INTEGRATED ENVIRONMENTAL SOLUTIONS

Development of a Risk Based Corrective Action Program for Kuwait Environmental Remediation Project

Dr P. K. Krishnan, Mr Brian Freeman, PE, and Dr Mark Johns (Exponent Inc)
Integrated Environmental Solutions Company, W.L.L.

ABSTRACT

Risk Based Corrective Action (RBCA) is a tool that helps determine remedial objectives and methods appropriate for many types of environmental restoration problems. Risk-based decision making streamlines and accelerates the environmental restoration process by considering end-use requirements and is used extensively in the United States and Europe for complex environmental remediation projects. Different organizations – including the American Society of Testing and Materials (ASTM) -- have developed RBCA standards and procedures for addressing petroleum product contaminated sites. This paper attempts to highlight the key principles and concepts of the RBCA approach, compare the approaches developed by different organizations and address the issue to the Kuwait Environment Restoration Program (KERP).

Introduction

The problems associated with cleaning petroleum-contaminated sites are well documented. The remediation technologies used on these sites should be feasible, quick, cost-effective and deployable in a wide range of physical settings. Current land-based remediation technologies include soil washing, soil vapor extraction, land-farming, soil flushing, solidification/stabilization, thermal desorption, bio-piles, phyto-remediation, bio-slurry systems and bio-venting depending upon the type of pollutants and/or the characteristics of the site. All over the world considerable resources have been expended to restore sites contaminated with petroleum constituents because of the adverse impacts on human health and the environment.

Historical Clean-Up Thresholds

In the past, clean-up goals were usually established without evaluating potential effects to human health. Sites were considered restored when the effected groundwater contamination was reduced back to background or non-detect levels, to maximum contaminant levels, or to some level of total petroleum hydrocarbons. Such practices used restoration goals that were often difficult or impossible to achieve making site restoration prohibitively expensive.

Until recently, protection of the hypothetical "Maximally Exposed Individual" (MEI) was used as the basis to establish cleanup goals. A Maximally Exposed Individual (MEI) is one who - because of proximity, activities, or living habits - could potentially receive the maximum possible dose of radiation or of a hazardous chemical from a given event or process. Because of the focus on protecting the MEI, risk assessment of contaminated sites often focused on the "worst case" or "reasonable worst case". This has proved costly to implement with minimal positive impacts for the public (Crawford et al 2003).

Assuming a site where both soil and groundwater are contaminated, the MEI is assumed to be someone who lives on the site and is exposed to the contamination through all possible exposure pathways. However, in reality, it is extremely unlikely that an individual would be exposed to all the pathways. In the past, many countries required cleanup based on fixed numerical criteria that were established using generic assumptions of site conditions such as soil type, depth to groundwater, geology and hydrogeology, and proximity to potential receptors.

Such an approach ignores the fact that contaminated sites vary widely in terms of complexity, and the potential risk to either human health and/or the environment. As fixed numerical criteria are usually always set at very low levels to ensure safety at a wide variety of sites, their use has led to more stringent cleanup efforts than may be necessary. This has led to a waste of industry resources (and ultimately adds to the consumer's expense) and to conducting cleanups with no incremental reduction in risk to human health and the environment (Guerin 2002).

As a result of these inequities in site conditions and evaluations, the risk-based corrective action (RBCA) process was adopted in the US and several other countries.

Risk assessment can be used to help estimate the risk as a function of site conditions and chemical contaminants in the absence of remedial action; focus site-characterization activities on the exposure pathways, media and chemicals that pose the greatest risk to health and the environment; establish realistic cleanup or treatment goals; compare alternatives restoration techniques to cost-effectively achieve the cleanup goals and other remedial action objectives; and develop post-remediation monitoring plans (Washburn and Edelmann 1999).

Petroleum Pollution

The chemical complexity of petroleum released to the soil arises, in part, from the chemical complexity of petroleum itself. The chemical structure of the crude oil varies according to both the nature of the parent material and conditions under which it was formed. Commercial fractions of petroleum naphtha, gasoline, kerosene, gas oil fuel oil etc.), which are defined in terms of their boiling point range, each contain many hundreds of individual chemicals amassed together as a "spectrum" of closely related compounds. Once released to the environment, petroleum constituents partition to differing extents between the oil phase, and the air, soil and water phases of the environment (Zemanek et al. 1997). Physical, chemical and biological processes weather or age the spilled product resulting in additional changes in composition, complexity availability, and distribution (partitioning) within the environment (Fig 1) (Morgan and Watkinson 1989, Pollard et al. 1999).

Such degradation processes include adsorption, volatilization, dissolution, biotransformation, photolysis, oxidation, and hydrolysis. The extent of weathering experienced is particularly important when characterizing petroleum contamination prior to remediation (Wang and Fingas, 2003). While there is a large body of literature describing the composition and properties of petroleum products, there is a relative paucity of information on the toxicity, distribution, transport, and availability of weathered hydrocarbons in the environment (Pollard et al. 1994).

