Managing Soil Contamination in the United States: Policy and Practice

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Abstract

Soil contamination in the United States is managed using a risk-based decision making process. In other words, we don't ask, "how much soil contamination can be cleaned up?" Instead we ask, "how much contamination can be <u>safely</u> left in place?" The determination of "safe" levels of contamination is based upon the potential for exposure and the toxicity of the contaminants of concern in soil. Potential for exposure is determined by evaluating potential exposure pathways from source to receptor given current or reasonably anticipated land use. Soil cleanup goals are then calculated for any complete exposure pathways based upon toxicity and the route of exposure. In some cases, institutional or engineering controls are also used to limit the potential for exposure. In order to prevent a continuous degradation of environmental quality, risk-based cleanup approaches must be combined with strong contamination prevention programs. In addition, alternative risk management approaches should be incorporated into an overall risk reduction strategy.

Introduction

Soil contamination in the United States is managed using a risk-based decision making (RBDM) approach. There is not enough money or resources available to clean up all soil contamination in the United States to uncontaminated conditions. Basing cleanup decisions on risk reduction allows resources that are inevitably finite, to be allocated across sites for maximum risk reduction benefit. However, this change in emphasis from engineered on-site mass (or concentration) reduction to risk-reduction at the point of exposure may also result in greater quantities of residual soil contamination being left in place at some sites upon cleanup completion. Though this may be a more economically efficient approach to cleanup, it knowingly accepts some finite cost of the remaining contamination or the associated environmental resource degradation, and in at least some cases the cost may be higher than we realize.

By applying a RBDM approach to soil contamination cleanup, we have gone from asking, "how much contamination can we clean up?" to asking, "how much contamination can we safely leave in place?" This subtle but important shift in perspective has potentially far-reaching implications for the way we manage soil contamination. Because of the difficulties associated with removing contamination from the subsurface the answer to the first question of how much can we clean up has often been "not much, at least in the short run." Therefore, we have already been leaving some contamination in place by default or as a result of our inability to remove it with the resources that have been allocated.

Risk-Based Decision Making (RBDM), Deciding What is Safe

Addressing the question of how much contamination we can safely leave in place becomes a risk management decision. Risk management at contaminated soil sites usually takes the form of preventing harmful impacts to receptors as expressed through cleanup concentration goals. On a regional scale this means determining which contamination, or contaminated sites will do the least resource damage if left in place.

Concentration-Based Cleanup Goals

State and Federal regulations require that the lateral and vertical extent of soil contamination be defined through environmental sampling and investigation. Based on data gathered during the site assessment process sources of contamination, potential migration pathways, and human and ecological receptors are defined. Exposure Assessment is used to evaluate the potential for contaminants to migrate from soil through water or air and impact a receptor (Figure 1).

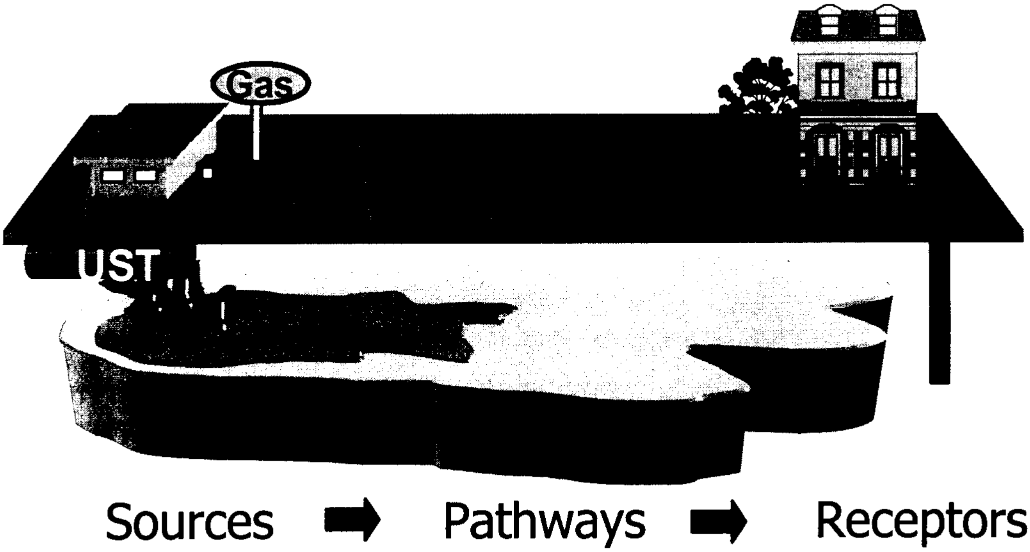

Figure 1. Exposure assessment is used to evaluate the potential for contaminants to migrate from soil through pathways such as aquifers to receptors

