RELATIONSHIP BETWEEN TERRESTRIAL BACKGROUND AND REMEDIAL CRITERIA FOR NATURALLY OCCURRING RADIOACTIVE MATERIAL IN THE UNITED STATES *

Steven H Brown, CHP

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Background

- In the US, Federal and State agencies have established radiological public exposure limits and remedial action ("clean up") criteria (e.g. Bq / gram) for naturally occurring radioactive material (NORM) primarily for uranium and thorium series radionuclides.
- These criteria are intended to control human exposure to "Technologically Enhanced Naturally Occurring Radioactive Material" (**TENORM – US TERM ONLY**).
- TENORM = any NORM for which the potential for human exposure has been enhanced due to anthropogenic (human) activities, e.g., removal from its place in nature, and/or processed in some way resulting in concentration.

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Background - continued

- In some cases, the values of these regulatory criteria can be similar to, or even less than those levels of exposure and those concentrations of NORM that exists in nature independent of any previous human activity
- Potential variability of NORM radionuclides in the soil and rocks can be significant, even over relatively short distances or depths due to factors such as geology, hydrology and geochemistry
- It is therefore important to recognize that defining “the radiation background” for establishing remedial action criteria and/or exposure limits requires recognition of the specificity at the location(s) of interest, not in other geological and/or mineralogical regimes several miles away.

Purpose / Objectives

- Purpose of this paper is to demonstrate this variability for comparison to exposure levels and concentrations being defined in the US as levels above which require regulatory control and / or above which are being defined as an "unacceptable risk" *
- The primary background exposure component of specific interest here is the annual dose contribution from terrestrial radiation exposure, i.e., primarily from uranium and thorium series radionuclides in the ground, excluding radon inhalation
- The average annual **terrestrial** component of background can vary by upwards of a few tenths of a mSv across the US and can be **several times higher** than the applicable exposure limits

* For example, the US Environmental Protection Agency (EPA) carcinogenic risk basis for establishing remedial action criteria at radiological sites is 3 X 10^{-4} (about 0.12 mSv yr^{-1}) based on the Linear No Threshold Hypotheses (LNT). Above this level is considered "an unacceptable risk" (USEPA 2014)

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Purpose / Objectives - continued

- The statistical and analytical uncertainties of distinguishing NORM from anthropogenic (human caused) activities (i.e., TENORM) can be quite challenging and in some cases may be technically impossible
- Consideration must be given to the relationship of the amount of actual total risk avoidance achieved if any, relative to the traditional health and safety risks of remedial construction and associated construction, waste management and transportation costs
- Accordingly, it is hoped that a more practical and scientifically based approach for development of these remedial action criteria can be achieved moving forward.

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Exposure to Natural Background Radiation in the United States (NCRP 2009)

Source of Exposure	Average Annual in US mSv (%)
Internal, inhalation (radon and thoron)	2.28 (73%)
External, cosmic (space)	0.33 (11%)
Internal, ingestion (food and water)	0.29 (9%)
External, terrestrial	0.21 (7%)
Total	**3.11 (100%)**

Comparison of Average Annual Radiation Backgrounds In US {mrem (mSv)}

Source	Florida [a]	Colorado [a]	Illinois [a]	South Dakota [a]	Leadville Co. [b]
Cosmic	27 (0.27)	49 (0.49)	28 (0.28)	31 (0.31)	85 (0.85)
Terrestrial	13 (0.13)	39 (0.39)	24 (0.24)	27 (0.27)	97 (0.97)
Internal incl. Radon	54 (0.13)	300 (3.00)	181 (1.81)	440 (4.40)	344 (3.44)
Totals	93 (0.93)	387 (3.87)	233 (2.33)	498 (4.98)	526 (5.26)

[a] From USEPA 2006 [b] From Moeller 2006 (Traditional units presented first for ease of comparison)