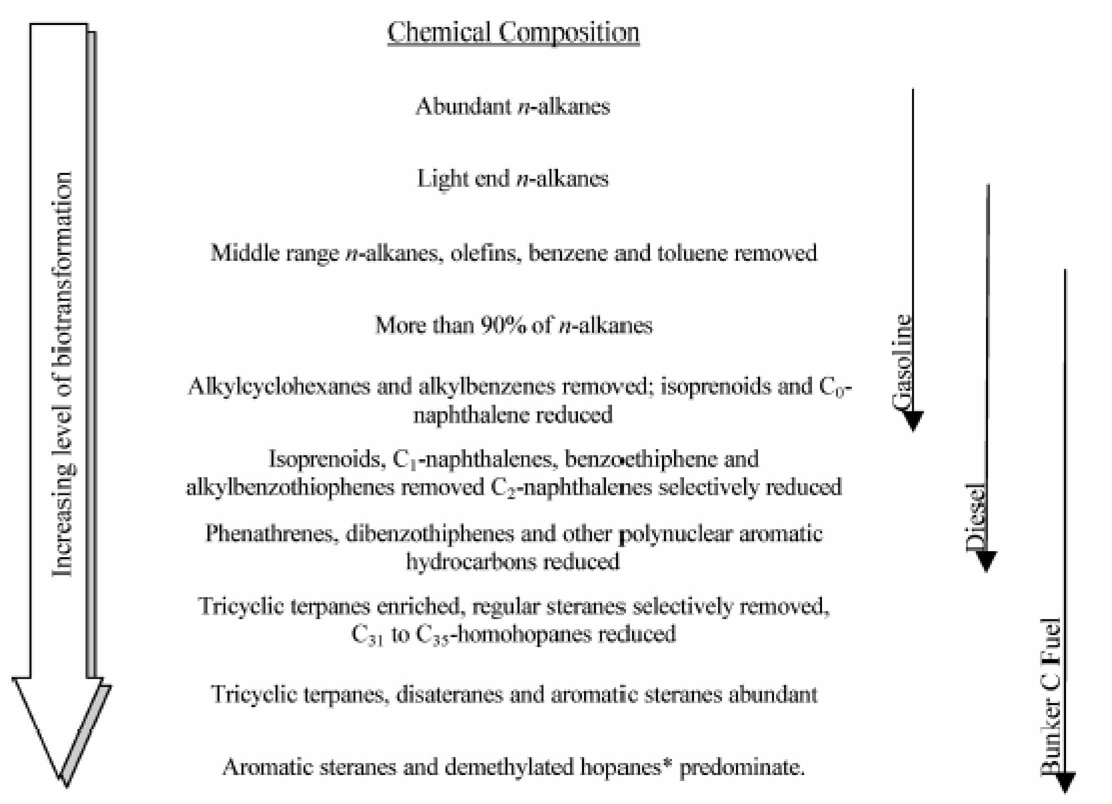


Fig 1. General petroleum hydrocarbon degradation pattern. Modified after Kaplan et al.(1996).

In the case of Kuwait, almost 17 years have passed since the catastrophic events of 1991.

Evaluating Human Health Risks from Petroleum Hydrocarbons in Soils

In spite of the large amount of information available on analysis of environmental samples for mineral oil or Total Petroleum Hydrocarbon (TPH), it is still difficult to relate the data to risks. The difficulties for risk assessment are caused by the complexity of the mineral oil composition, the origin of the crude oil and the fate of the oil in the environment.

TPH analysis is widely used as a general measure of the presence of crude oil or petroleum product in soils. TPH is defined as the measurable amount of petroleum-based hydrocarbon in an environmental media. While providing an overall concentration of petroleum hydrocarbons, TPH itself is not a direct indicator of the risk (i.e., mobility, toxicity, and exposure to human and environmental receptors) posed by petroleum hydrocarbon contamination (Gustafson 2008).

Three basic approaches have been used to estimate the potential human health risks posed by TPH contamination (Crawford et al 2003). The most generally applied and appropriate for evaluation of the carcinogenic risk from TPH is an "Indicator" approach, which assumes that the estimated risk from TPH is characterized by a small number of indicator compounds. Non-threshold indicator compounds include benzene, benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene and indeno[1,2,3-c,d]pyrene. The threshold indicator compounds include toluene, ethylbenzene, xylene, naphthalene, fluoranthene, phenanthrene and pyrene (Askari and Pollard. 2005).

The second approach, known as the "Surrogate" approach, assumes that a single surrogate compound can characterize TPH. This approach can overestimate toxicity and mobility because of the toxicity and mobility of the compounds typically available for use as surrogates. For example with respect to toxicity, benzene is often used as a surrogate compound for all aromatics; it is also one of only a few hydrocarbons that is assessed as carcinogenic. Thus, its use as a surrogate can significantly *over* estimate the potential risk.

A variant of the "Surrogate" approach is the "Whole Product" approach in which the toxicity and mobility of the TPH product are based on that of a whole product of similar characteristics.

It is easier to relate risk to the concentration of individual compounds or groups of related compounds than to a group parameter like mineral oil. However, this is also a limited approach. Risks can be better predicted using the approach of bioavailability (ISO/DIS 17402, Harmsen et al. 2005a). In contrast to heavy metals and Polycyclic Aromatic Hydrocarbons (PAHs), no methods are available to predict the bioavailability of mineral oil to target organisms. This is also related to the way mineral oil is present and adsorbed as individual molecules, but also as a separate phase. The concept of bioavailability has to be kept in mind while developing chemical methods for predicting risks. As long as a free oil phase is present, this phase will be in equilibrium or close to equilibrium with the water phase and risks can be related to total concentration of compounds present in the mineral oil. Having low concentration or low residual concentration as present after natural attenuation and bioremediation of soil, the equilibrium approach will not be valid and a method based on total concentration will overestimate the risks.

Different organisations in different countries have developed different methods to measure the fraction of oil responsible for toxicological effects (Table 1). These methods use different boiling fractions, mostly combined with a separation of the extracted oil into aliphatics and aromatics (Harmsen et al. 2005b).

Table 1: Methods developed by different institutions to predict toxicity (adapted from Harmsen et al. 2005b)

S#	Agency	Extraction Method*	Carbon range
1.	Massachusetts Department of Environment Protection (MaDEP)	2	5-36
2.	Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG)	1	5-35
3.	Canadian Council of the Ministers of Environment (CCME)	2	6-34
4	The National Institute of Public Health and Environmental Protection, Netherlands (RIVM)		5-35
5	New Zealand	2	7-36
6.	Texas Natural Resource Conservation Commission (TNRCC)	1	6-35
7.	API		6-44+
8.	Environmental Agency, UK		6-70
9.	Danish EPA	1	Benzene-35

* *1= Single extraction; 2 = extraction for volatiles + extraction for non-volatiles*

Key concepts in Risk Assessment

The US National Academy of Sciences (NAS 1983) and the U.S. Environment Protection Agency (USEPA 1991) have established guidelines for performing risk assessment. According to these guidelines a quantitative risk assessment typically includes the following steps.

1. **Hazard identification,** in which the main potential adverse health effects are identified. In practice, hazard identification has been replaced by the term "site characterisation" and involves examination of the site and collation of relevant data and information.

2. **Exposure assessment**, in which the potential intake levels/exposures for target populations are calculated;
3. **Dose-response assessment**, in which the relationship between dose level and adverse health effects of chemicals are defined; and
4. **Risk characterisation**, which combines the exposure and dose-response information to predict the likelihood of adverse health effects arising in the target population.

Hazard identification and dose–response assessment provide the summary of information that identifies potential hazard agents and the levels at which exposures present risk to human populations. These two steps present a common basis for judging the implications in public health concerns. Exposure assessment estimates the types and magnitudes of exposures to potential hazard agents (Chu et al. 2001).

Future Use Decision

Assessments made during the risk assessment may affect later decisions regarding the need for, the extent of, and the type of remediation. One such assumption relates to future land use. According to USEPA guidelines under Superfund,

> "the potential land use associated with the highest level of exposure and risk that can be reasonably expected to occur should be addressed in the baseline risk assessment and should be used in developing remediation goals." (USEPA 1991)

Residential land use is often associated with the highest level of exposure and risk and is often assumed in a risk assessment unless an alternate future land use can be supported by site-specific information. The additional effort to perform a detailed land use evaluation can be worthwhile because "different land uses" result in different human exposure pathways as well as different exposure durations, thus varying remediation standards that may be appropriate based upon land use (NJDEP 1994).

