Exposure Assumptions Underlying Cleanups to Industrial Versus Unrestricted Uses: Comparison of State and Federal Approaches - 17228

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ABSTRACT

The Environmental Protection Agency (EPA) and various states have designated a variety of cleanup levels ranging from restricted (too much residual contamination to allow any use) to unrestricted or residential. Although there are many potential exposure scenarios, the States of Washington and New Jersey identify only two levels for cleanup of chemical contaminants in soil: “unrestricted” and “industrial” (Washington) and “residential” vs “non-residential” (New Jersey). Other agencies such as EPA and DOE recognize several levels of recreational use, between unrestricted and industrial, and likewise there are several levels of residential use as well. Cleanup criteria may allow or preclude the use of ground water for drinking, swimming pools, gardens, or lawns. Tribal unrestricted scenarios include the use of water (probably surface water in most scenarios) for sweat lodges, and have calculated high level exposure pathways for both dermal and inhalation pathways as well as ingestion.

For residential scenarios, inadvertent ingestion of soil, drinking of ground water, and consumption of local foods represent the highest exposure pathways. Intermediate, recreational pathways may be non-consumptive (hiking, bird watching, photography) or consumptive (hunting, fishing, harvesting plants and medicines), the latter entailing much higher potential exposures. For each land-use there is a corresponding exposure scenario, with different assumptions about the maximally exposed individual, their age, and the amounts of air, water, soil, and foods they consume. For each exposure pathway one can compute the ratio between the exposure assumptions for any two scenarios. The product of the ratios comprises a Vulnerability Index. The index is higher for children than adults. For Washington this Index is reflected in the “industrial” vs “unrestricted” soil cleanup levels, which are 43.7 times lower for “unrestricted”. This paper explores the similarities and differences in the exposure scenarios and vulnerability of the maximally exposed individuals and the consequences of a mismatch between current cleanup levels and possible future land uses.

INTRODUCTION

The combination of industrialization, urbanization, mining, agriculture, and war has resulted in contamination of many areas of the world, with hazardous concentrations of inorganic, organic and radioactive contaminants in soil, sediment, and both ground and surface water supplies. This paper addresses soil cleanup levels and the consequences of a mismatch between current cleanup levels and future land uses. We compare two States (Washington and New Jersey) with excellent hazardous waste cleanup approaches. Washington is home to the Hanford Reservation embodying the largest hazardous waste cleanups of its nuclear weapons production legacy in the nation. New Jersey was, until recently, the most densely industrialized state in the nation, and its challenge was the widespread uncontrolled (often undocumented) disposal of industrial wastes. By the 1970s this toxic legacy was a major public policy issue, and legislation was passed in New Jersey (1976 *Spill Compensation Act*) and the Nation (1980 *Comprehensive Environmental Response Compensation and Liability Act*) to halt future illegal dumping and to clean up existing contamination. The nuclear weapons legacy represents a special case. The urgency of developing an Atom Bomb in World War II and the subsequent arms race, allowed widespread contamination of large sites now controlled by the Department of Energy [1]. The Hanford Site in central Washington contains numerous waste sites, facilities and tanks containing this nuclear legacy. Trenches, soil, groundwater, and the banks of the Columbia River are contaminated with a diverse chemical and radiologic inventory [2]. Cleanup of this contamination is underway and is projected to continue for another 50 years, by which time facilities will be decontaminated and demolished, tank contents will be stabilized, contaminated soil will be removed or covered, and highly hazardous radiation inventories will be contained and capped. The question remains: What can be done with all these sites? This paper builds on our paper presented at HW2015 [3], which focused on alternative land use plans. It is part of the Hanford Risk Review Project conducted by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) [2].

