Radiation Risk and Cleanup Standards

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Abstract

Radiation cleanup standards have traditionally been expressed in terms of one of two ways. The first method is by directly measurable quantities such as contamination levels (e.g. dpm 100 cm^{-2} for surface contamination or Bq g^{-1} (pCi g^{-1}) for soil contamination). The second method is by derived, calculated quantities such or dose limits (e.g. mSv y^{-1} (mrem y^{-1})). The Atomic Energy Commission (AEC), and later the Nuclear Regulatory Commission (NRC) and the Department of Energy (DOE) established these standards. These standards were promulgated in various regulatory and guidance documents including AEC Regulatory Guide 1.86, 10 CFR 20 and DOE Order 5400.5. The various state radiological control organizations also adopted these same standards. In the mid 1990s, the EPA also embraced the concept of radiation dose based standards for soil (e.g. 40 CFR 196 (Draft), EPA 402-R-96-011A, OSWER 9200-4.18). Since then, however, the EPA has increasingly distanced itself from radiation dose based standards and instead, adopted radiation risk based standards. These CERCLA risk goals were originally adopted for chemical cleanup at Superfund sites and were based on a range of 1-in-ten-thousand cancer risk to a 1-in-a-million cancer risk. Adoption of these goals for radiation cleanup by various parties in the EPA (e.g. FGR 13, OSWER No. 9355.01-83A), and by other stakeholders, has forced those in the nuclear industry to address the challenges of these new rules. These challenges include the technical feasibility of measuring down to these low risk levels, and the need to accept the reality of theoretical radiation risk at low doses. The recent confirmation of the linear-no-threshold model of radiation risk at low doses by the BEIR-VII committee has only added to these challenges. Examples of recent DOE cleanup programs at the Energy Technology Engineering Center (ETEC) are used to illustrate how the use of traditional dose based radiation cleanup goals in the remediation planning process can readily achieve CERCLA risk goals in implementation.

Keywords: radiation, risk, cleanup, standard

Radiological Cleanup Standards

Cleanup standards are designed to assure that nuclear and radiological facilities that have been decontaminated are safe for unrestricted use with no further radiological controls. The objective is that any potential exposure from residual radioactivity is as low as reasonably achievable (ALARA) and that health impacts should be minimal.

0.15 mSv y^{-1} Dose Limit

In the mid 1990s both the NRC and EPA conducted public hearings on dose-based limits for cleanup of radiological facilities. In May 1994, EPA published for comment, draft 10 CFR 196 “EPA Radiation Site Cleanup Regulation” (EPA 1994a). Some pertinent statements from 10 CFR 196 included,

- *These proposed regulations set standards that will place limits on the radiation doses received by members of the public to an annual committed effective dose of 15 mrem/yr (0.15 mSv/yr)."*
- *"The committed effective dose of 15 mrem/yr corresponds to a lifetime excess cancer risk of less than 3 x 10^{-4} over a thirty year exposure."*
- *"EPA is proposing cleanup standards that are fully protective of human health and the environment."*
- *"EPA acknowledges that cleanup of radioactive materials to achieve a standard of 15 mrem/yr for unrestricted use for all exposure pathways is not always technically feasible."*

Clearly, the EPA fully supported a dose-based standard in 1994. However 10 CFR 196 was subsequently withdrawn and is now not available either on-line or from EPA’s Office of Radiation and Indoor Air.

In August 1997, EPA published OSWER No. 9200.4-18 (EPA 1997) in which the Office of Radiation and Indoor Air and the Office of Emergency and Remedial Response clarified the EPA's position on "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination". In this memorandum, the EPA states,

- *"If a dose assessment is conducted at the site, then 15 millirem per year (mrem/yr) effective dose equivalent (EDE) should generally be the maximum dose limit for humans. This level equates to* *approximately 3 x 10^{-4} increased lifetime risk and is consistent with levels generally considered protective in other governmental actions, particularly regulations and guidance developed by EPA in other radiation control programs."*

- *"Protectiveness for carcinogens under CERCLA is generally determined with reference to a cancer risk range of 10^{-4} to 10^{-6} deemed acceptable by EPA. Consistent with this range, EPA has considered cancer risk from radiation in a number of different contexts, and has consistently concluded that levels of 15 mrem/yr (which equate to approximately 3 x 10^{-4} cancer risk) or less are protective and achievable."*

Clearly, the EPA fully supported a dose-based standard of 0.15 mSv y^{-1} (15 mrem y^{-1}) in 1997. The objective of OSWER No. 9200.4-18 was, in fact, to argue that 15 mrem y^{-1} (3 x 10^{-4} lifetime cancer risk) was protective of public health while the NRC's recently adopted 25 mrem y^{-1} (5 x 10^{-4} lifetime cancer risk) in the 10 CFR 20 Subpart E license termination rule was not protective. In the same breath, EPA argued that 3 x 10^{-4} risk was essentially the same as 1 x 10^{-4} risk and therefore met the intent of CERCLA.

