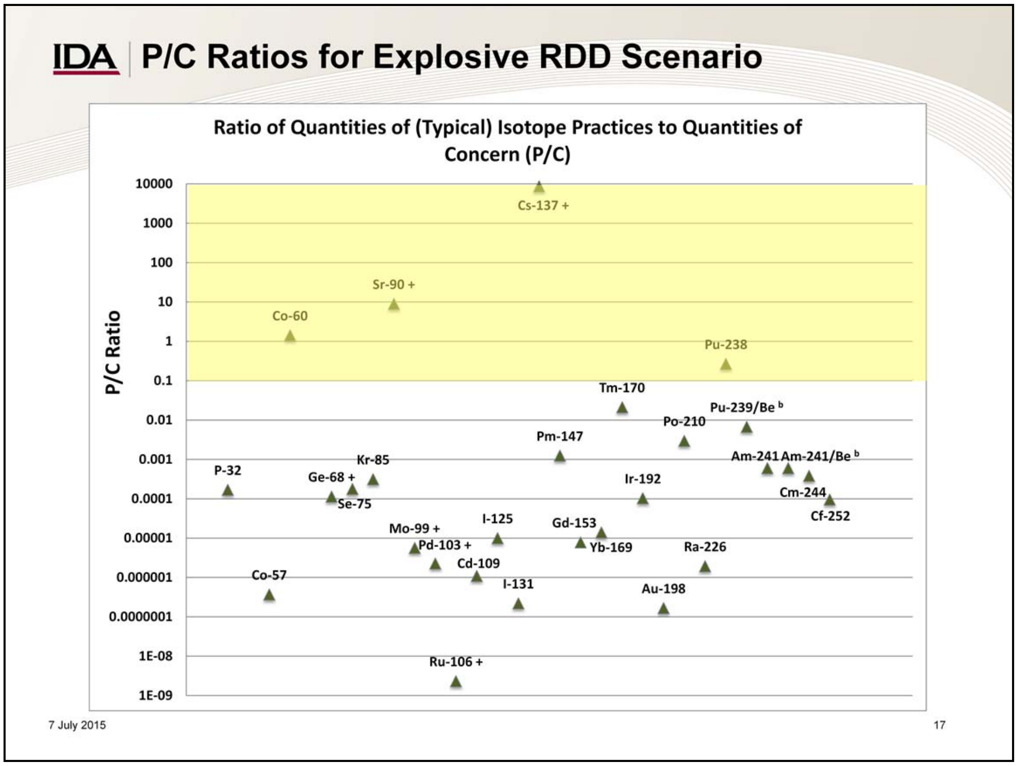


Derived from table III.3 of Federal Guidance Report No. 12 (FGR12)

Keith F. Eckerman and Jeffrey C. Ryman, *External Exposure to Radionuclides in Air, Water, and Soil*, Federal Guidance Report No. 12, US EPA, Washington, DC, 1993, 93 -109.

[b]The activity given is that of the alpha-emitting radionuclide, e.g., ^{239}Pu or ^{241}Am.

