RIPB in ALARA

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What is risk and risk management?

- Risk = Consequences x Probability
- Risk increases proportionately with either the consequences of the event or its likelihood
- Risk management requires all risks be first brought to an equivalent level and then all reduced accordingly.
- Many people associate any claim that nuclear power can be safe to be synonymous with a zero risk†
- Any expectation that an activity have zero risk then requires that the activity simply not take place as any activity will have some risk

†Myslobodsky M. Origin of radiophobias. *Perspectives in Biol. Med.* **44**, 543-555, 2001

Risk management fundamentals

B_i is the risk of the outcome A_i
C_i is the risk reduction of A_i per $

$$K_D = (B_D/C_D) \Big/ \sum_{i=1}^{N} B_i/C_i$$

- In technical jargon;
  - In a generic sense, this would be to say that if risks from outcomes A_1 through A_N have risk metrics of B_1 through B_N, then if each of these risks can be reduced by amounts C_1 through C_N per $, then the optimal fraction of the monetary distribution or effort equivalency K_D for outcome A_D in reducing all the risks would be found from the weighted average above
  - If the total resource equivalence budget for risk reduction is then some value F, then the optimized $ to be spent on outcome A_D is then $F \times K_D$.
- In other words; A low risk should not be lowered further unless it is really cheap to do so. Only high risks warrant large cost and effort but the process can and should be optimized for RIPB.

B_D is the risk of the outcome A_D
C_D is the risk reduction of A_D per $

RADIATION PROTECTION PROGRAMS GUIDE for Use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection

- Numerical criteria (e.g., dollars per rem avoided) developed for site ALARA decisions should be used to determine those design features that are reasonable.
  - An individual with expertise in radiation protection…
- Optimization methodology provides the technical and managerial basis for setting numerical criteria for ALARA decisions in the design of facilities, development or review of work processes, and the design/purchase of special tools and equipment

How much can a millirem be worth then?

- The correct answer must always comes from proper risk management (though the math may be tricky)
- If an exposure is legal, then additional cost for reduction should be suspect as subject to gross abuse
  - The caveat for cost effectiveness can negate this if a tiny amount of money can make a demonstrable improvement
  - It is also always possible that legal limits could be too high or too low to also contradict this assertion
- An example of spending more than a million dollars to avoid a millimrem should be offensive to any familiar with nuclear science and technology

Radioactivity in food, we must eat some for life and health

- Medical studies show we do not get enough ^{40}K in our diet leading to excess hypertension
  - *J. Amer. Soc. Hypertension*, **7**:395-400; 2013.
  - *Mayo Clinic Proc.* **88**:987-995; 2013
- Compare ^{40}K to ^{137}Cs
  - ^{40}K has a gamma energy more than double that of ^{137}Cs
  - Both emit a high energy beta
  - Both elements are in the same chemical family
- A large muscular male can get 40 mrem/y whereas a small petite female might get 10 mrem/y