Countries and organizations consider aspects of risk assessment frameworks differently. For example, residential exposure scenarios have not been considered as relevant in the American Petroleum Institute (API) framework. This is because the most realistic future uses for exploration and production (E&P) sites are ranch, agricultural, or parkland (API 2001).

There has been a significant regulatory shift toward risk-based standards and a growing acceptance of natural attenuation as an important component of petroleum contaminated site remediation in the United States since 1994. Decisions that determine the proper risk-based remediation approach are based upon technical, regulatory, cost, legal, and political factors. Many states in the US have developed guidelines, which aid in the decision process. A wide variety of options including a host of agency specific methods and commercial risk assessment softwares are available. This wide array of analytical methods has made an impact on the choice of remediation technologies selected for individual sites (Chen et al 2004).

Developing Site Characterization Plan

Site characterization serves a number of different purposes. Data are collected to determine physical characteristics of the site (soil characteristics and groundwater movement), identify the nature and extent of contamination, and support the design of remedial alternatives in addition to supporting the needs of the risk assessment. However, sampling designed specifically to characterize the extent of contamination may not be adequate for estimating exposure concentrations in the risk assessment. By the same token sampling efforts can often be reduced in scope if they are tailored to an overall risk-based remediation technology.

Determining whether corrective action is necessary

Although any contaminated site can pose some level of risk to human health and the environment, not all sites with contamination require remediation. The need for remediation required depends on the chemicals present, their concentrations in the various environmental media, including soil, groundwater, surface water and air, and the extent of potential exposure to these media. Risk assessment techniques are used to identify those sites that may pose unacceptably high risks to human health or the environment and thus require some type of corrective action.

Selecting among potential remedial alternatives

The appropriate remedy for a particular site can range from "no action required" to complete removal of contaminated materials with off-site treatment and disposal. Beyond identification of principal threats, selecting the most appropriate remedy involves the consideration and balancing of a number of important factors. According to the Superfund program of the US, the two threshold criteria that all alternatives must achieve are the overall protection of human health and environment, and compliance with Applicable or Relevant and Appropriate

Requirements (ARARs). Under the 1990 National Contingency Plan (NCP) once these criteria are satisfied, five primary criteria should be considered for selecting the potential remedial alternatives. These criteria are long-term effectiveness, short-term effectiveness, implementability, cost and reduction of toxicity, and mobility or volume through treatment.

Genesis of RBCA

The application of the risk assessment process in establishing petroleum contaminated soil cleanup levels was first reported in the literature by Stokman and Dime (1986) who used a variety of assumptions and a simple risk assessment approach to determine that soil cleanup levels of 100ppm Total Petroleum Hydrocarbons (TPH) would not exceed a 1 x 10^{-6} cancer risk when applied to gasoline spills. This approach was flawed, however, by the use of TPH as the measurement unit and the assumption that the chemical composition of the gasoline product was the same as the chemicals present in the soil matrix of a spill. Regular analytical procedures for the determination of TPH do not distinguish between the wide varieties of possible hydrocarbons each of which present different health hazards. The use of TPH as a risk-based cleanup standard was successfully addressed by the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) in the early 1990's.

The Council for the Health and Environmental Safety of Soils (CHESS) was established in 1988 by the Society for Regulatory Toxicology and Pharmacology and funded primarily by the USEPA's Agency for Toxic Substances and Disease Registry (ATSDR) to develop an advanced risk assessment model for petroleum contaminated sites. The Council's efforts resulted in a comprehensive review of available risk assessment approaches (Calabrese and Kostecki 1992) and recommendations for appropriate environmental fate models and a number of default exposure parameters.

ASTM developed a risk-based corrective action process, which is the integration of site assessment, remedial action selection, and monitoring with appropriate risk and exposure assessment practices. The efforts of both TPHCWG and ASTM have helped solidify the use of risk assessment in establishing soil cleanup level.

ASTM Method

The ASTM RBCA approach involves three tiers: Tier 1 involves a traditional initial site assessment based on source characterization, the potential for exposure, the extent of contaminant migration, and a summary of the site characterization results.

A look-up table containing screening level concentrations is used to determine whether site conditions satisfy the criteria for a quick regulatory closure or warrant a more site-specific evaluation. Groundwater, soil, and vapor concentrations may be presented in this table for a range of site descriptions and types of petroleum products. The look-up table of risk-based screening levels (RBSLs) is developed in Tier 1 or, if a look-up table has been previously developed and determined to be applicable to the site by the user, then the existing RBSLs are used in the Tier 1 process. Tier 1 RBSLs are typically derived for standard exposure scenarios using current Reasonable Maximum Exposure (RME) and toxicological parameters as recommended by the USEPA. These values may change as new methodologies and parameters are developed. Tier 1 RBSLs may be presented as a range of values, corresponding to a range of risks or property uses.

Contaminant concentrations are compared with RBSLs derived from conservative default fate-and-transport and risk assessment parameters. If the results of a Tier 1 assessment, which is based on conservative default parameters, are unacceptable due to cost or feasibility considerations, additional site information can be collected for reassessment according to Tier 2 criteria. In general, a Tier 1 evaluation identifies sites which require "no further action."

For sites which exceed the Tier 1 limit, Tier 2 analysis provides a more cost-efficient basis for an evaluation of remedial measures. Tier 2 involves the use of site-specific data (instead of Tier 1 default levels) to develop Site-Specific Target Levels (SSTLs), which are based on the site's relevant physical and chemical characteristics, augmented by analytical fate-and-transport and risk assessment modeling. This measures migration and attenuation of contaminants from the source area(s). As with Tier 1, site conditions in Tier 2 are analyzed to determine achievable, appropriate, and economical remedial action goals. Tier 1 RBSLs and Tier 2 SSTLs represent concentration limits for constituents within the source zone.

Tier 2 provides the user with an option to determine SSTLs and point(s) of compliance. Both Tier 1 RBSL and Tier 2 SSTLs are based on achieving similar levels of protection of human health and the environment. However, in Tier 2 the non-site-specific assumptions and point(s) of exposure used in Tier 1 are replaced with site specific data and information. Additional site-assessment data may be needed. For example, the Tier 2 SSTL can be derived from the same equations used to calculate the Tier 1 RBSL, except that site-specific parameters are used in the calculations. The additional site-specific data may support alternate fate and transport analysis. At other sites, the Tier 2 analysis may involve applying Tier 1 RBSLs at more probable point(s) of exposure. Tier 2 SSTLs are consistent with USEPA recommended practices.