[+]Includes dose from decay products



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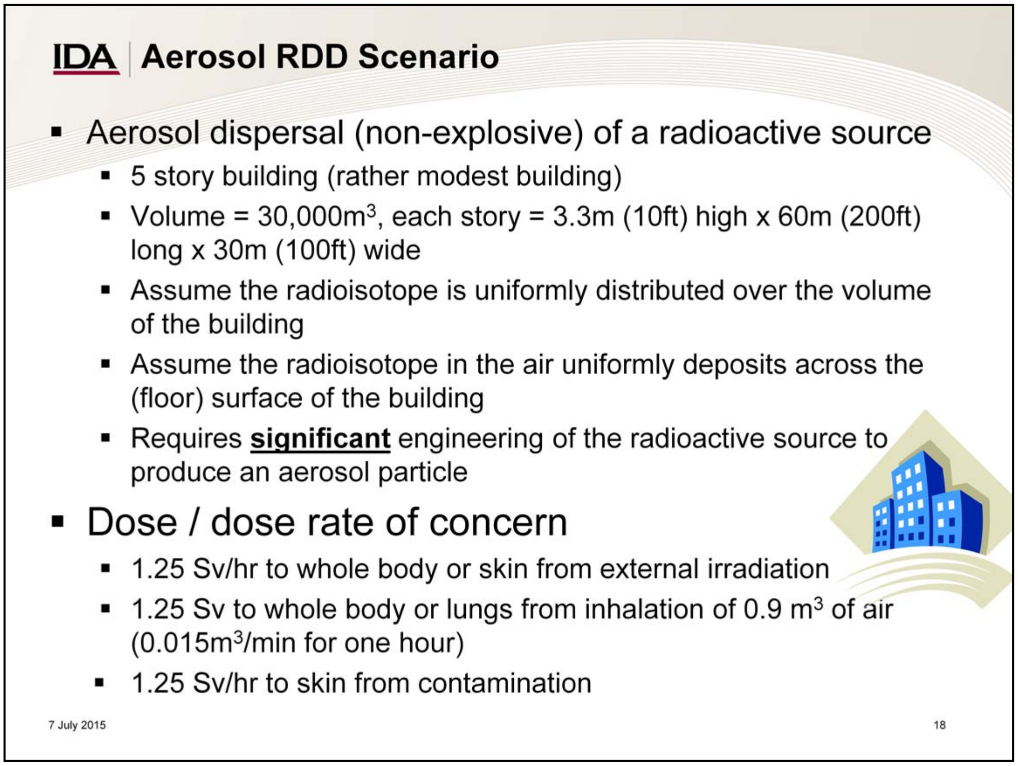
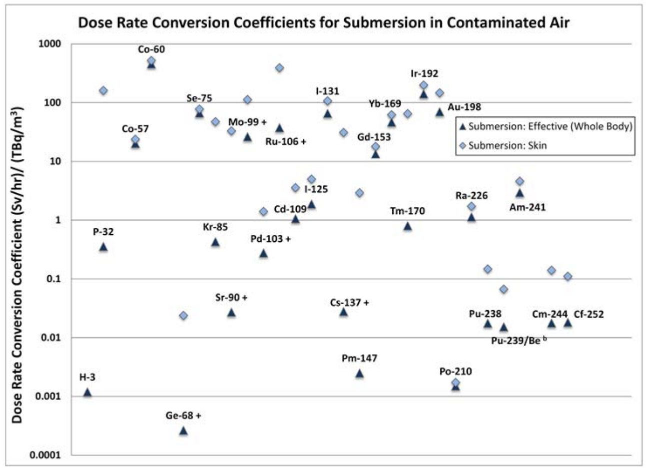
^{60}Co, ^{90}Sr, ^{137}Cs, ^{238}Pu



The "respirable intake fraction" is assumed to be 0.0001 of the radioactive material present in the source (this is the same as used by the IAEA for the inhalation scenario). IAEA 2006, 38.

Effective Dose Equivalent Coefficient from Submersion in Contaminated Air (Sv/hr)/(TBq/m^3)

- The effective (whole body) and skin dose equivalent rates, from submersion in contaminated air