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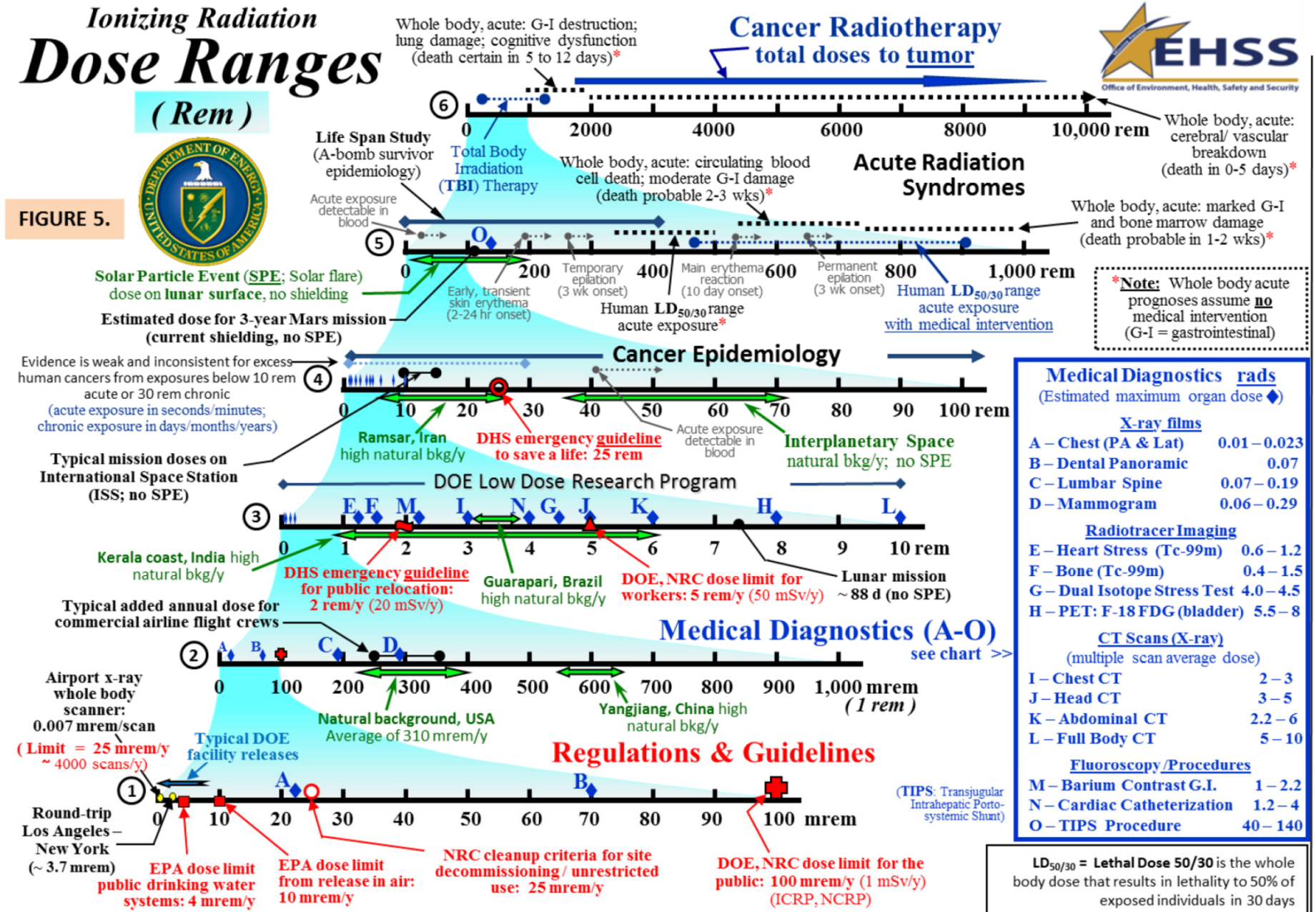
Ionizing Radiation **Dose Ranges**

(Rem)

FIGURE 5.



Medical Diagnostics rads
(Estimated maximum organ dose ◆)

X-ray films	
A – Chest (PA & Lat)	0.01 – 0.023
B – Dental Panoramic	0.07
C – Lumbar Spine	0.07 – 0.19
D – Mammogram	0.06 – 0.29
Radiotracer Imaging	
E – Heart Stress (Tc-99m)	0.6 – 1.2
F – Bone (Tc-99m)	0.4 – 1.5
G – Dual Isotope Stress Test	4.0 – 4.5
H – PET: F-18 FDG (bladder)	5.5 – 8
CT Scans (X-ray) (multiple scan average dose)	
I – Chest CT	2 – 3
J – Head CT	3 – 5
K – Abdominal CT	2.2 – 6
L – Full Body CT	5 – 10
Fluoroscopy /Procedures	
M – Barium Contrast G.I.	1 – 2.2
N – Cardiac Catheterization	1.2 – 4
O – TIPS Procedure	40 – 140