According to Husain et al (2000) and RAAG (2000) SSTLs differ from RBSLs in three significant ways as follows:

1. Site-specific data is used to calculate risk-based cleanup goals;
2. Human exposure to affected media may occur not only at the source zone, but at a separate point of exposure (POE); and
3. The effects of NA on constituent concentrations during lateral transport from the source to an off-site POE are considered in the SSTL calculation.

Tier 3 involves a further expanded site assessment with SSTLs based on more sophisticated statistical, fate-and-transport and risk assessment models. Tier 3 Evaluation provides the user with an option to determine SSTLs for both direct and indirect pathways using site-specific parameters and point(s) of exposure and compliance when it is judged that Tier 2 SSTLs should not be used as target levels. Tier 3, in general, can be a substantial incremental effort relative to Tiers 1 and 2, as the evaluation is much more complex and may include additional site assessment, probabilistic evaluations, and sophisticated chemical fate/transport models.

Tier 3 is rarely used because of the complexity of the models and the requirement for highly specific data, without a significant improvement in the predictions (Khan and Husain 2001).

Remedial Action

In the ASTM framework risk management decisions are generally based on assessing the potential impacts from a select group of “indicator” compounds as "it is not practicable to evaluate every compound present in a petroleum product to assess the human health or environmental risk from a spill of that product." The ASTM approach assumes that a significant fraction of the total potential impact from all chemicals is due to the chemicals of concern. The selection of chemicals of concern is based on the consideration of exposure routes, concentrations, mobilities, toxicological properties, and aesthetic characteristics (taste, odor, etc).

According to ASTM (1995), TPH should not be used for “individual constituent” risk assessments because the general measure of TPH provides insufficient information about the amounts of individual compounds present."

If the concentrations of chemical(s) of concern at a site are above the RBSL or SSTL at the point(s) of compliance or source area, or both, and the user determines that the RBSL or SSTL should be used as remedial action target levels, the user develops a remedial action plan in order to reduce the potential for adverse impacts. The user may use remediation processes to reduce concentrations of the chemical(s) of concern to levels below or equal to the target levels or to achieve exposure reduction (or elimination) through institutional or engineering controls.

The flowchart for ASTM Risk-Based Corrective Action is given in Fig 2.

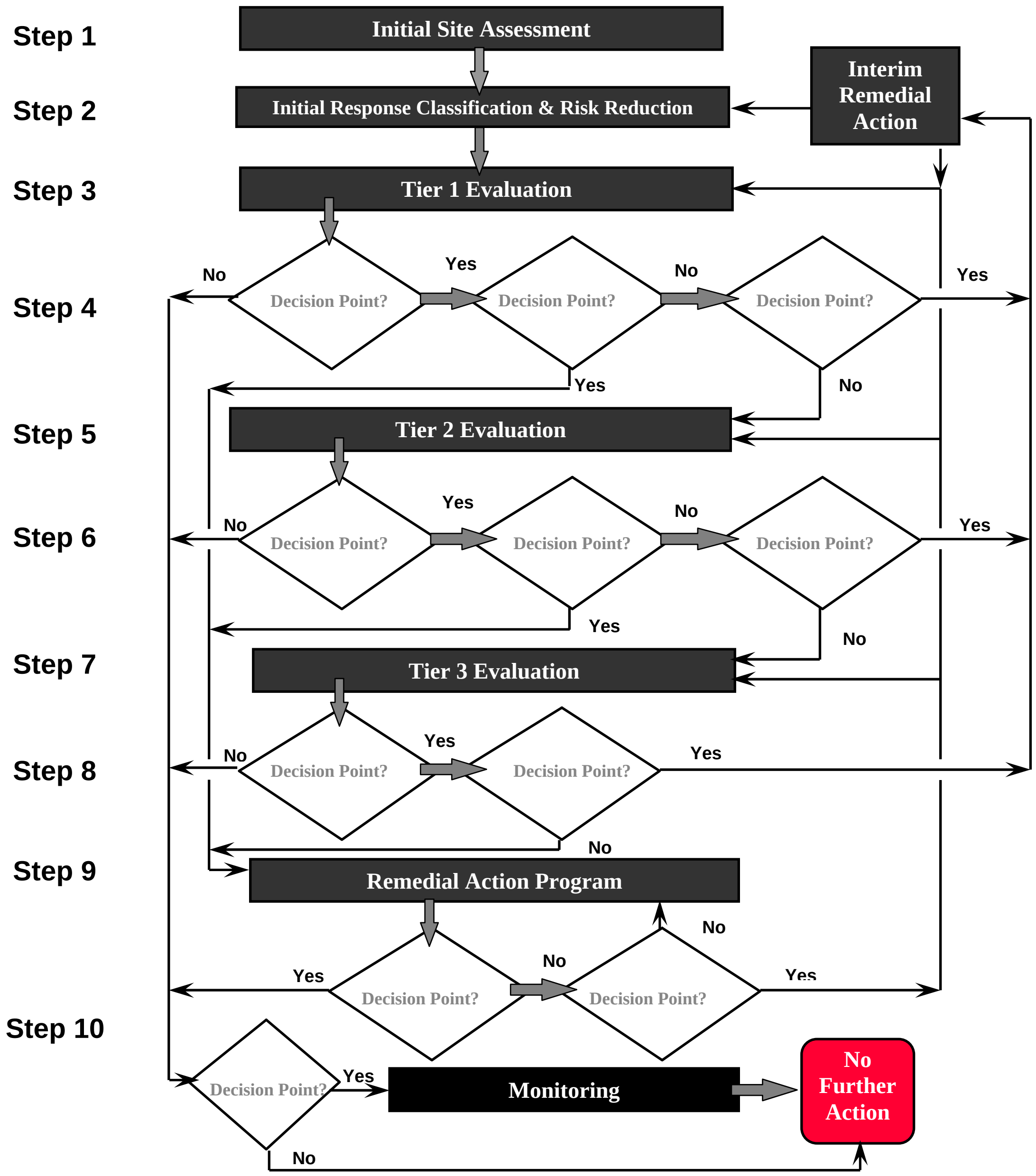


Fig 2: ASTM Risk-Based Corrective Action (RBCA) Flowchart

CONCAWE approach

The Conservation of Clean Air and Water in Europe (CONCAWE) has prepared a guideline for risk-based assessment of contaminated sites with the objective to provide a simple-to-use, rational methodology for addressing potential contamination at oil industry sites in a manner which is protective of human health and the environment. This guideline will allow risk-based decisions to be made in an efficient and cost-effective manner and can be used to prioritize remedial actions at numerous sites (Crawford et al 2003).