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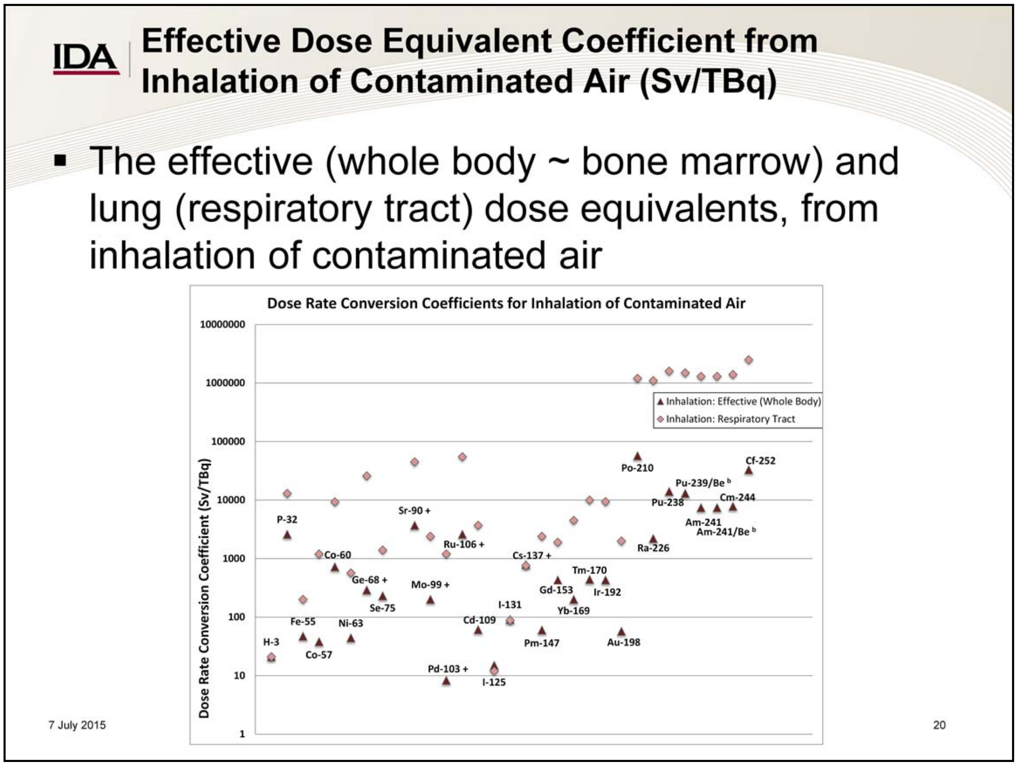
Note, as an observation, that the skin dose rate conversion factor is almost always significantly higher than the equivalent whole body dose rate conversion factor

Derived from Table III.1 of Keith F. Eckerman and Jeffrey C. Ryman, *External Exposure to Radionuclides in Air, Water, and Soil*, Federal Guidance Report No. 12, US EPA, Washington, DC, 1993, 93 -109.

[b]The activity given, and other coefficients and values, are for that of the alpha-emitting radionuclide, e.g., ^{239}Pu or ^{241}Am. The dose from neutrons was not considered.



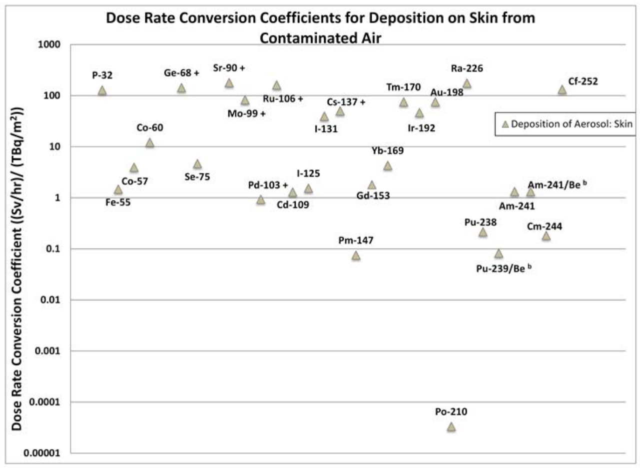
*Derived from International Atomic Energy Agency (IAEA), *Dangerous Quantities of Radioactive Materials*, 2006, Table 18, pp 83-93

**The activity given, and other coefficients and values, are for that of the alpha-emitting radionuclide, e.g., ^{239}Pu or ^{241}Am. The dose from neutrons was not considered.

$^{+}$ Indicates the radionuclides for which the progeny were significant sources of dose.

Effective Dose Equivalent Coefficient from Skin Contamination (Sv/hr)/ (TBq/m^2)

- The skin dose equivalent rates, from deposition of aerosols in contaminated air



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*Derived from International Atomic Energy Agency (IAEA), *Dangerous Quantities of Radioactive Materials*, 2006, Table 19, pp 94-102

**The activity given, and other coefficients and values, are for that of the alpha-emitting radionuclide, e.g., ^{239}Pu or ^{241}Am. The dose from neutrons was not considered.