When a complete exposure pathway is found between the source of contamination and a receptor, risk assessment is used to evaluate the impacts to the receptor. Chemical dose response data from laboratory studies with animals is extrapolated to estimate health impacts in humans. These estimates are generally based on either toxic effects of a compound expressed as reference dose or carcinogenic effects expressed as a slope factor. Reference doses and slope factors are combined with standard exposure factors to determine concentrations that will not exceed acceptable risk levels. Acceptable risk levels are usually set at a non-carcinogenic hazard Quotient of less than 1 and an incremental cancer risk between one in ten thousand (1×10^{-4}) and one in a million (1×10^{-6}). Standard risk calculations can then be used to determine Figure 1. Exposure assessment is used to evaluate the potential for contaminants to migrate from soil through pathways such as aquifers to receptors concentrations that will not exceed acceptable risk levels, as shown in the example equations for combined exposures to carcinogenic and non-carcinogenic contaminants in residential soil respectively (EPA, 2002a).

$$C(mg/kg) = \frac{TR \times AT_c}{EF_r \left[\left(\frac{IFS_{adj} \times CSF_o}{10^6 mg/kg} \right) + \left(\frac{SFS_{adj} \times ABS \times CSF_o}{10^6 mg/kg} \right) + \left(\frac{InhF_{adj} \times CSF_i}{VF_a^a} \right) \right]}$$

$$C(mg/kg) = \frac{THQ \times BW_c \times AT_n}{EF_r \times ED_c \left[\left(\frac{1}{RfD_o} \times \frac{IRS_c}{10^6 mg/kg} \right) + \left(\frac{1}{RfD_o} \times \frac{SA_c \times AF \times ABS}{10^6 mg/kg} \right) + \left(\frac{1}{RfD_i} \times \frac{IRA_c}{VF_a^a} \right) \right]}$$

Where:

C = “safe” concentration in soil (mg/kg)

CSFo = Cancer slope factor oral (mg/kg-d)

CSFi = Cancer slope factor inhaled (mg/kg-d)

RfDo = Reference dose oral (mg/kg-d)

RfDi = Reference dose inhaled (mg/kg-d)

TR = Target cancer risk 10^{-6}

THQ = Target hazard quotient 1

BWa = Body weight, adult (kg) 70

BWc = Body weight, child (kg) 15

ATc = Averaging time - carcinogens (days) 25550

ATn = Averaging time - noncarcinogens (days) ED*365

SAa = Exposed surface area for soil/dust (cm2/day) adult resident 5700, worker 3300

SAc = Exposed surface area, child in soil (cm2/day) 2800

AFa = Adherence factor, soils (mg/cm2) adult resident 0.07, adult worker 0.2

AFc = Adherence factor, child (mg/cm2) 0.2

ABS = Skin absorption defaults (unitless)

IRAa = Inhalation rate - adult (m3/day) 20

IRAc = Inhalation rate - child (m3/day) 10

IRWa = Drinking water ingestion - adult (L/day) 2

IRWc = Drinking water ingestion - child (L/day) 1

IRSa = Soil ingestion - adult (mg/day) 100

IRSc = Soil ingestion - child (mg/day), 200

IRSo = Soil ingestion - occupational (mg/day) 100

EFr = Exposure frequency - residential (d/y) 350

EFo = Exposure frequency - occupational (d/y) 250

EDr = Exposure duration - residential (years) 30
EDc = Exposure duration - child (years) 6
EDo = Exposure duration - occupational (years) 25
Age-adjusted factors for carcinogens:
IFSadj = Ingestion factor, soils ([mg-yr]/[kg-d]) 114
SFSadj = Dermal factor, soils ([mg-yr]/[kg-d]) 361
InhFadj = Inhalation factor, air ([m3-yr]/[kg-d]) 11
IFWadj = Ingestion factor, water ([L-yr]/[kg-d]) 1.1
VFw = Volatilization factor for water (L/m3) 0.5
PEF = Particulate emission factor (m3/kg)
VFs = Volatilization factor for soil (m3/kg)

Using this approach, risk-based "safe" concentrations can be established for a variety of exposure pathways including soil ingestion, ingestion or contact with water that has been in contact with contaminated soil, dermal contact with contaminated soil, and inhalation of vapors volatilizing from contaminated soil. Generic, conservative parameters are used to develop screening levels that can be used rapid preliminary risk evaluation (EPA, 2002b). Site-specific parameters along, contaminant fate and transport modeling, and alternative points of compliance can then be used to calculated site-specific "safe" concentrations.