In broad terms the approach can progressively incorporate the following key steps, as required:

1. Initial Assessment;
2. Emergency Response Decision/Action;
3. Tier 1 Assessment and Corrective Action Decision;
4. Tier 2 Assessment and Corrective Action Decision;
5. Tier 3 Assessment and Corrective Action Decision.

The outcome of each step can include tier upgrade, corrective action, compliance monitoring or a conclusion that no further action is required.

The three-tiered approach is based on the principle of source-pathway-target. It starts with an initial assessment of the site which involves gathering general data including potential sources of contaminants, obvious evidence of contamination, land-use, presence of potable groundwater etc. The pathways by which contaminants could reach identified potential receptors or populations at risk are then identified. This enables a Tier 1 assessment to be performed, in which chemical data on the degree of contamination of the site is collected and compared with Risk Based Screening Levels (RBSL) and other relevant criteria. RBSLs comprise of a set of trigger concentrations for contaminated soil and groundwater. These figures are not intended to be soil standards or clean-up targets. If exceeded, they are simply an indication that further study is required. RBSLs are derived using conservative assumptions and, as such, are based on a generalized risk assessment. If the observed values are below these levels, then the risk is considered insignificant.

Each tier involves increasingly sophisticated levels of data collection and analysis. The first tier consists in a simple screening step where the site conditions are compared with existing conservative screening criteria which have used generic assumptions. In subsequent tiers more site-specific information is used in developing remediation goals. In moving from a lower to a higher tier of analysis there is a reduction in the level of conservatism in the assumptions made but the degree of protection of human health and the environment remains the same.

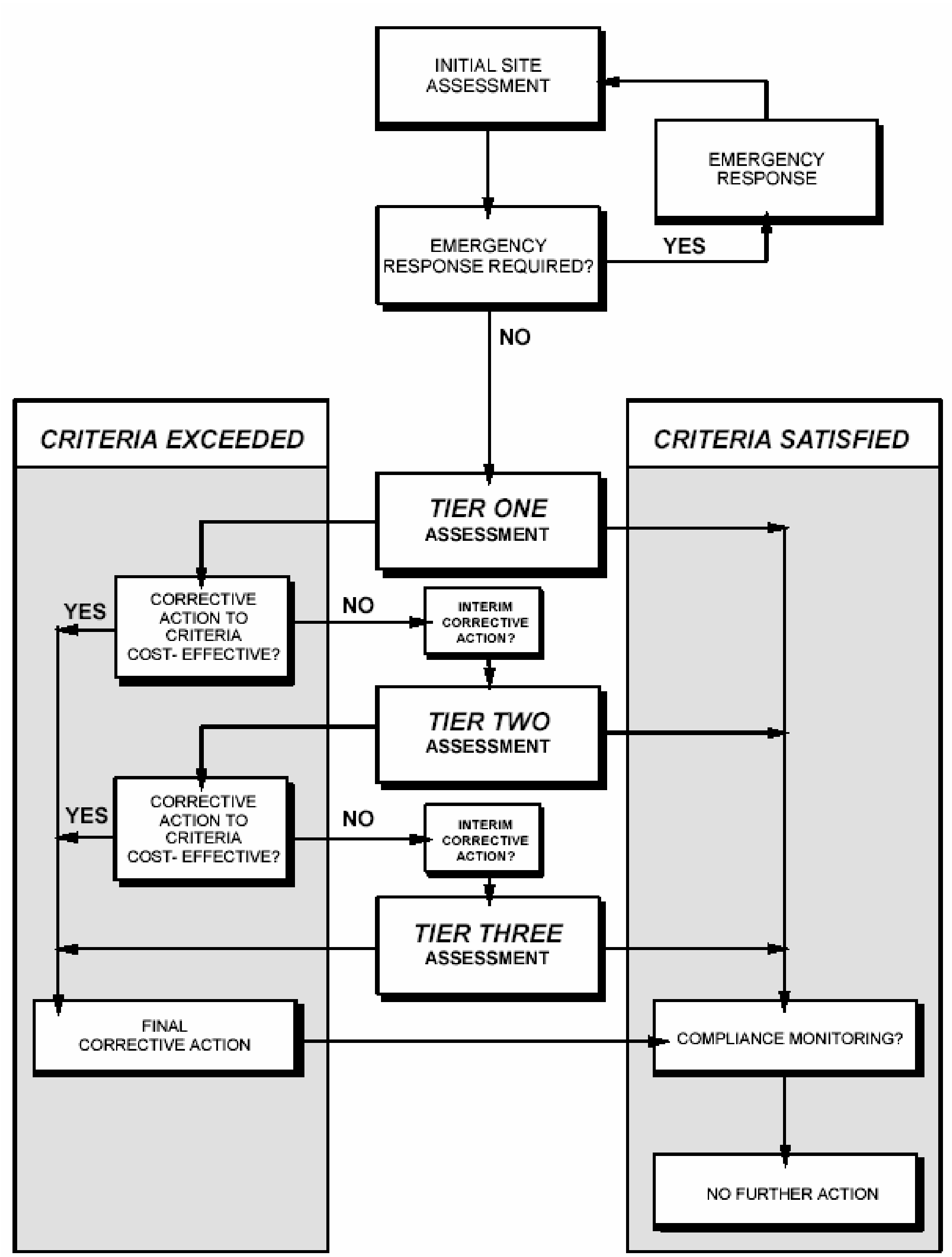
The decision to move to a higher tier is determined by whether it is cost effective or practical to carry out corrective action based on the remediation goals determined at the lower tier. At the higher tier there is less uncertainty involved in establishing the appropriate remediation but the data and analysis required for the higher tier has to be obtained at an added cost.

Although this approach is very similar to ASTM's RBCA, there are several significant differences. One such difference between the current approach and ASTM's RBCA is that CONCAWE Tier 1 RBSLs can be derived using Monte Carlo simulation techniques. This reflects the increasing use of such techniques worldwide and it allows for the explicit consideration of uncertainty.

A further difference between the two approaches is the opportunity to carry out "forward" calculations of risk at Tiers 2 and 3. (Under the ASTM approach, these tiers involve changes to clean-up target levels). A "forward" risk is consistent with European regulators' requirements for performing a risk calculation in support of contaminated land decision-making.

Minor differences between the two approaches include the use of European exposure/toxicity assumptions and the inclusion of a child receptor.

The flowchart for the three-tiered framework suggested by CONCAWE is given in Fig. 3.