$LD_{50/30}$ = **Lethal Dose 50/30** is the whole body dose that results in lethality to 50% of exposed individuals in 30 days

Absorbed Dose: 100 rads = 1 Gray
1 rem ~ 1 rad for x- and gamma-rays
Dose Equivalent: 100 rem = 1 Sievert
= (absorbed dose x radiation quality)

NOTE: This chart was constructed with the intention of providing a simple, user-friendly, "order-of-magnitude" reference for radiation exposures of interest to scientists, managers, and the general public. In that spirit, most quantities are expressed as "dose equivalent" in the more commonly used radiation protection units, the rem and Sievert. Medical diagnostics are expressed as estimated maximum organ dose; as they are not in "effective dose" they do not imply an estimation of risk (no tissue weighting). Dose limits are in effective dose, but for most radiation types and energies the difference is numerically not significant within this context. It is acknowledged that the decision to use these units is a simplification, and does not address everyone's needs. -- (**DHS** = Department of Homeland Security; **EPA** = Environmental Protection Agency; **NRC** = Nuclear Regulatory Commission)
Disclaimer: Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information disclosed.

Chart compiled by NF Metting, ScD
Office of Public Radiation Protection,
Department of Energy (**DOE**)
"Orders of Magnitude" revised **Jan 2017**

Source: Office of Public Radiation Protection, Office of Environment, Health, Safety and Security, U.S. Department of Energy
http://energy.gov/ehss/environment-health-safety-security

Dose levels (approx.) and effects

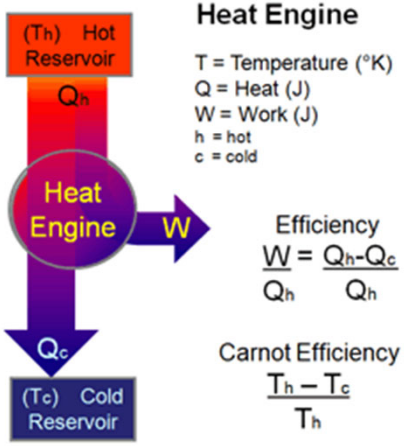
Note average cancer risk from all sources is just over 40%

Dose level (rem)	Relevant effects and typical sources (approximate or on average) rounded for simplicity
0.001	Average daily natural background dose
0.01	Internal potassium annual dose or mammogram x-ray dose, annual EPA limit to the public
0.1	Pelvis or hip X-ray, DOE and NRC public limit
1	Nuclear medicine stress test or a CT scan of the hip, torso or head, EPA minimum PAG for emergency evacuation
5	Legal radiation worker maximum dose and around 0.2% cancer increase if LNT holds, max EPA emergency evacuation dose
10	Minimum suspected LNT sufficient to increase cancer probability by 0.5% by a limited number of studies to children
100	Erythema, mild sterilization, blood count effects and 5% cancer probability increase

ALARA Safety

ALARA compliance and demonstration

- As Low As Reasonably Achievable
  - Shielding
  - Distance
  - Time



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Can any aspect of a Radiation Protection Program (RPP) do without QA?

RPP QA = ALARA

- Internal audits
- Written procedures
- Monitoring of Individuals and Areas
- Environmental releases
- Shipment and receipt of radioactive material
- Posting and Labeling
- Radiation safety training
- Design and control
- Facility design and modifications
- Radioactive Contamination Control

Slide 10

RBH1 Each of those bullets are proxies for risk reduction. I could then ask the questions, "How does each work to reduce risk?", "Is there evidence that actual risk reduction occurs?"
Some of them, like training and contamination control clearly reduce risk.
The questions could be asked of each one and a figure of merit may be developed, perhaps?
Robert Bruce Hayes, 3/23/2021