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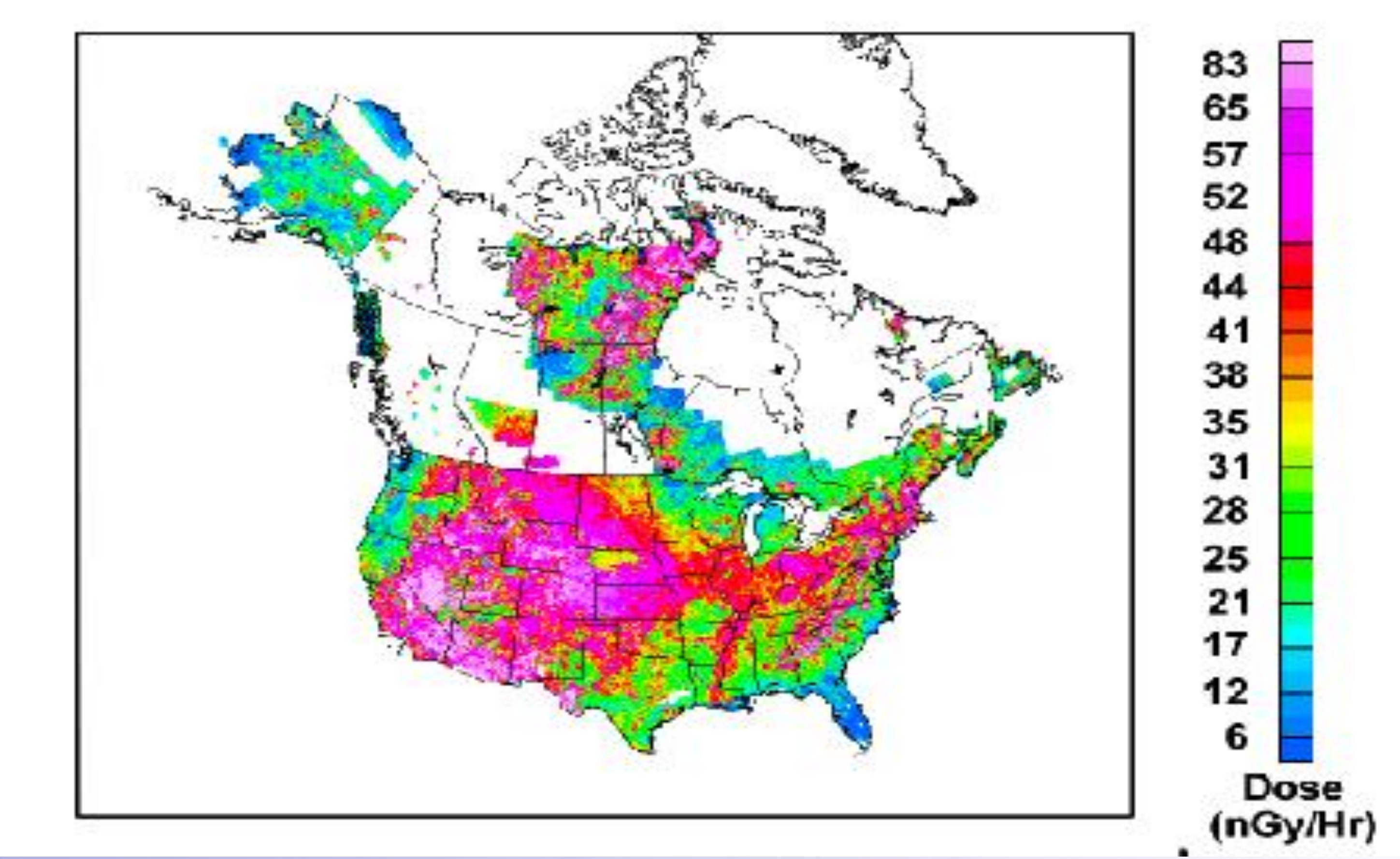
Terrestrial Background Defined

- Primary sources of terrestrial exposure are ^{40}K and the U / Th series nuclides present in the soil and rocks of earth's crust (the "primordial radionuclides").
- Terrestrial pathway dominated by external exposure to photons from U, Th and progeny (Brown et al 2018)
- Although dissolved in water and taken up from soil by plants into food chain, dose from ingestion of food and water typically included in the internal component of background (ingestion, inhalation) dominated by inhalation of Radon
- Since these are same nuclides in same media and similar exposure pathways most important for TENORM regulation and control, the variability of the terrestrial component is particularly relevant to the subject of this paper

Terrestrial Background Varies Considerably Across US



National Council on Radiation Protection and Measurements; NCRP Report No. 160, “Ionizing Radiation Exposure of the Population of the United States”, 2006

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Comparison of Average Annual Terrestrial Radiation Backgrounds In the U.S. {From EPA 2006 - mrem (mSv)}

Mississippi	Maryland	Georgia	Hawaii	New Mexico	Colorado
13 (0.13)	19 (0.19)	24 (0.24)	27 (0.27)	31 (0.31)	39 (0.39)