(Crawford et al 2003)

Fig 3. Three-tiered framework suggested by CONCAWE

UK Environment Agency Approach

As a part of its Contaminated Land Exposure Assessment (CLEA) science program, the United Kingdom's Environment Agency has developed a framework for evaluating the health risks from petroleum hydrocarbons in soil through public consultation and discussions with relevant stakeholders (Askari and Pollard. 2005).

The EA decided to adopt a "combined indicator and fraction approach" with the consensus that

1. indicator compounds should be the most toxic compounds and most prevalent in the petroleum hydrocarbon-contaminated environment;
2. health criteria values for fractions will reflect threshold toxicity, the basis of which will be toxicologically relevant surrogate compounds or mixtures;
3. SGVs will be developed for indicator compounds and fractions;

The flowchart for petroleum hydrocarbons risk assessment according to the UK approach is given in Fig 4.

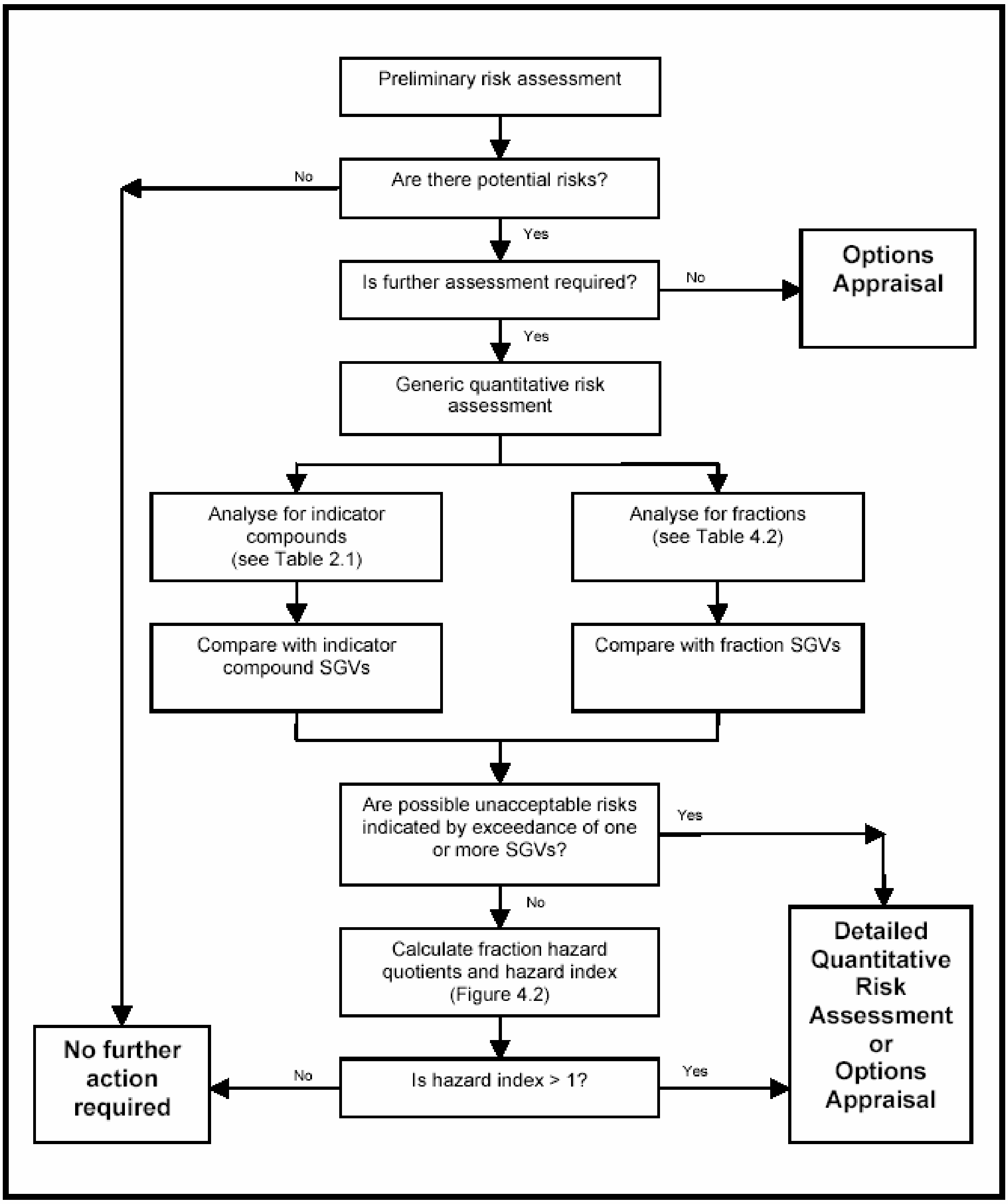


Fig 4. Petroleum hydrocarbons risk assessment: UK approach

A comparison of the risk-based corrective action methods suggested by different institutions is given in Table 2.

Examples of Corrective Action Techniques

Some of the methods by which corrective action at contaminated sites can be achieved, whether as an interim measure or a long-term solution are as follows (Crawford et al 2003):

1. Ongoing monitoring of the natural attenuation of contaminated media (in particular in cases where source removal has been achieved and/or where natural processes (e.g. biodegradation) are expected to reduce the contaminant levels over time)

2. Contractual instruments or physical barriers limiting the use of property or land to avoid a potentially unacceptable exposure to current or future site users. This includes fencing-off contaminated areas, restricting access to sub-soils and restricting site land-use;

3. Installation of specialist physical isolation barriers to restrict exposure /migration pathways at existing or redeveloped sites. This includes the capping of contaminated areas where direct exposure pathways drive the risk assessment or where the leaching of soil contaminants to groundwater via rainfall infiltration is a concern;

4. Construction of physical barriers or collection systems to restrict contaminant migration to surface and or groundwater. This includes cut-off walls or collection drains, vitrification, and stabilization;

5. In-situ treatment of contaminated materials to reduce the source volume or concentration. It may include vacuum extraction for volatiles and semi-volatiles, air sparging or bioremediation;

6. Receptor point corrective action, which includes the treatment of contaminated water as it is abstracted from a groundwater supply well;

7. Removal and disposal/treatment of contaminated soils. This includes ex situ bioremediation, land-filling, incineration, soil washing, thermal desorption.