Although Hanford represents the largest collection of hazardous waste sites in the US, many cities in New Jersey, Washington and elsewhere have old, contaminated industrial facilities that also require remediation. Urban land is valuable, and communities anticipate that once-remediated, such sites can be put to use for commercial or industrial development, as parks, or even for residential development, assuming they can be cleaned up sufficiently. “Sufficiently” becomes the operative term for cleanup. What level of cleanup is required to allow construction and operation of a factory, a supermarket, a daycare center, soccer fields, townhouses, family farms or a range of tribal cultural uses?

We emphasize that there is a reflexive relationship between the desired future land use, and the level of cleanup required today. Where cleanup cannot be accomplished because of technical or financial limitations, future land uses will be constrained [3]. Land is a valuable, non-renewable resource, and cities desire and need to restore damaged land to useful purposes, certainly an issue around the Hanford Site. However, often the costs of cleaning such contamination outweigh any monetary value of the land in the foreseeable future.

Regardless of who defines land use, each proposed land-use type has an associated exposure scenario identifying a maximally exposed representative and describing the assumed volume of air, drinking water, and soil consumed in a day by the inhalation, ingestion and dermal pathway as well as the frequency (days/yr.) and duration of exposure (yrs.). Direct exposure to radioactive sources is a particularly large issue at the Hanford Site [3].

The following sections compare Washington and New Jersey.

Washington State

Washington State's Model Toxics Control Act (MTCA Washington 1989 Chapter 70.105D RCW), and implementing sections (WAC 173-340-XXX) identify approaches for determining soil cleanup levels. MTCA recognizes only two categories of cleanup: “unrestricted” (WAC 173-340-740) and “industrial” (WAC 173-340-745). These documents specify the default exposure assumptions to be used for each category (see below), while allowing site specific modifications. Numeric cleanup levels are given in *Cleanup Level and Risk Calculation* (CLARC) Tables [4]. Although Washington's Department of Ecology is the lead agency on hazardous waste, the radiologic cleanup guidelines derive from the Department of Health (*Hanford Guidance for Radiological Cleanup* (WDOH/320-015).

The MTCA documents (e.g. WAC 173-340-740 and 745) specify that soil cleanup levels must be based on the “reasonable maximum exposure expected to occur under both current and future site use conditions. The State defines “industrial” as “properties that are or have been characterized by, or are to be committed to, traditional industrial uses” (WAC 173-340-200). Details on qualifying for “industrial” designation are provided in WAC 173-340-745. The maximally exposed receptor is the adult industrial worker of the future, on site for 225 days/yr with inadvertent ingestion of 50 mg of soil daily. Residential uses are excluded, as are construction workers digging the foundations for the future industries and the ecological workers that perform the restoration or future landscaping (our reference [5]). The industrial cleanup site requires institutional controls (WAC 173-340-440) to assure future land uses are compatible with the “industrial” designation and do not entail excess risk.

Washington State's definition of “unrestricted” is that no restrictions are required to ensure continued protection of human health and the environment.”[WAC 173-340-200] “Unrestricted” assumes that groundwater would be potable for future site users, although many residential communities and cities do not rely on the underlying groundwater. The reasonably maximum exposed receptor is a 16 kg child living on site 350 days per year and ingesting 200 mg/day of soil. The soil ingestion pathway is the major exposure route, even though the site was capped before being released for industrial uses (see below).

The MTCA identifies three methods for setting cleanup levels. In method A, soil levels are listed for 25 compounds, of which 21 have identical “unrestricted” and “industrial” cleanup levels based on protection of ground water. These concentrations should also “result in no significant adverse effects on…ecological receptors.” [WAC 173-340-200] For most large and complex cleanups, other methods (designated B and C) are used to calculate site specific cleanup level, to assure that no one will be exposed to a Hazard Index greater than 1 or an excess cancer risk. For such sites, cleanup levels are derived from a risk equation for non-cancer effects (see equation 740.1 below), basing the cleanup level for any substance on its reference dose to achieve a hazard index (HI) of one. For carcinogens (equation 740.2 below) the cleanup level is based on the cancer potency factor and on not exceeding a cancer risk of 1E-06 for the unrestricted site child or 1E-05 for the future industrial worker. Other agencies, including DOE, are more lenient, allowing a 1E-04 cancer risk for workers.