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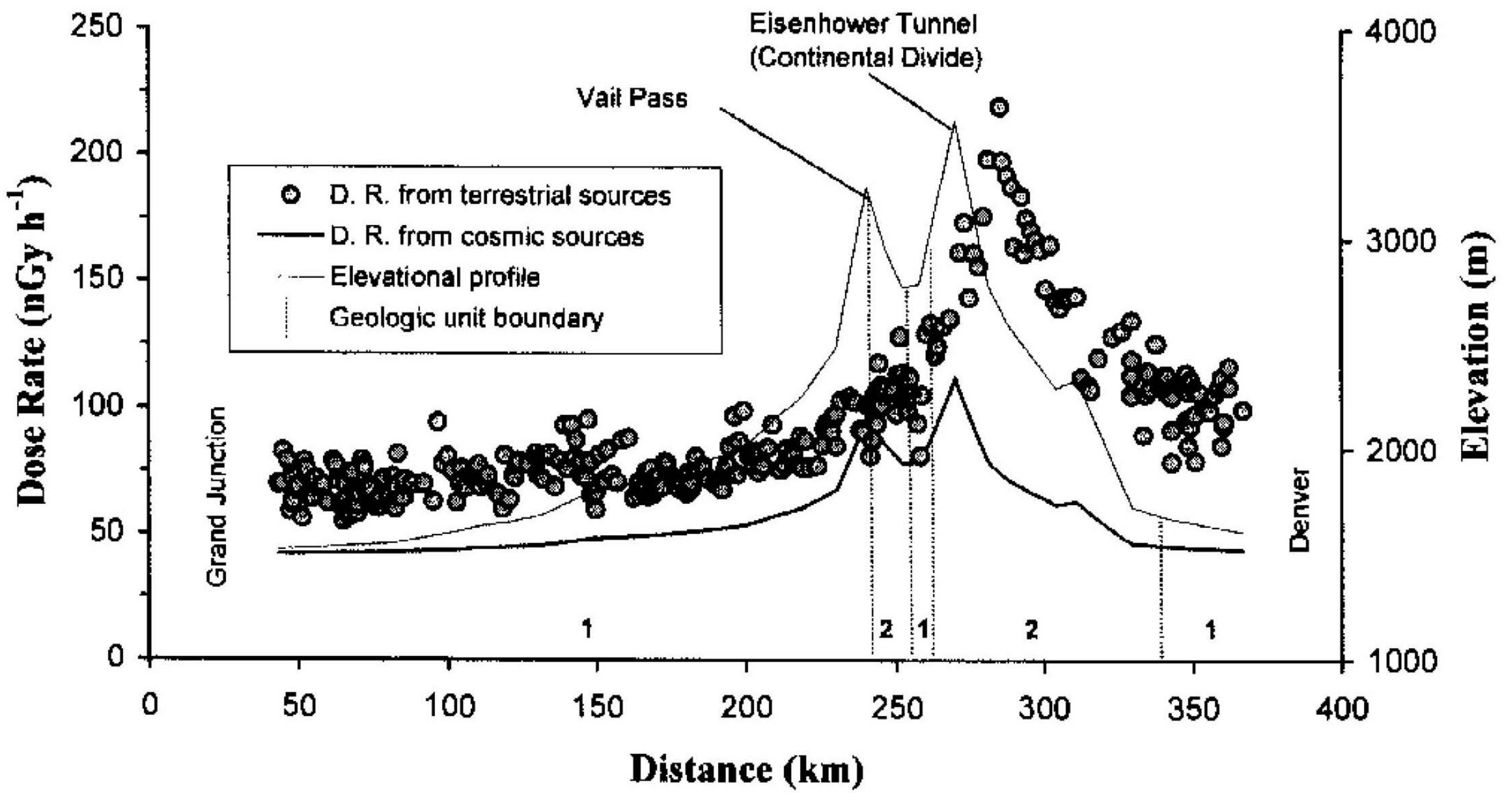
Radiation Background Can Vary Considerably Over Relatively Short Distances*



* Reproduced from from Stone, Whicker, Ibriham and Whicker 1999

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Despite International Consensus, Multiple Public Exposure Limits Have Developed in the US

Exposure Condition	Annual Dose Limit (mrem {mSv})	Agency Reference
Member of Public (MOP) – from licensed nuclear or other radiological facilities and/or activities	100 (1)	USNRC (10 CFR 20.1201), Agreement States, USDOE, NCRP, ICRP
MOP – General	25 (0.25) excluding radon [(a)]	USEPA 40 CFR 190.10
MOP — Iodine Emissions from Federal Facilities	3 (0.03)	USEPA 40 CFR Part 61, Subpart I
MOP– gamma and beta emitters in drinking water	4 (0.04) [(b)]	USEPA 40 CFR 141.66
MOP– (1) Air Emissions constraint on Air particulates excluding Rn / progeny and (2) Rn from Uranium Mine Vents	10 (0.1)	USEPA: (1) 40 CFR 61 and referenced by USNRC in 10 CFR 20.1101 and (2) 40 CFR Part 61, Subpart B)
MOP – CERCLA sites including NORM at Legacy U mines and sites under the Formerly Utilized Sites Remedial Action Program (FUSRAP)	12 (0.12)	USEPA Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) directives; See in particular USEPA 2014

(a) Regulation presents this limit as Dose Equivalents "to any organ". For example, using a tissue weighting factor for the lung of 0.12 (ICRP 1977 would have been the referenced source at that time), 25 millirem yr' "permissible dose to any organ" (0.25 mSv), when applied to lung would result in a permissible "whole body dose" limit of 3 millirem yr' (0.03 mSv).