This approach incorporates risk reduction as the driving force for cleanup decisions. Cleanup goals are based on reducing concentrations at the site to levels that will not exceed a predetermined risk at the point of exposure. The estimate of risk reduction is typically contingent on site conditions and land use remaining relatively static into the future.

Engineering and Institutional Controls

With increased attention and funding being focused on redevelopment of contaminated properties, or Brownfields, there is often pressure to employ a combination of concentration reduction and exposure pathway elimination through the use of engineering and institutional controls. Engineering controls are usually barriers such as slurry walls, asphalt caps, or vapor barriers under foundations that prevent migration of contaminants from soil to receptors. Institutional controls typically take the form of regulating and permitting activities that create the potential for exposure such as soil excavation and water well drilling The key challenge for institutional and engineering controls is ensuring the longevity of these controls by providing for appropriate monitoring and enforcement.

Alternative Risk Management Approaches

There are a number of limitations associated with the current risk-based approach employed in the United States. In general, synergistic effects are not accounted for. In fact, some chemicals may interact to increase or decrease overall toxicity. Pre-remediation exposures are often neglected. Elevated background risks for heavily impacted communities may also be neglected. The following alternative risk assessment and risk management paradigms hold some promise for addressing these issues if they can be integrated into with the current risk-based decision making approach.

X*Anti-degradation Policies* - Policies and regulations requiring environmental restoration to pre-release conditions. Typically applied to water resources. Often economically and technically difficult to achieve.

X*Pollution Prevention* - accomplished through best management practices for chemical storage, transportation, and handling, land use planning, waste minimization, and programs that provide incentives for protecting resources.

X*Precautionary Principle* - "When an activity raises environmental threats, precautionary measures should be taken even if some cause-and-effect relations are not fully established scientifically. The proponent of an activity should bear the burden of proof" Replace the Environmental Protection Agency approach where chemicals are ok to use until proven hazardous with the Food and Drug Administration approach where drugs are dangerous until proven safe.

X*Use of Biodegradable Industrial Chemicals* - Recalcitrant compounds such as halogenated organics and ethers are some of the most widespread, problematic, and toxic compounds in the environment. Biodegradable substitutes exist for many of these compounds in most applications (Thornton, 2001).

X*Life Cycle Analysis* - Evaluate the entire production, use, disposal, and waste management cycle for chemicals. Particularly recalcitrant chemicals in widespread use. Process inventory, impact assessment, time and location independent effects may ignore local impacts and thresholds. Often expressed as negative effect on number of years that can be lived in good health.

X*Environmental Justice* - Environmental protection is a right, not a privilege. Environmental protection is not equal across class and racial lines. For example, preferential siting of hazardous waste facilities. High correlations have been found between minority populations and levels of toxic pollutants. Accusations of less aggressive cleanups in minority communities.

X*Long-term Management of Residual Contamination* - Institutional controls, permitting restrictions (wells and excavations), well-head protection and vulnerability analysis, land-use restrictions based on aquifer vulnerability and basin management, long-term plume and site tracking using geographic information systems (GIS), multi-agency data sharing and access

Incentives and Disincentives for Contaminating Soil (Accountability)

Historically soil contamination has been treated as an accident, with no moral retribution or punishment for owners and operators who showed a good faith effort to clean up. As polluters were still liable for the damage, a strong disincentive to releasing petroleum remained, namely, the staggering cost of cleaning up. However, RBDM may only require polluters to clean up when there is a risk. This removes much of the financial disincentive for contaminating, particularly in "lower risk" areas. In light of this we may need to re-examine disincentives for contaminating soils. Given all of the programs and priorities competing for resources we don't want to pour money into the ground unless it will be well used. However, there is some cost associated with resource damage and loss of beneficial uses of soils.