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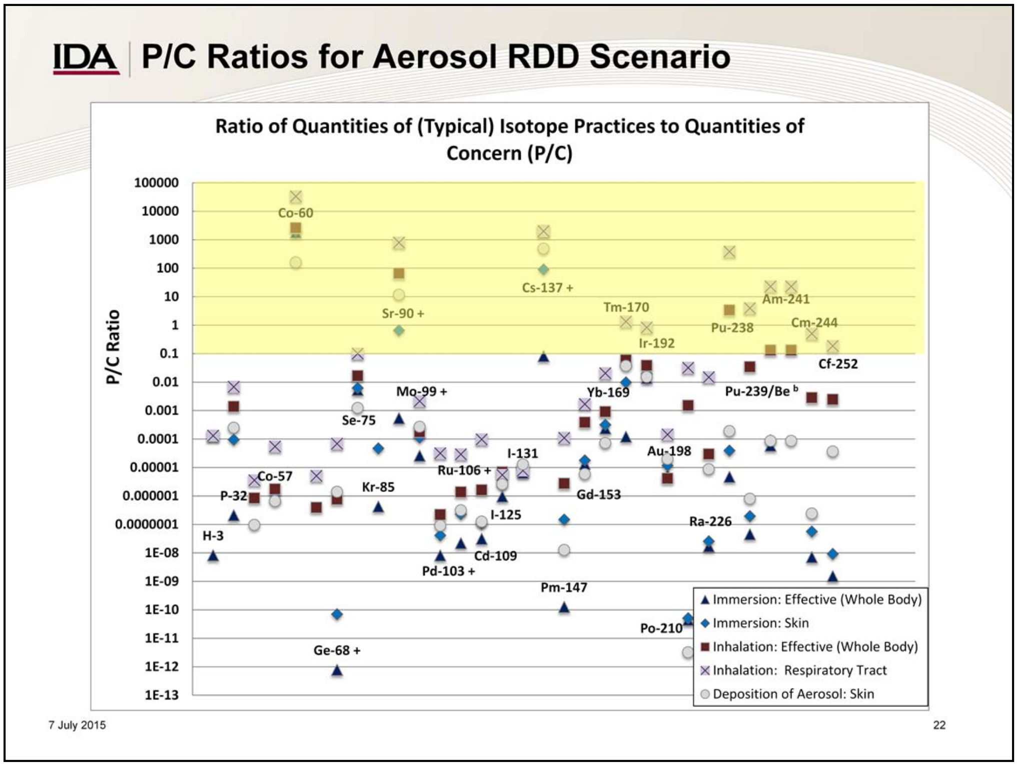

Yellow highlight is the radioisotopes with P/C >0.1

Submersion: Effective (Whole Body) Co-60,

Submersion: Skin Co-60, Sr-90, Cs-137

Inhalation: Effective (Whole Body) Co-60, Sr-90, Cs-137, Pu-238, Am-241, Am-241/Be,

Inhalation: Respiratory Tract Co-60, Se-75, Sr-90, Cs-137, Tm-170, Ir-192, Pu-238, Pu-239/Be, Am-241, Am-241/Be, Cm-244, Cf-252

Deposition of Aerosol: Skin Co-60, Sr-90, Cs-137,

^{60}Co, ^{75}Se, ^{90}Sr, ^{99}Mo, ^{131}I, ^{137}Cs, ^{153}Gd, ^{169}Yb, ^{170}Tm, ^{192}Ir, ^{198}Au, ^{226}Ra, ^{238}Pu, ^{239}Pu/Be, ^{241}Am, ^{241}Am/Be, and ^{252}Cf

Ingestion RDD Scenario

- Dispersal of a radioactive source into a volume of 40,000 liters (40 m^3, or 5,280 gal, approximately the volume of a large tanker truck)
  - Assume the radioisotope is uniformly distributed over the entire volume
  - Highly dependent on the solubility of the radioactive source
- Ingestion of 2 liters per day for five days
- Committed Effective Dose Equivalent of concern
  - 1.25 Sv