These exposure-based equations show a substantial difference between the two land uses and between cancer-based and non-cancer exposure assessments. Typically the cleanup level to prevent a cancer excess is lower than the corresponding level for non-cancer outcomes. Although cleanup to industrial levels would include capping or clean soil covers (probably to a depth of 5 m), the unrestricted scenario allows digging of basements and swimming pools and assumes that future occupants will dig a 6” diameter well down to groundwater, and the drilled material will be spread evenly over a 100 ft diameter circle around the well, thus providing the child with potential access to contaminated soil (WAC-173-340-740). If the groundwater is still contaminated at this future date when the breach of institutional controls occurs, the exposure will be higher than estimated below.

Equation 740-1 (WAC 173-340-740) details the factors used to calculate the soil cleanup level based on non-cancer effects. The same equation is used for both unrestricted and industrial scenarios, with the substitution of appropriate exposure factors (see Table I).

[Equation 740-1]

$$\text{Soil Cleanup Level (mg/kg)} = \frac{RfD \times ABW \times UCF \times HQ \times AT}{SIR \times AB1 \times EF \times ED}$$

Where:

RfD	=	Reference dose as defined in WAC **173-340-708** (7) (mg/kg-day)
ABW	=	Average body weight over the exposure duration (16 kg)
UCF	=	Unit conversion factor (1,000,000 mg/kg)
SIR	=	Soil ingestion rate (200 mg/day)
AB1	=	Gastrointestinal absorption fraction (1.0) (unitless)
EF	=	Exposure frequency (1.0) (unitless)
HQ	=	Hazard quotient (1) (unitless)
AT	=	Averaging time (6 years)
ED	=	Exposure duration (6 years)

Equation 740-2 [WAC 173-340-740] details the approach for calculating cleanup for carcinogenic chemicals. For carcinogens listed in CLARC tables (Washington 2015), the cleanup levels based on cancer risk is almost always lower than the corresponding cleanup levels based non-cancer levels. Significant assumptions include the cancer risk must not exceed one in a million (1E-6 or 10^{-6}) for unrestricted, but can be one in a hundred thousand (1E-5, 10^{-5}) for the worker. The assumptions still apply to a 16 kg child, ingesting 200 mg soil/day, and exposed for six years, but the averaging time, during which a cancer may occur is 75 years.

[Equation 740-2]

$$\text{Soil Cleanup Level (mg/kg)} = \frac{\text{RISK} \times \text{ABW} \times \text{AT} \times \text{UCF}}{\text{CPF} \times \text{SIR} \times \text{AB1} \times \text{ED} \times \text{EF}}$$

Where:

RISK	=	Acceptable cancer risk level (1 in 1,000,000) (unitless)
ABW	=	Average body weight over the exposure duration (16 kg)
AT	=	Averaging time (75 years)
UCF	=	Unit conversion factor (1,000,000 mg/kg)
CPF	=	Carcinogenic potency factor as defined in WAC **173-340-708** (8) (kg-day/mg)
SIR	=	Soil ingestion rate (200 mg/day)
AB1	=	Gastrointestinal absorption fraction (1.0) (unitless). May use 0.6 for mixtures of dioxins and/or furans
ED	=	Exposure duration (6 years)
EF	=	Exposure frequency (1.0) (unitless)

The calculations for the difference between the MTCA unrestricted and industrial scenarios are shown in Table I for non-cancer outcomes for a hypothetical contaminant with a Reference Dose = 0.001 mg/kg-day. For chemical contaminants that are not carcinogens, cleanup levels for industrial are 43.75X higher than for the unrestricted/non-cancer. This corresponds to the 43.75X higher exposure. Multiplying the ratios together provides a Vulnerability Index (in this case 43.75), comparing the resident child compared with the factory worker. The method for arriving at this is illustrated below (Table I).