One-in-a-million Cancer Risk Goal

Environmental advocacy groups, legislators, and certain elements in EPA believe that radiological cleanup should achieve a risk level of 10^{-6} or less. Using the same linear no threshold (LNT) model of radiation risk employed by EPA, background radiation from all sources is approximately 10^{-2} lifetime cancer risk; radiation exposure from naturally occurring radionuclides in soil and rock is approximately 10^{-3} lifetime cancer risk, and radiation exposure from the naturally occurring radionuclides in the foods that we eat is approximately 10^{-3} lifetime cancer risk.

In September 1994 EPA published "Radiation Site Cleanup Regulations – Technical Basis Document for the Development of Radionuclide Cleanup Levels for Soil" EPA 402-R-96-011 A (EPA 1994b) in which EPA assesses the feasibility of cleanup for a variety of risk levels. In general, it is technically infeasible to distinguish radionuclide contamination in soil at a 1-in-a-million risk level above background because these levels (1) are less than most radionuclide minimum detectable concentrations

(MDC) of laboratory soil analysis techniques, (2) are always less than the detection limits of field instrumentation, and (3) are less than the variability of natural background soil radionuclide concentrations. This is discussed in detail in EPA 402-R-96-011-A, Chapter 7.2 “Technical Feasibility Issues Associated with Implementation”, pages 7-14 through 7-41.

In February 2002, EPA published preliminary remediation goals for soils based on a 10^{-6} risk level (EPA 2002). Using these PRGs, a comparison of detectability and distiguishability from background was made using the same technical feasibility criterion employed in EPA 402-R-96-011-A. The following conclusions were determined for 10^{-6} PRGs for agricultural soil.

- At the 10^{-6} PRG risk level, no radionuclides can be detected by field instrument surveys.
- At the 10^{-6} PRG risk level, the following radionuclides cannot be detected by laboratory analysis – Am-241 (marginal), Co-60, Cs-134 (marginal), Cs-137, Fe-55 (marginal), K-40, Ni-63, Pu-238, Pu-239, Pu-240, Pu-241 (marginal), Pu-242, Ra-226, Sr-90, Th-228, Th-232, U-234, U-235 and U-238.
- At the 10^{-6} PRG risk level, the following radionuclides cannot be distinguished from background variability by laboratory analysis – Am-241, Co-60, Cs-134 (marginal), Cs-137, Fe-55 (marginal), H-3, K-40, Ni-59, Ni-63, Pu-238, Pu-239, Pu-240, Pu-241 (marginal), Pu-242, Ra-226, Sr-90, Th-228, Th-232, U-234, U-235 and U-238.Th-228, Th-232, U-234, U-235 and U-238.

In conclusion, it is technically infeasible to distinguish radionuclide contamination in soil at a 1-in-a-million risk level above background for most radionuclides, because these levels are, in general, less than laboratory soil detection limits, less than field instrumentation detection capability, and less than background soil variability.

EPA’s Risk-Based Cleanup Policy

During the past twelve years, EPA’s policy toward radiation cleanup goals has shifted from clearly embracing a 0.15 mSv y^{-1} (15 mrem y^{-1}) dose based goal to that of a purely risk-based policy. The EPA published preliminary remediation goals (PRGs) in 2002 (EPA 2002) for agricultural soil, residential soil, and workplace soil. These PRGs are based on a 10^{-6} risk level. It is likely that this shift in policy is partly due to the 0.15 vs. 0.25 mSv y^{-1} conflict between EPA and NRC, and partly due to the acknowledged x3 to x1/30 variation in the non-isotope specific 0.15 mSv $y^{-1} = 3 \times 10^{-4}$ risk correlation. For instance, RESRAD (ANL 2001) risk levels for a 0.15 mSv y^{-1} residential scenario range from a high of 8.7×10^{-4} for Ni-59 to a low of 1.1×10^{-5} for Am-241.