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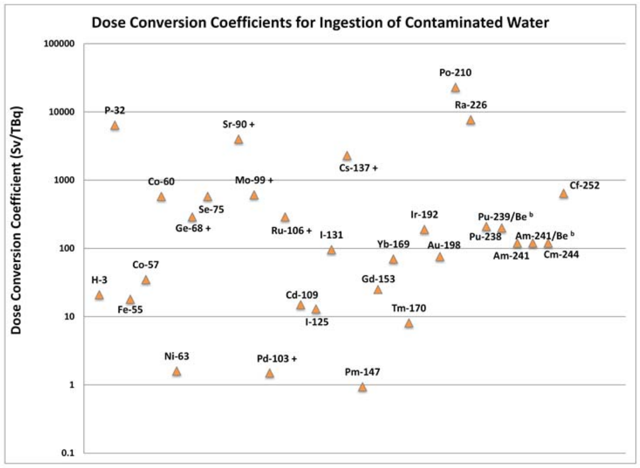
Effective Dose Equivalent Coefficient for Ingestion (Sv/TBq)

- The effective (whole body ~ bone marrow) dose equivalents, from ingestion of contaminated water



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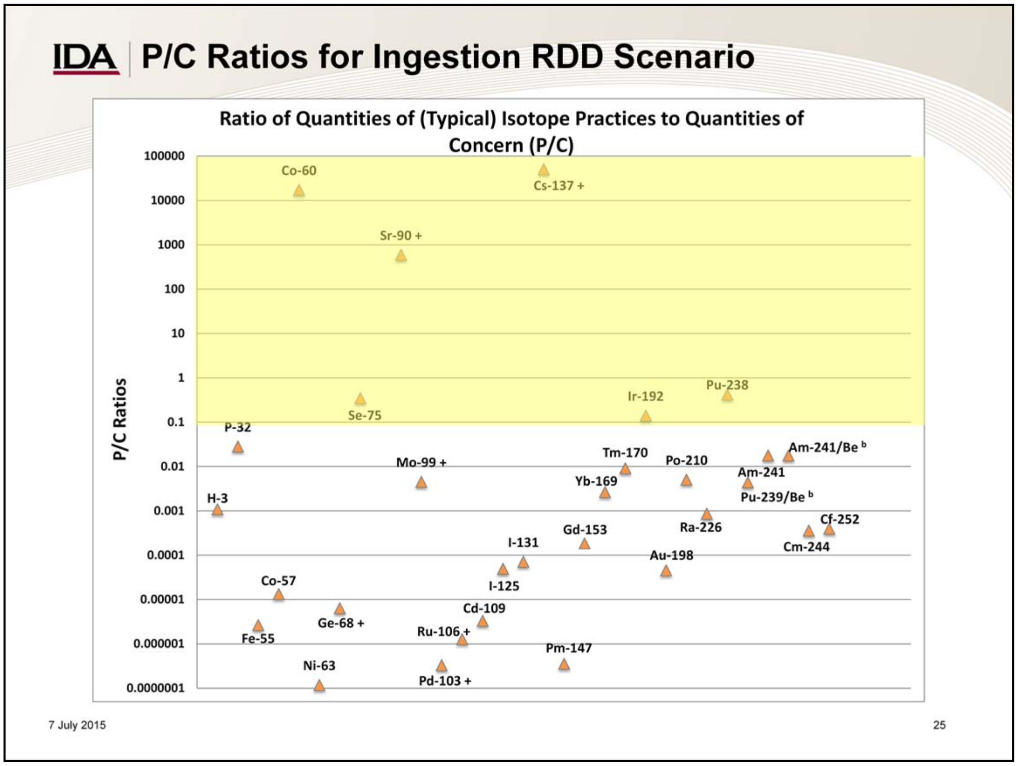
*Derived from International Atomic Energy Agency (IAEA), *Dangerous Quantities of Radioactive Materials*, 2006, Table 19, pp 94-101

**The activity given, and other coefficients and values, are for that of the alpha-emitting radionuclide, e.g., ^{239}Pu or ^{241}Am. The dose from neutrons was not considered.