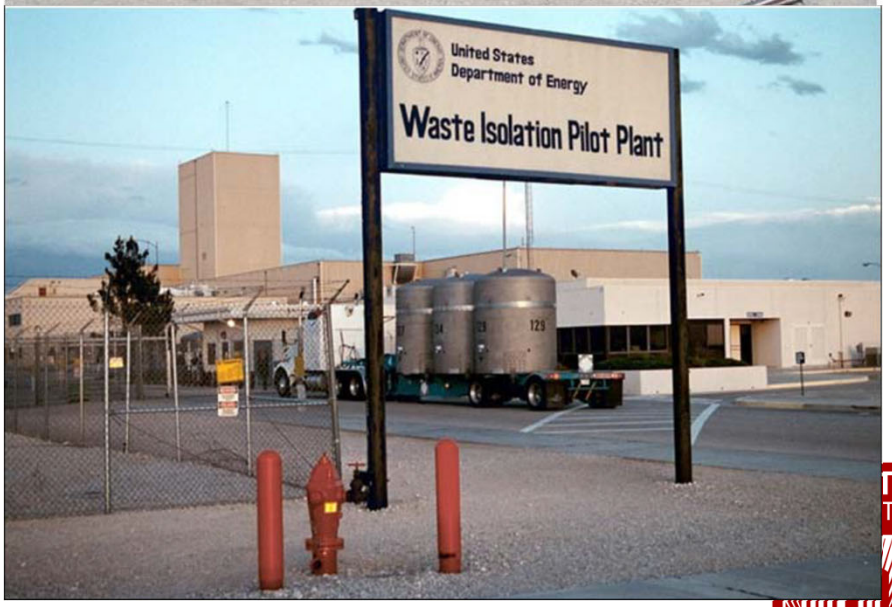
Dose rate effectiveness factor (DREF) or a Linear Quadratic (LQ) model?

- Does jumping from a 10 cm block 100 times have the same health effects as jumping once from a 10 m block?
  - Cleary NO, one is outright harmful and the other is recommended for daily health and fitness
  - The work is numerically equivalent but the health effects are opposite extremes
- A typical dose rate effectiveness factor is estimated to be a factor of 2† but could be over an order higher
  - Brooks, A. L., Hoel, D. G., & Preston, R. J. (2016). The role of dose rate in radiation cancer risk: Evaluating the effect of dose rate at the molecular, cellular and tissue levels using key events in critical pathways following exposure to low LET radiation. *International Journal of Radiation Biology, 92*(8), 405-426. https://doi.org/10.1080/09553002.2016.1186301
- The DREF/LQ should be considered in regulations and guidance as it is very well established science†

†ICRP 2007 Recommendations of the International Commission on Radiological Protection *ICRP Publication 103; Ann. ICRP* **37** (2-4)

WIPP vs Yucca Mountain?

- WIPP has cost taxpayers around 6 billion US$ to date
- This does not include generator sites own funding for TRU waste
- Yucca Mountain has cost around 10 billion US$.
- Clearly very different scope and missions for geological repositories.
- Is this a reasonable comparison? Maybe not, there are a number of factors.



A metric for cost effectiveness?