EPA's radiation cleanup philosophy and policy is supported by, and dependent on, the LNT model of radiation risk. Without the LNT, EPA would be forced to re-adopt a dose-based standard.

Linear No Threshold Model of Radiation Risk

The preceding discussions of the equivalence of radiation dose and induced fatal cancers are based on a theoretical model derived at high doses and high dose rates and extrapolated to zero. This is the so-called linear no threshold (LNT) model of radiation risk. BEIR V (NAS 1990) provided the basis for the correlation between radiation exposure and lifetime cancer risk of 5×10^{-2} per person-Sv for fatal cancers[1] and 6×10^{-2} per person-Sv for all cancers. More recently, the BEIR VII committee (NAS 2005) has confirmed the belief that the LNT model holds true for low level radiation exposures down to zero and re-calculated the fatal cancer rate to be approximately 5.6×10^{-2} per person-Sv (average of male and female rates), a slight increase from BEIR V rates.

The LNT model is a hypothetical statistical model, and that its validity at low doses (less than 100 mSv or 10 rem) is still subject to extensive debate notwithstanding BEIR VII's recent pronouncement. There is little or no empirical evidence that small variations in low levels of radiation exposure, much less than the variability in natural background, result in any increase in cancer risks. A variety of scientific, professional and governmental bodies support the concept of a threshold at about 50 to 100 mSv (5,000 to 10,000 millirem) above background, below which there is no cancer risk from radiation exposure.

The Geometric Scale of Safety

Assuming the LNT model of radiation risk is valid below background exposure levels, we can calculate the contributions to cancer risk from various sources (column A) in Table 1. It is apparent that

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[1] Note that the nuclear industry tends to use fatal cancer risk correlated to radiation exposure whereas EPA uses cancer incidence risk.

no matter which cleanup standard is chosen, the number of theoretical additional cancer fatalities at ETEC (Area IV of the Santa Susana Field Laboratory) is less than 1 (that is to say zero) and therefore does not increase the total natural cancer fatalities. This table also illustrates the fallacy of the "geometric scale of safety." Some would argue that a 10^{-6} risk level is 300 times "safer" than a 3 $x10^{-4}$ risk level. The fallacy of this thinking is apparent from Table 1. Most radiological sites that are remediated are relatively small in size. Area IV of SSFL is approximately 300 acres in size (although the physical footprints of its various nuclear facilities are much smaller). Hypothetically, approximately 200 acres could be developed for housing. Using the population estimates shown, the population risk (measured in fatalities) for a variety of radiation sources including dose and risk limits from residual contamination, rapidly decreases to well below unity. Thus although the individual risk continues to decrease in a geometrical fashion below 0.3 mSv y^{-1} (30 mrem y^{-1}), the population risk (measured in fatalities) is already essentially zero. Of course population risk (measured in fatalities) can only be 0, 1, 2, 3 etc. Fractional deaths have no meaning in population risk. In column E, it is seen that the total population fatal cancer risk is essentially constant no matter what cleanup standard is utilized. Therefore 10^{-6} is not 300 times safer than $3x10^{-4}$.

Cost Benefit Example #1

In September, 2000 the NRC published NUREG-1727, "NMSS Decommissioning Standard Review Plan" (NRC 2000). Appendix D of this document gave a mathematical model by which one could assess the cost benefit of various soil cleanup goals. This model enabled one to mathematically demonstrate something, that to some, is already intuitively obvious, namely that the NRC's 0.25 mSv y^{-1} (25 mrem y^{-1}) (and by extrapolation, ETEC's 0.15 mSv y^{-1} (15 mrem y^{-1})) soil cleanup goal is already ALARA. That is to say, further cleanup below 0.25 mSv y^{-1} (25 mrem y^{-1}) would cost more that it would payback, in terms of reduction in person-rem, and reduction in the monetary value of lives saved. Figure 1. illustrates implementation of this model. In order to remove all soil to a 10^{-6} risk level from the current level would require expenditure of an additional ~$77M. This would avert an additional 0.26 person-Sv (26 person-rem) of exposure to future residents at the site. This is equivalent to saving approximately 0.015 cancer fatalities or approximately 0.03 cancer incidences. Therefore attempts to cleanup soil, such that all soil is below a 10^{-6} risk level, would not save any lives.