The costs of resource damage and loss of beneficial uses can be difficult to quantify, but it may be worthwhile to explore ways to hold polluters more financially accountable for current and future worth of damaged environmental resources. Possible approaches include requiring contribution to a trust fund, paying for source water protection programs in the impacted watershed, or undertaking supplemental environmental projects to compensate for the value of the resources which have been damaged. For example, let us consider a hypothetical case where contaminated ground water under a site is worth $100 and it costs $50 to remove half of the contamination, but $150 to remove the remaining contamination. In other words the cost of the resource damage may be less than the cost of the cleanup, but it is not zero. Perhaps it would be appropriate to remove the first $50 of contamination, and charge the responsible party $50 more for the damages associated with leaving the remaining contamination in the ground.

Conclusions

Preventing soil contamination in the first place is the best way to protect soil resources. This can be accomplished through best management practices, land use planning, waste minimization, and programs that provide incentives for protecting resources. We must also be more proactive in managing the potential for soil contamination. We can use land-use planning and basin management plans to reduce the potential for resource damage from contaminant releases in the future. Communities can choose to site potentially contaminating activities in areas where the potential to impact soil and water resources is lower.

When soil does become contaminated, we must continue to hold responsible parties accountable. We must use all of the risk management approaches at our disposal for resource restoration, public health protection, and cleanup. Managing short-term exposure risks through source control, engineered and monitored remediation, engineering controls to prevent exposure, monitored natural attenuation (when appropriate), and engineered containment (when appropriate). Managing long-term exposure risks through institutional controls, permitting restrictions (wells and excavations), land-use restrictions, and multi-agency data sharing and access.

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국문요약

Introduction

모든 오염된 지반을 복원하기에는 자본과 자원이 충분치 않기 때문에 미국에서는 risk-based decision making(RBDM) 접근법에 기초해서 토양오염을 다루고 있다. 위해성 감소를 위한 정화결정은 유한한 자원을 위해성의 감소를 최대화할 수 있는 현장에 활용하는 이점을 얻을 수 있다. 그러나, 농도 저감에 중점을 둔 방법에서 위해성의 저감에 중점을 두는 방법으로의 전환은 토양 내 잔류하는 오염물질이 상당량 남을 수 있다. 또한 이 방법이 비록 정화에 있어서 더 경제적일 수는 있지만, 어떠한 경우에는 우리가 생각하는 것 보다 더 많은 비용이 소요될 수도 있다.

Risk-Based Decision Making(RBDM), Deciding What is Safe

유해성에 기초한 결정법에서는 우리에게 피해를 주지 않는 농도가 어느 정도인가하는 문제가 중요하다. 오염지역에 대한 위해성 관리는 정화를 통해 수용체에 미치는 나쁜 영향을 막을 수 있는 목표 농도를 정하는 방식으로 취해지며, 실제 현장에서는 지중내에 오염물질이 남더라도 피해를 최소화할 수 있는 농도와 영역을 결정하는 방식으로 결정되게 된다.

Concentration-Based Cleanup Goals

미국의 경우에는 시료채취와 현장조사를 통해 토양 오염의 범위를 결정할 것을 규정하고 있다. 현장 조사를 통해서 오염원, 이동경로 뿐 아니라 인간을 포함한 수용체까지 결정되며, 그림 1 과 같이 토양에서 물, 공기를 통한 오염물질의 이동 가능성과 수용체에 미치는 영향에 대한 평가는 노출평가를 통해 이루어진다.

오염원에서 수용체로의 노출경로가 정해지면 수용체에 미치는 영향에 대한 위해성 평가가 수행된다. 실험실에서 동물을 사용하여 실험을 하고 이를 토대로 인간에게 미치는 영향을 추정하게 된다. 이 과정에서는 일반적으로 화학물질의 독성이나 slope factor 로 표현되는 발암성에 기초해서 추정하게 된다. 일반적인 위해 농도는 위험을 줄 수 있는 정도를 초과하지 않는 농도로 결정된다. 보통 제시된 두 개의 식은 각각 발암성과 비발암성 오염물질에 대한 계산식의 예를 보여주는 식이다.

이러한 접근법에서는 위해성에 기초한 안전한 농도는 다양한 노출 경로에 대해 제시될 수 있다. 현장의 특수성은 오염물질 거동과 이동 모델링을 통해서 그 현장에서의 허용 가능한 농도가 계산될 수 있다. 이 방법에서는 정화 결정에 있어서 위해성의 감소를 고려하게 되며, 노출지점에서 예측된 위해성을 넘지 않는 수준으로 농도를 감소시키는 것이 정화의 목표 수준이 된다.