Issues for Kuwait EPA

Kuwait is on the verge of embarking on an ambitious program to remediate desert soils contaminated with crude oil during the Iraqi invasion of 1990-1991. The Iraqi forces released an estimated 11 million barrels of crude oil into the Arabian

Gulf during the period from January to May 1991 (Sadiq and McCain, 1993) as well as setting hundreds of oil wells on fire. The oil leaking from the well heads, storage tanks, and pipelines formed huge oil lakes as deep as 2 meters (Kostreba 2008). The oil fires produced clouds of darkness, decreased atmospheric temperatures and residual air pollution (Stone, 1992). The scorched-earth tactic used throughout Kuwait by the Iraqi forces released about 156 million barrels of crude oil in the desert, forming 399 oil lakes and covering a surface area of 49 sq.km; whereas the smoke and soot that resulted from the uncontrolled fires contaminated approximately 953 sq.km of desert (GCI, 1999).

Estimates of the extent of Kuwait's total surface area covered by tarcrete, a solid residue created from heavy crude oil, ranges from approximately 398 to 1,772 square kilometers (CIC 2003).

For the remediation of oil polluted soils in Kuwait seven potential categories -- including *in situ* biological treatment, *in situ* physical/chemical treatment, *in situ* thermal treatment, *ex situ* biological treatment (assuming excavation), *ex situ* physical/chemical treatment (assuming excavation), *ex situ* thermal treatment (assuming excavation) and off-site disposal or natural attenuation (i.e., the "no action" alternative) -- with a total of 18 technologies were considered (EEI 2001). Finally high-temperature thermal desorption was selected as the recommended remedial technology for the following reasons:

1. It is effective in removing polynuclear aromatic hydrocarbons and other semi-volatile organic compounds to meet a wide range of cleanup goals;
2. Its process is flexible and can be modified to treat a variety of soil types and contaminant concentrations;
3. It offers potential for hydrocarbon recycling;
4. It has a history of treating hydrocarbon-contaminated soils; and
5. It incurs only moderate costs.

However, in its Decision No. 258, the United Nations Compensation Commission (UNCC) has stressed that "primary emphasis must be placed on restoring the environment to pre-invasion conditions, *in terms of its overall ecological functioning rather than removal of specific contaminants or restoration of the environment to a particular condition*." The UNCC has also suggested that "where more than one remediation approach or technique is appropriate to achieve a desired remediation goal, the most cost-effective option should be selected."

This calls for a risk-based decision making approach. The ultimate goal of risk assessment is to develop a model, based on scientifically defensible probabilities, that assess the risk to human health and the environment and then applies a cost-benefits analysis to determine the appropriate response to the problem (Percival et al. 2003). Spending millions of dollars on cleanup initiatives is not the best allocation of resources of there is virtually no risk or hazard associated with the contamination (Pepper et al 2003).

Current Kuwaiti environmental laws do not embody the concept of risk assessment nor does the Public Authority for Assessment and Compensation for Damages Resulting from Iraqi Aggression (PAAC) direct potential contractors from using this approach other than through UNCC Decision No. 258. Recommended courses of action to implement an RBCA approach are:

1. Undertake evaluation of the toxicology of petroleum hydrocarbons
2. Review petroleum hydrocarbons fate and transport data
3. Develop Soil Guideline Values/RBSL for petroleum hydrocarbons; and
4. Provide practical guidance on petroleum hydrocarbons risk assessment

RBCA Summary

Decision-makers charged with making informed and scientifically sound decisions about how to manage risks at the oil contaminated sites must take into account the complexity of the situation, within a practical decision framework. Among the factors they must take into account are:

1. The chemical and physical complexity of the contamination, and the changes in composition of the crude oil that may have taken since they it was let out into the environment

2. How to measure the extent and nature of contamination in a way that is meaningful and relevant to the risks it may pose

3. How to establish toxicological criteria for petroleum contamination in soil

4. How to account for the different toxicities of the thousands of individual compounds that may be present in the contaminating material and the range of potential adverse health effects that could result

5. How to make clear, consistent, pragmatic and sustainable decisions that protect human health but do not burden the society in terms of cost of remediation.

References

API. 2001. Risk-based Methodologies for Evaluating Petroleum Hydrocarbon Impacts at Oil and Natural Gas E&P Sites, API Publication 4709, Regulatory and Scientific Affairs Department American Petroleum Institute Publishing Services, Washington, DC, 2001."

Askari, K. and S. Pollard. 2005. The UK Approach for Evaluating Human Health Risks from Petroleum Hydrocarbons in Soils. Science Report P5-080/TR3, The Environment Agency, Almondsbury, Bristol, BS32 4UD. www.environment-agency.gov.uk

Calabrese, E. J. and P.T. Kostecki. 1992. Risk Assessment and Environmental Fate Methodologies. Lewis Publishers, Chelsea, MI.

Chen, K.; Wu, L.; Kao, C.; Yang, C.C.G. 2004. Application of Health Risk Assessment to Derive Cleanup Levels at a Fuel-Oil Spill Site. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, 8(2): 99-104

Chu, W. H., Wang, J. Y., and C.M. Kao. 2001. A simplified risk-based approach for process screening in municipal wastewater reclamation and reuse. IWA Asia environmental technology, Suntech City, Singapore.

Consortium of International Consultants (CIC). 2003. “Oil Lakes” Monitoring and Assessment Report. Volume 1, Appendix A-1: Overview of Studies and Publications on Oil-Contaminated Desert Soil and Tarcrete in Kuwait through 2002. Monitoring and Assessment of the Environmental Damages and Rehabilitation in the Terrestrial Environment (Cluster 3), UNCC Claim 5000434, August 27, 2003

Crawford, R.L., Alcock, J., Couvreur, J.F., Dunk, M., Fombarlet, C., Frieyro, O., Lethbridge, G., Mitchell, T., Molinari, M., Ruiz, H., Walden, T. and D.E. Martin. 2003. European oil industry guideline for risk-based assessment of contaminated sites (revised). Report No. 3/03 Prepared for the CONCAWE (Conservation of Clean Air and Water in Europe) Water Quality Management Group, CONCAWE, Brussels, July 2003

Crawford, R.L., Alcock, J., Couvreur, J.F., Dunk, M., Fombarlet, C., Frieyro, O., Lethbridge, G., Mitchell, T., Molinari, M., Ruiz, H., Walden, T. and D.E. Martin. 2003. European oil industry guideline for risk-based assessment of contaminated sites (revised). Report No. 3/03 Prepared for the CONCAWE (Conservation of Clean Air and Water in Europe) Water Quality Management Group, CONCAWE, Brussels, July 2003

EEI (Ecology and Environment, Inc.). 2001. Kuwait's Fourth Instalment Environmental Damage Claims. Claims for Future Measures Reasonably Necessary to Clean and Restore the Environment Exhibit 2: Damage Assessment Report Damage Resulting from Oil Lakes. Prepared for: Public Authority for Assessment of Compensation for Damages Resulting from Iraqi Aggression

GCI (1999), Environmental Legacy in Kuwait: An Environmental Assessment of Kuwait Seven Years after the Gulf War – Final report, Green Cross International, Geneva.