Cost Benefit Example #2

One soil remediation project at ETEC in the 1990s involved removal of approximately 12,000 cubic yards of chemically and radiologically contaminated soil. Only approximately 700 cubic yards were radiologically contaminated. Based on 82 soil samples, cesium-137 ranged from non-detect to 1.9 Bq g^{-1} (52 pCi g^{-1}), with an average activity of 0.29 Bq g^{-1} (7.9 pCi g^{-1}) and a total content of 218 MBq (5.9 mCi). Strontium-90 ranged from non-detect to 1.4 Bq g^{-1} (38 pCi g^{-1}), with an average activity of 0.059 Bq g^{-1} (1.6 pCi g^{-1}) and a total content of 33 MBq (0.9 mCi). The Phase I remediation cost approximately $10 million. By comparing RESRAD soil derived concentration guideline limits (DCGLs) with the pre-remedial residual contamination, one can estimate the person-rem averted by the remediation to be 0.12 person-Sv (12 person-rem). Using 5.6×10^{-2} fatal cancers per person-Sv, this meant that $10 million were spent to save 0.0067 theoretical statistical fatal cancer. By ratioing up, this is equivalent to spending $1.5 billion to save one theoretical statistical fatal cancer based on the controversial LNT model of radiation risk.

Post Remedial Radiation Risk

The dominant radiological contaminant of concern at ETEC is cesium-137. Incremental doses above background have been calculated based on the distribution of measured cesium-137 remaining in the soil following remediation. Doses are much lower that the 0.15 mSv y^{-1} (15 mrem y^{-1}) goal in use at ETEC. This is an effective demonstration of the ALARA process at work in soil removal. Theoretical fatal risk attributable to the residual cesium-137 in soil have also been calculated based on the LNT model. All risk values are well within the EPA's CERCLA risk range and some are below the 10^{-6} "point of departure."

Conclusion – Two Processes, One Goal

The Department of Energy (DOE) and the Environmental Protection Agency (EPA) have different processes to achieve the same goal which is to protect human health and the environment (Figure 2.). At

ETEC, post-remedial sampling at radiological cleanup sites has demonstrated that achieved effective doses are well below the 0.15 mSv y^{-1} (15 mrem y^{-1}) goal and that achieved theoretical risk levels are at or below the 1 in 100,000 risk level and many are close to or less than the 1,000,000 risk level.

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Table 1. Contribution of Cancer Risk from Various Sources

A	B	C	D	E
Contributions to Cancer Risk	**Radiation Exposure (mrem y^{-1})**	**Theoretical individual fatal cancer risk**	**Incremental population risk (cancer fatalities)**	**Total population risk (cancer fatalities)**
U.S. average fatal cancers	N/A	~0.23	184	184
U.S. average natural background exposure	~300	~0.01	8	184
Average background exposure from soil	~30	~0.001	0.8	184
NRC license termination dose	25	0.0005	0.4	184.4 (=184)
DOE/SSFL cleanup standard	15	0.0003	0.24	184.24 (=184)
Upper EPA CERCLA risk range (1 in 10,000)	5	0.0001	0.08	184.08 (=184)
Geometrical mean of CERCLA risk range	0.5	0.00001	0.008	184.008 (=184)
Lower EPA CERCLA risk range (1 in 1,000,000)	0.05	0.000001	0.0008	184.0008 (=184)
Zero risk level	0.0	0.0	0.0	184

Table assumptions

Column B. Radiation exposure from background sources and various cleanup levels.
Column C. Theoretical individual cancer risk using the LNT model of radiation risk. Exposure times for natural background sources are 75 years. Residence times for various cleanup standards are 40 years.
Column D. Habitable area of Area IV of SSFL = 200 acres. Assumed home lot size of 1acre consistent with neighboring Bell Canyon community to the south. Assumed 4 people per home to give 800 residents. Incremental population risk (fatalities) = individual risk x 800.
Column E. Total population risk (fatalities) = sum of risk from natural causes plus radiation sources.