Table I. Cleanup level calculations for unrestricted and industrial scenarios for both non-cancer toxic effects under Washington's MTCA. The calculation is based on the Reference Dose and Hazard Index. The UCF correction adjusts the outcome to mg/kg. Note in equation 740-1 above, that the AT and ED cancel out in the non-cancer assessment. The sample calculation is provided for a hypothetical toxic chemical with a reference dose of 0.001. The Vulnerability Index is estimated by multiplying together all of the exposure ratios.

	Non-cancer Calculations		Exposure Ratio
NUMERATOR	Unrestricted child	Industrial worker	
RfD (Reference Dose based on EPA IRIS and WAC 173-340-708 (mg/kg-d)	.001	.001	
Acceptable risk level	Not applicable	Not applicable	
ABW (Average body weight[a]) (kg)	16	70	4.4
UCF=correction factor for ppm	1,000,000	1,000,000	
HQ=Hazard quotient set to 1	1	1	
AT Averaging time for outcome (years)	6	20	3.3
Numerator Product	96,000	1,400,000	
DENOMINATOR			
SIR (Soil ingestion rate) (mg/day)	200	50[b]	4
AB1 GI absorption rate[c]	1	1	

EF Exposure frequency[d]	1	0.4	2.5
ED (yrs)	6	20	.33
Denominator Product	1200	400	
Calculated Cleanup level	80	3500	
Difference in cleanup levels	43.75 fold difference		Vulnerability Index [e] 43.75

a = EPA may use other exposure factors such 15kg for child, 80kg for adult.
b = Some exposure assessments use 100 mg/day for adults with regular soil contact
c = Default assumption for intestinal absorption is 100% (=1 in the equation). Substances that are poorly absorbed will have higher cleanup levels determined from the equations.
d = EF takes into account 350 days/year vs 225/days per year
e = A Vulnerability Index can be estimated by multiplying together all the exposure ratios.

Using the above calculations (WAC 173-340-740) as starting points for determining cleanup levels results in a 43.75-fold difference for non-carcinogens between the two scenarios. By this reasoning a child exposed for six years on a site remediated to an industrial cleanup level of 3,500 mg/kg of our hypothetical chemical (corresponding exactly to a Hazard Quotient of 1) would experience an HQ of 43.75, from the single substance. This is implicit in the exposure formula and applies generally to any non-carcinogen. For a 70 kg adult resident (soil ingestion=50 mg/day, 20 year averaging time) the Vulnerability Index, and hence differences in cleanup levels would be HI = 12.5.

For carcinogens, the calculated cleanup level is almost always lower than the corresponding cleanup level derived for non-cancer effects. In some cases (e.g. benzene) the Method A level protective of groundwater is the lowest cleanup level. EPA classifies all radionuclides as carcinogens, based on their property of emitting ionizing radiation and on the extensive weight of evidence provided by epidemiological studies of radiogenic cancers in humans [7]. For most radionuclides (except uranium isotopes), only the radiogenic cancer risk is applicable. For uranium, both radiotoxicity and chemical toxicity are normally evaluated.

Cleanup levels for radionuclides are expressed as picocuries per gram (pCi/g) of soil. DOE [8] provides a table of Preliminary Remediation Goals (pCi/g) for cancer risks to industrial workers corresponding to 1E-6 (10^{-6}), 1E-5 (10^{-5}), and 1E-4 (10^{-4}). Cancer risk is estimated using a linear model, so these 10-fold differences in cancer risk are matched by 10-fold differences in cleanup level. The State of Washington requires use the of 1E-6 (10^{-6}) criterion for determining excess cancer risk for unrestricted and 1E-5 as the risk level for workers, while DOE uses 1E-4 as the criterion for workers. For carcinogens, at a cleanup level corresponding exactly to a 1E-6 (10^{-6}) risk level, the cancer risk for the maximally exposed child living on an industrial-cleanup site could be as high as 4.37E-5), depending on when the breach of institutional controls occurs, and the opportunity for medium-lived radionuclides such as cesium-137 and strontium-90 to decay.