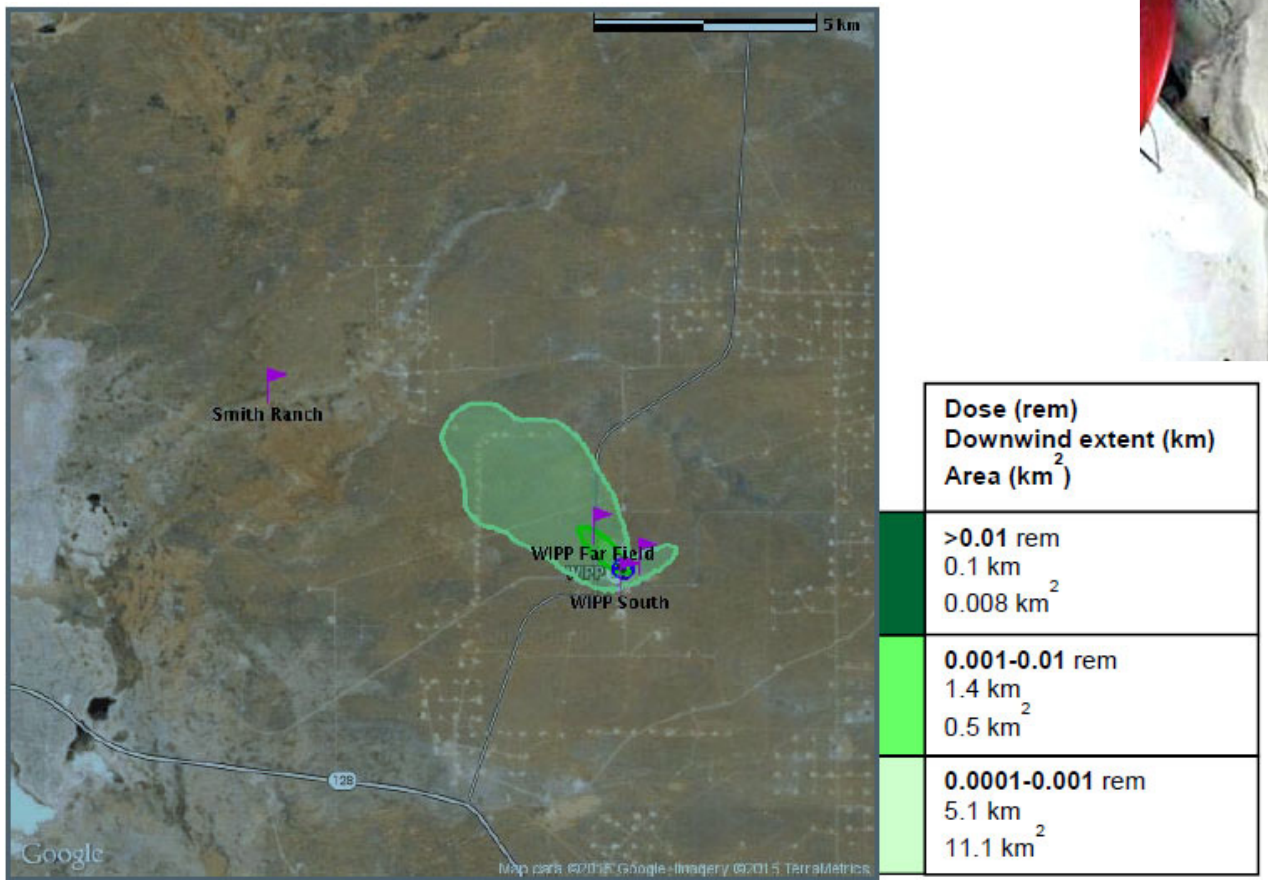
- Start with an ad-hoc estimation for the LD50 (limit assumed to kill 50% of those exposed) for internal uptake of 10,000 ALI
- From this relationship, 1 LD50 = 1E4 ALI and 2E6Ci=1E12 ALI, we get 1E12 ALI x 1LD50/1E4 ALI = 1E8 LD50
- The WIPP would then have permanently removed from the biosphere 1E8 LD50 of activity.
- Using then the number 1E10 US$ as a total cost estimate for WIPP, this means that taxpayers have spent around 1E10 US$/1E8 LD50 =100 US$ per LD50
  - Permanently removed from the biosphere via the WIPP
- Using these units is misleading insofar that they suggest the activity can be distributed for intake (or is already completely inside the food you are eating).

WIPP was a crown jewel of operational excellence … and then this happened…

- The waste arrived in over 10,000 shipments traveling over more than 13 million loaded miles!
- Equivalent to more than 27 trips to the moon and back without a single detectable release of radioactivity
- Total waste emplaced is both over 2.9E6 ft^3 and 2E6 Ci
- Capacity limited to 6.2E6 ft^3
- Activity limited to 5.1E6 Ci
- Better safety record than most libraries

How was this possible?