(b) To demonstrate compliance to the 4 millirem (0.04 mSv) annual exposure criteria for drinking water (US EPA 2001) requires determining permissible radionuclide concentrations in water based on archaic metabolic models as presented in NBS 1963 (See the US Code of Federal Regulations at 40 CFR 141.66).

Some Observations and Implications
Implications – 1 of 5

- Federal annual MOP limit = 1 mSv vs. 3 mSv per yr. difference CO vs. FL
- USEPA has established different annual exposure limits based on the specific radiation source and/or industry producing the radiological effluent. (e.g., 0.25 mSv vs. 0.12 vs. 0.10 vs. 0.03) - From a radiation biology perspective, it is unclear why our tissues and organs would respond differently depending on source of the photon, ignoring differences in the energy and/or quality of the source. = “BAD SCIENCE” - shb

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Some Observations and Implications
Implications – 2 of 5

- Note difference of 0.26 mSv for average annual **terrestrial** component of background, Mississippi vs. Colorado.
- Contrast to EPA annual limit of 0.12 mSv - “unacceptable risk” - for radiological CERCLA sites including former (abandoned) uranium mine sites (AUMs).
- Contaminants of concern at these sites are almost exclusively natural uranium usually in secular equilibrium with its progeny (NORM radionuclides) – which are also the major source of terrestrial background exposure !

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Some Observations and Implications
Implications – 3 of 5

- Colorado terrestrial component of background = 0.39 mSv yr^{-1} so remedial action concentrations (e.g., Bq / gram in soil) associated with EPA limit (0.12 mSv) could be < 1/3 of natural background concentrations in Co. soils / rocks.
- Regulatory criteria are to be applied “above background” - common to use this as justification for appropriateness and ability to measure these limits.
- However applicable dose limits can translate to concentrations of primordial nuclides in soil / rocks that are statistically equivalent to or < levels of naturally occurring terrestrial radioactivity. Technical challenge to differentiate a few atoms of TENORM radionuclides (“ contamination”) from the many more atoms of NORM that have been there since before humans.

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Some Observations and Implications Implications – 4 of 5

- Often ignored in establishing “acceptable radiological risk” criteria for remedial action of land are the inherent, more traditional construction related health and safety risks to workers associated with the excavation, transportation and disposal of large volumes of soil and rock.
- These types of risks do not arise from “theoretical cancer estimates” but are real and “countable” and serious injuries and/or fatalities associated with these types of construction activities occur annually and are well documented.*

* Per U.S. Bureau of Labor Statistics, 115 fatalities in 2018 associated with non roadway incidents involving motorized land vehicles, which would include accidents involving backhoes, front end loaders, and similar heavy equipment (USBLS 2018).

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Some Observations and Implications
Implications – 5 of 5

- Several example cost estimates from the General Accounting Office's Report to Congress on the clean up of abandoned uranium mining and milling sites on the Navajo reservation relative to the 0.12 mSv / yr. criteria are also instructive (GAO 2014).
- These include reclamation costs for the Northeast Church Rock site (New Mexico) of $ 44 M, for the Tuba city site (Arizona) of $ 22 – 72 M and an estimate of $ 150 M for the cleanup of half of GAO's "priority sites" (21 individual former uranium mines).

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Conclusions - 1 of 5

- Given considerable variability of annual average radiation exposure across US from NORM, it is clear that the "decisions" people make on where and how to live, what to eat, etc., have a much larger impact on their "radiation dose" than the dose controlled by the numerous regulatory public exposure limits discussed herein

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Conclusions - 2 of 5

- This is particularly relevant for population exposure to the naturally occurring primordial radionuclides in the soil and rocks under our feet.
- The exposure sources being controlled by some of these regulatory limits are primarily associated with the primordial radionuclides in soil.

Conclusions - 3 of 5

- Average annual terrestrial component of background can vary by several tenths mSv, (several tens of mrem) which can be several times > than applicable exposure limits. This can result in “unacceptable” or “remedial action” concentration criteria statistically equivalent to or less than background soil concentrations of these same primordial nuclides (U,Th, Ra, other progeny).