$^{+}$ Indicates the radionuclides for which the progeny were significant sources of dose.



Yellow highlight is the radioisotopes with P/C >0.1

Ingestion ^{60}Co, ^{75}Se, ^{90}Sr, ^{137}Cs, ^{192}Ir, ^{238}Pu

IDA | Immersion RDD Scenario

- Immersion in gaseous radioactive material
  - Limited number of radioactive materials are gasses at room temperature and pressure
    - Neon-13
    - Argon
    - Krypton
    - Xenon
  - Different from immersion in air contaminated with an aerosol
- Requires a **large** quantity of radioactive material in a relatively small enclosed space to result in significant dose to the whole body (red marrow).
- Immersion in radioactive material is **not** considered a credible threat.

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Summary

- Using a P/C ratio for a scenario of concern can identify radioisotopes that may credibly pose a threat in that scenario:
- Radiation Exposure Device
  - ^{60}Co, ^{75}Se, ^{90}Sr, ^{99}Mo, ^{131}I, ^{137}Cs, ^{153}Gd, ^{169}Yb, ^{170}Tm, ^{192}Ir, ^{198}Au, ^{226}Ra, ^{238}Pu, $^{239}Pu/Be$, ^{241}Am, $^{241}Am/Be$, and ^{252}Cf
- Explosive Radiological Dispersal Device
  - ^{60}Co, ^{90}Sr, ^{137}Cs, ^{238}Pu
- Aerosol Radiological Dispersal Device
  - Submersion: Effective (Whole Body) – ^{60}Co
  - Submersion: Skin – ^{60}Co, ^{90}Sr, ^{137}Cs
  - Inhalation: Effective (Whole Body) – ^{60}Co, ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{241}Am, $^{241}Am/Be$,
  - Inhalation: Respiratory Tract – ^{60}Co, ^{75}Se, ^{90}Sr, ^{137}Cs, ^{170}Tm, ^{192}Ir, ^{238}Pu, $^{239}Pu/Be$, ^{241}Am, $^{241}Am/Be$, ^{244}Cm, ^{252}Cf
  - Deposition of Aerosol: Skin – ^{60}Co, ^{90}Sr, ^{137}Cs
- Ingestion Radiological Dispersal Device
  - ^{60}Co, ^{75}Se, ^{90}Sr, ^{137}Cs, ^{192}Ir, ^{238}Pu
- Immersion Radiological Dispersal Device - NONE

IDA | Conclusion

- ^{60}Co, ^{90}Sr, ^{137}Cs, ^{238}Pu
  - Common as credible across most (if not all) scenarios
- But ALSO:
  - Radiation Exposure Device – ^{75}Se, ^{99}Mo, ^{131}I, ^{153}Gd, ^{169}Yb, ^{170}Tm, ^{192}Ir, ^{198}Au, ^{226}Ra, ^{239}Pu/Be, ^{241}Am, ^{241}Am/Be, ^{252}Cf
  - Aerosol Radiological Dispersal Device
    - Inhalation: Effective (Whole Body) – ^{241}Am, ^{241}Am/Be
    - Inhalation: Respiratory Tract – ^{60}Co, ^{75}Se, ^{90}Sr, ^{170}Tm, ^{192}Ir, ^{239}Pu/Be, ^{241}Am, ^{241}Am/Be, ^{244}Cm, ^{252}Cf
  - Ingestion Radiological Dispersal Device – ^{75}Se, ^{192}Ir
- This does not account for physical form or security, which may pose a significant engineering challenge …
- Can be applied to different scenarios, specific to the particular area, operation, or issue

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Questions?

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This presentation is prepared for the 2015 meeting of the Radiation Injury Treatment Network (RITN) and is intended to provide a context to the type and scale of radiological weapons that would result in casualties.

15. SUBJECT TERMS

Radiation Injury Treat Network, NITN, radiological weapons

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