EPA and New Jersey: An Interstate Comparison

The EPA and several states have established various soil screening levels for a large number of chemical contaminants for either residential or industrial designations. EPA has recently [9] harmonized its soil screening levels across regions under the rubric of “Regional Screening Levels”. EPA provides tables based on achieving a cancer risk level of 1E-6 and a Hazard Index = 1. In addition to residential and commercial/industrial, EPA distinguishes residential with and without use of ground water, as well as outdoor vs indoor vs construction workers, and recreationists [9]. About 750 chemicals have both residential and commercial/industrial screening values [10]. The ratio of the latter to the former averages 10.6. For most metals the ratio of the industrial to the residential screening level is in the 13 to 15 range. For most volatile organics the ratio is in the 4 to 5 range. Soil screening levels are not necessarily cleanup levels, although they are often used that way.

In the 1970s, New Jersey took the lead in identifying hazardous waste sites requiring cleanup. The New Jersey Department of Environmental Protection (NJDEP) published tables of Residential and Non-residential soil cleanup standards, based on direct contact [11]. Examining exposure factors used by New Jersey [12] reveals a Vulnerability Index for the resident child of 14 (Table II). By comparison, in New Jersey the ratio between industrial and residential cleanup levels are in the 5 to 10 fold range (see Table III).

For New Jersey, "Non-residential use" applies to an adult outdoor worker, potentially exposed 8 hrs/day, 225 days/yr for 25 years [12] . "Residential use" is based on exposure of a 15 kg child to contaminated media for 24 hours a day, 350 days a year for 30 years [12]. The exposure factors and their ratio are shown in Table II. Averaging Time appears in the numerator of Equation 1, thereby raising the Cleanup level.

Table II. NJDEP Default exposure factors [12] calculating soil cleanup levels and their ratios and a composite Vulnerability Index.

Factor	Non-residential	Residential	Ratio
Body Weight (kg	70	15	4.7
Averaging Time (yrs)	25	30	0.8[a]
Frequency (days/yr)	225	350	1.5
Duration (yrs)	25	30	1.2
Soil Ingestion Rate (mg/day)	100	200	2
Target Cancer Risk	1E-6	1E-6	1

		Vulnerability Index	14

a = Averaging Time and Duration of Exposure may cancel out. Longer averaging time increases the cleanup level by decreasing the risk.

Although the Vulnerability Index from the NJDEP Guidance [12] is 14, the ratio between the cleanup levels reported on the New Jersey web site, tends to be less than 10 (see Table III) [11].

Table III. Summary of the non-residential to residential direct contact soil cleanup ratios by chemical category for New Jersey. For each of the categories, the average ratio between non-residential and residential soil cleanup levels is given. The grand average ratio is 8.05. (NJDEP Site Remediation Program Soil Cleanup Criteria [11].

Category of Contaminant	Number of Compounds in NJ List	Average ratio
Alkanes	24	5.89
Ketone, Alcohol, Ether	5	2.38
Aromatics	16	6.40
Metals	15	7.36
Organics	16	10.38
Polyaromatic hydrocarbons	14	5.01
Pesticides	12	7.56
Phthalates	6	4.37

Variations of the Recreational and Residential Scenarios

Both EPA [9, 10] and DOE [13] consider recreational scenarios as appropriate future land uses. Recreational scenarios may include “extraction” such as hunting, fishing and gathering, or may be “non-extractive” such as hiking and photography. Even at one recreational day visit a week (52 days/yr), the number of days on site is lower than the industrial scenario. Thus a 70 kg recreationist spending one day/week on site hiking or bird-watching, would incur about 1/5 the exposure of the industrial worker, even allowing that they consume 50 mg/day of soil.