An overview of the history of the WIPP event leading to the release



Dose (rem) Downwind extent (km) Area (km^2)
>0.01 rem 0.1 km 0.008 km^2
0.001-0.01 rem 1.4 km 0.5 km^2
0.0001-0.001 rem 5.1 km 11.1 km^2

Hayes R. B. (2016) Consequence assessment of the WIPP radiological release from February 2014. *Health Phys.* **110**(4), 342-360.

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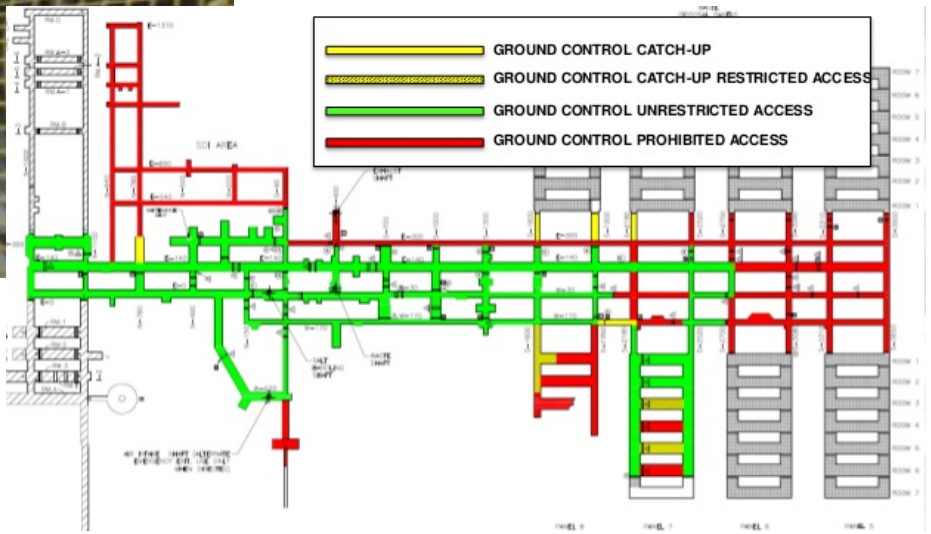
Additional ventilation

New equipment

Ground control



Contamination control in a salt mine, huh? Yeah!

New Mexico State University independent oversight for NM makes radical claims!

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Paper claims no filtration needed at WIPP

Maddy Hayden, Carlsbad Current-Argus Published 4:03 p.m. MT April 1, 2017

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(Photo: Maddy Hayden - Current-Argus)

Researchers at the Carlsbad Environmental Monitoring & Research Center believe Waste Isolation Pilot Plant officials are being unnecessarily cautious by continuing to filter air leaving the underground.

The center independently monitors and researches activities at WIPP.

A paper presented in March at the 2017 Waste Management Conference in Phoenix claims radiation levels in the air underground and air being ventilated out into the environment contain benign levels of radiation.

"In my opinion, this is scientific evidence that WIPP can release the air to the atmosphere and I don't think it's going to do any damage the environment or public health," said Punam Thakur, the lead author of the paper.

Thakur P, Khaing H, Hardy R. "Should WIPP resume unfiltered discharge of underground ventilation". *Trans. Amer. Nuc. Soc.* **116**, 235-238, 2017.

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Hayes R. B. (2016) Implementation of a portable HPGe for field contamination assay. *Health Phys.* **110**(6), 571-579.

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Can an ALARA program be likened to a QAQC program?

Essential but an optimization, not minimization

- Quality is not a safety issue but you can't have safety without it
  - Quality is necessary but not sufficient condition for safety
- ALARA is not a safety issue but it is required to demonstrate control of radiological materials and ionizing radiation
  - A regulatory compliant ALARA program is the quintessential evidence of your ability to safely handle nuclear materials
  - ALARA can never mean that you have caused physical harm to an individual when *only* ALARA regulations have been violated