Engineering and Institutional Controls

오염된 지반의 재개발에 대한 관심과 자본이 증대됨에 따라 종종 공학적, 제도적으로 마련된 방법을 통한 농도의 저감과 노출 경로의 제거가 모두 요구된다. 공학적 방법에는 토양에서 수용체로 오염물질이 이동하는 것을 막을 수 있는 슬러리월, 아스팔트 캡과 같은 벽체의 사용이 있으며, 제도적인 방법으로는 굴착과 water well drilling 과 같이 오염물질이 노출될 가능성을 갖고 있는 것들에 대한 규제가 있다. 이러한 방법들이 잘 유지되기 위해서는 적절한 관리와 제재가 수반되어야 한다.

Alternative Risk Management Approaches

미국에서 채택된 통상적인 위해성 접근법에는 시너지 효과가 설명되지 못하는 등의 한계가 있다.

·Pollution Prevention

- 화학물질의 저장, 운반, 토지 이용계획, 폐기물의 최소화를 위한 최적의 유지관리와 자원보호에 대한 인센티브 프로그램을 통해 이루어질 수 있다.

·Precautionary Principle

- 어떠한 활동이나 행위가 환경의 오염을 일으킬 수 있을 때 그에 맞는 예방책이 수립되어야 한다. 화학물질이 유해한 것으로 증명되지 않는 한 사용해도 된다는 미환경청(EPA)의 방식은 약품이 안전하다는 것이 증명될 때까지는 위험한 것이라고 보는 식약청(Food and Drug Administration)의 방식으로 대체되어야 한다.

·Use of Biodegradable Industrial Chemicals

- 할로겐화 유기화합물과 에테르 같은 화학물질은 가장 널리 사용되며 많은 문제도 있는 독성이 있는 화학물질이다. 이러한 화학물질의 대부분은 생분해가 가능한 성분들이다.

·Life Cycle Analysis

- 화학물질의 생산, 사용, 처분, 폐기물관리의 전반적인 사항이 평가되어야 한다.

·Environmental Justice

- 환경보호는 일부에게 국한된 것이 아니라 모두에게 해당되는 것이다.

·Long-term Management of Residual Contamination

- 오염에 대한 장기적인 관리는 제도적 장치, 제한, 우물 보호, 취약성 분석, 토지 사용 제한, GIS 를 이용한 장기적인 오염운과 현장의 관리와 여러 기관의 데이터의 공유와 활용을 통하여 이루어질 수 있다.

Incentives and Disincentives for Contaminating Soil (Accountability)

자원의 피해를 금전적으로 정량화하는 것은 어려운 일이지만, 오염된 환경 자원의 현재와 미래의 가치를 금전적으로 설명하는 것은 가능할 수 있다. 예를 들어 $100 의 가치를 지닌

지하수가 오염된 상황을 가정하여 생각해보면, 오염의 절반 수준을 제거하는 데는 $50 이 소요되지만, 나머지 절반을 처리하는데는 $150 이 소요된다. 환경자원의 피해액은 정화의 비용보다 작을수는 있지만 없는 것은 아니다. 따라서, 초기 정화 비용인 $50 은 지반 내에 오염물질이 남는 것과 관련된 피해를 유발한 책임이 있는 당사자에게 $50 이상의 비용을 부담하게 하는 것이 적절할 것이다.

Conclusions

우선 토양 자원의 보호를 위해 가장 좋은 방법은 오염을 방지하는 것이다. 이것은 토지이용 계획, 폐기물의 최소화, 자원보호를 위한 인센티브 제공 프로그램 등을 통하여 가능할 것으로 생각된다. 우리는 토양 오염의 가능성에 사전에 준비해야하고, 토지이용계획과 관리를 통하여 향후 오염물질의 누출로 인한 자원의 오염 가능성을 줄여야 한다.

토양이 오염되었을 때에는 자원의 복원, 공공 보건 유지와 정화를 위한 위해성 관리 접근법을 사용해야 한다. 단기적으로는 오염원 관리, 공학적 정화, 노출 방지를 위한 공학적 조치와 가능하다면 자연 저감 모니터링과 오염물질 차단기술등을 통하여 노출 위험성에 대한 관리를 수행하고, 장기적인 노출 위험성의 관리는 제도적 장치와 우물, 굴착등의 시설물 제한, 토지 이용 제한과 여러기관의 자료를 공유하는 것을 통해 이루어질 수 있다.