DOE calculated preliminary remediation goals (PRGs) for casual reactional users of Hanford’s 100 and 300 areas [13]. The PRGs are based on not exceeding a cancer risk of one in ten thousand (1E-4 or 10^{-4}). Compared to the industrial workers [8], the casual user is on site 30 instead of 250[a] days but has a soil ingestion rate of 100 mg/day vs 50 mg/day and an exposure duration of 30 vs 25 years. The product of these ratios yields a vulnerability index for the worker of 3.5. Accordingly the cleanup levels corresponding to the 1E-4 cancer risk area average 3-fold higher for casual compared to industrial scenarios (Table IV).

Table IV. Comparison of “commercial/industrial” [8] and “casual user” [13] Final Preliminary Remediation Goals for selected radionuclides (combining ingestion, inhalation and direct external exposure).

Radionuclide	Final Remediation Goal Commercial/industrial [8] pCi/g 10E-4 risk direct exposure only	Final Remediation Goal Casual User Direct exposure pCi/g	Final Remediation Goal Casual User [10] pCi/g All routes	Ratio of Casual/industrial
Cesium-137	18	101	100	5.6
Iodine-129	1943	27100	3030	1.6
Plutonium 239/240	2906	812,000	3340	1.1
Strontium-90	1968	11600	5060	2.6
Technetium-99	165,700	2150000	114,000	0.7
Uranium-235	61	311	295	4.8

Similarly, there can be a variety of residential scenarios [3] which range from no contact with soil (the High-rise residential land use) to the rural agricultural scenario, using ground water and raising and consuming livestock, garden crops, as well as hunting and fishing. Tribal scenarios include sweat lodge exposures as well as a high historical level of fish consumption. Exposure assessments conducted by and for the Confederated Tribes of the Umatilla [14] and the Yakama Nation [15] demonstrate that traditional Indian uses of the land result in higher estimates of exposure through sweat lodge use, and consumption of large quantities of fish, game, plant materials and groundwater. By contrast, the DOE’s baseline risk assessment [16] and remedial investigation/feasibility study (RI/FS) for the Hanford 300 area [1], which includes land along the Columbia River, defines five future land-use scenarios: industrial, casual recreation, resident monument worker, residential, and tribal, thus conflicting with the Department’s own Comprehensive Land Use Plan (CLUP). The RI/FS recognizes that the River Corridor and National Monument will include “recreational users, tribal users, and monument workers”, the latter of whom are site residents.

CONCLUSIONS

Cleanup of contaminated lands is conducted in conjunction with an understanding of potential future land uses, taking into account the effectiveness and permanency of the engineered barriers and institutional controls intended to protect health and the environment for centuries. The criteria for protecting health (excess cancer risks and Hazard Index) are not universally agreed upon. These are not bright lines. For example, exceeding a Hazard Index of 1 is undesirable but not lethal. This paper illustrates the challenge facing all remediation, with regard to the maintenance of barriers and institutional controls to protect people in the future from engaging in activities ill-suited to a site with residual contamination. For sites where cesium-137 and strontium-90 contribute significantly to the cancer risk, the risks will attenuate substantially over the first 100 years. Both have about a 30 year half-life and almost one half-life has already occurred since 1989. Even an unacceptable 1E-4 risk declines to less than 1E-6 after seven half-lives. The contribution of these two widespread isotopes will be negligible after another 200 years.

In an increasingly technology-dependent world, it is realistic to think that the smart phones of the future will be equipped with a range of detectors, sensors and dosimeters that would protect suburban residents, rural farmers and tribal members who may find themselves living on today's industrial-level cleanup sites. A cohort of foolhardy archaeologists 1000 years hence, attempting to unearth the sites DOE has worked so diligently to safely bury, will need such devices (much like today's archaeologists wield oxygen sensors before entering confined spaces).

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