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Conclusions - 4 of 5

- Given that at these very low remedial action levels (a few tenths Bq / gram in soil or even less), the statistical and analytical uncertainties of distinguishing naturally occurring radionuclides (i.e., NORM) from those resulting from anthropogenic activities (i.e., TENORM) can be quite challenging and may be technically impossible with current state of art (e.g., radiochemical analysis)

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Conclusions - 5 of 5

Decision makers need to consider the relationship of the amount of actual radiological risk avoidance achieved if any, relative to the traditional health and safety risks of construction and the associated construction, transportation and waste management costs so that a practical and scientifically based approach for development of these criteria can be achieved

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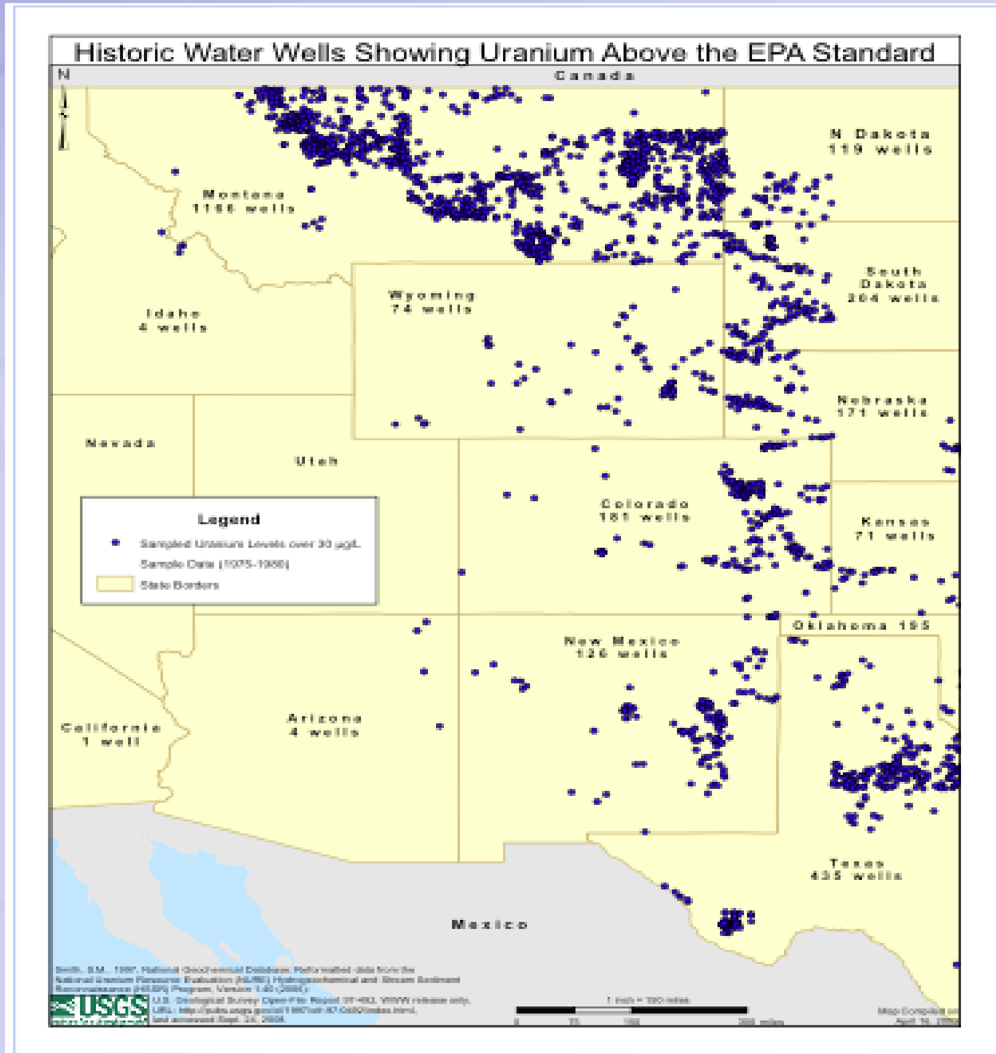
MY BOTTOM LINE

Regulators and other decision makers need to consider in a more holistic way, the relative value to society of accepting these very real and significant monetary costs and safety related risks in comparison to the magnitude of theoretical radiological risks that they believe are being avoided.

Thank You For Your Attention - Questions ?

Steve Brown, CHP
SHB Inc.
Centennial, CO. USA
+1 303 524 1124 (office)
+1 303 941 1506 (mobile)
www.shbinc.us



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