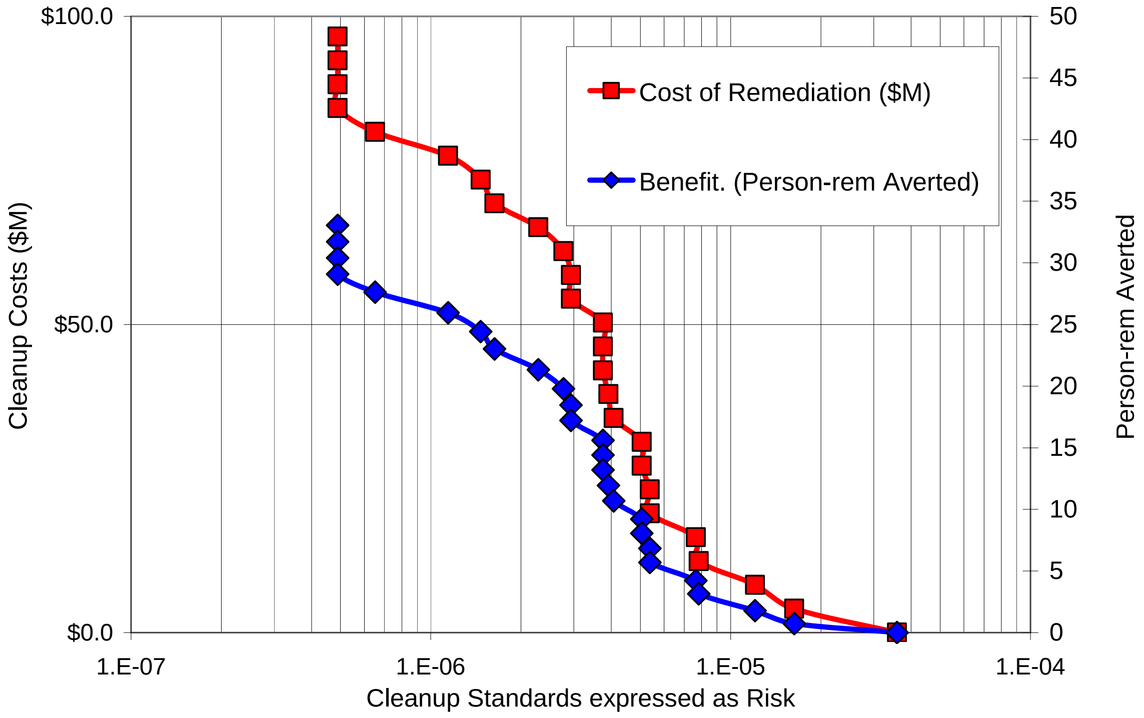

Figure 1. Comparison of Cleanup Costs to Person-rem Averted

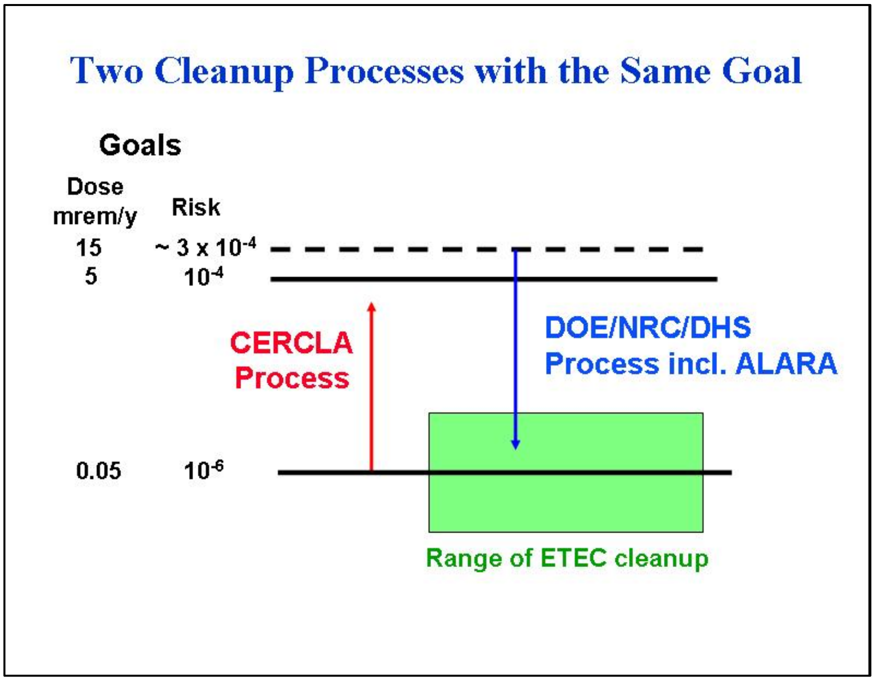

Figure 2. Comparison of Dose Based and Risk based Processes and Goal