Guerin, T.F. 2002. Managing Contaminated Sites and the Role of Domestic and International Forums. Federal Facilities Environmental Journal, 13(1): 85-107

Guerin, T.F. 2002. Managing Contaminated Sites and the Role of Domestic and International Forums. Federal Facilities Environmental Journal, 13(1): 85-107

Gustafson, J.B. 2008. Using TPH in Risk-Based Corrective Action. Accessed at http://www.epa.gov/OUST/rbdm/tphrbca.htm on March 3, 2008.

Harmsen, J., Hutter, J.W., Win, T., Barnabas, I., Whittle, P., Hansen, N. and H. Sakai. 2005b. Risk assessment for mineral oil: Development of standardized analytical methods in soil and soil-like materials, Wageningen, Alterra, Alterra-Report 1225.

Harmsen, J., Rulkens, W. and H. Eijsackers. 2005a. Bioavailability: concept for understanding or tool for predicting?. Land Contamination and Reclamation, 13(2): 161-172

Husain, T., Hejazi, R. and F.I. Khan. 2000. Remediation of Petroleum Contaminated Sites Using Monitored Natural Attenuation Approach, Proceedings of Chemistry and Industry - 2000, Bahrain (Oct. 30-Nov. 1, 2000)."

ISO/DIS 17402 "Soil quality – Guidance for the development and selection of methods for the assessment of bioavailability in soil and soil-like materials"

Kaplan, I.R., Galperin, Y., Alimi, H., Less, R.-P., and S.T. Lu. 1996. Patterns of chemical changes during environmental alteration of hydrocarbon fuels. Ground Water Monitoring and Remediation, 16 (4): 113–124.

Khan, F.I. and T. Husain. 2001. Risk-based monitored natural attenuation — a case study. Journal of Hazardous Materials B85: 243–272

Kostreba, L. 2008. Oil Spill Remediation Efforts in the Middle East. Restoration and Reclamation Review. http://www.hort.agri.umn.edu/h5015/99papers/kostreba.htm (accessed February 5, 2008).

Morgan, P. and R.J. Watkinson. 1989. Hydrocarbon degradation in soils and methods for soil biotreatment. CRC Critical Reviews in Biotechnology, 8(4): 305-333

National Academy of Sciences (NAS). 1983. Risk assessment in the Federal Government: Managing the process, National Academy Press, Washington, DC

NJDEP. 1994. Future land use: A key consideration in remedy selction. Site Remediation News, 6(4):1-2

Pepper C.B., Block N., and S. Baladi. 2003. Deciding How Clean is Clean Enough Under the Texas Law of Risk-Based Corrective Action. Federal Facilities Environmental Journal 14(2): 57-76

Percival, R.V., Schroeder, C.H., Miller, A.S. and J.P. Leape. 2003. Environmental Regulation: Law, Science, and Policy, Aspen Publishers.

Pollard, S.J.T., Hrudey, S.E. and P.M. Fedorak. 1994. Bioremediation of petroleumand creosote-contaminated soils: a review of constraints, Waste Management Research, 12: 173–194

Pollard, S.J.T., Whittaker, M., and G.C. Risden. 1999. The fate of heavy oil wastes in soil microcosms I: A performance assessment of biotransformation indices. The Science of The Total Environment 226(1-2): 1–22.

RAAG. 2000. Evaluation of Risk Based Corrective Action Model, Remediation Alternative Assessment Group, Memorial University of Newfoundland, St John's, NF, Canada.

Sadiq, M. and McCain, J.C. (1993), The Gulf War Aftermath, an Environmental Tragedy, Kluwer Academic Publishers, Boston, MA.

Stokman, S.F., and R. Dime. 1986. Soil cleanup criteria for selected petroleum products. In: Proceedings of the National Conference on Hazardous Wastes and Hazardous Materials. March 4-6, 1986. Atlanta, GA.

Stone, R. (1992), "Kuwait quits smoking", Science, No. 255, p. 1357.

USEPA. 1991. Role of the baseline risk assessment in Superfund remedy selection decisions. OSWER Directive 9355.0-30, Environmental Protection Agency, Washington DC.

Wang, Z. and M.F. Fingas. 2003. Development of oil hydrocarbon fingerprinting and identification techniques. Marine Pollution Bulletin, 47: 423–452.

Washburn, S.T. and K.G. Edelmann. 1999. Development of Risk-Based Remediation Strategies. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, 3(2):77-82

Zemanek M.G., Pollard S.J.T., Kenefick S.L. and S.E. Hrudey. 1997. Multi-phase partitioning and co-solvent effects for polynuclear aromatic hydrocarbons (PAH) in authentic petroleum- and creosote-contaminated soils. Environmental Pollution, 98(2): 239-252

Table 2: Comparison of methods suggested by different agencies

Item	ASTM	MaDEP	TPHCWG	ATSDR	RIVM	New Zealand	NSW
Indicator substances	Use of Chemicals of Concern only	Target analytes include most toxic compounds and others frequently tested for	Include most toxic compounds only	Include most toxic compounds only	Include most toxic compounds and others frequently tested for	Use of 'contaminants of concern' to address most toxic substances and aromatics	Individual compounds identified
Fractions, numbers and basis	None	6 analytical fractions (3 aromatic and 3 aliphatic) using 4 toxicity values (3 aliphatic and 1 aromatic).	13 analytical fractions (6 aromatic and 7 aliphatic) using 7 toxicity values (3 aliphatic and 4 aromatic).	Similar to TPHCWG. Minor modification to aromatic groups to include all BTEX compounds in same fraction.	7 fractions based on toxicity values (3 aliphatic and 4 aromatic)	3 aliphatic fractions only	2 petroleum hydrocarbo fractions.
		Fractions based on Carbon number and driven by analytical methods and toxicology	Fractions based on EC number, driven by fraction transport properties.	EC numbers as per TPHCWG	EC numbers as per TPHCWG	EC numbers as per TPHCWG	Various
Basis of toxicity and transport properties		Toxicity values based on surrogate compounds, transport properties based on TPHCWG approach	Toxicity values based on surrogate compounds, Transport properties based on entire fraction.	Most toxic compounds/mixture in fraction generally used as surrogate for toxicity values.	Toxicity values based on surrogate compounds, transport properties based on TPHCWG approach	Use of TPHCWG toxicity and transport data.	Soil thresho concentrati taken direct from other expert grou

		(i.e entire fraction).			(i.e entire fraction).		

Item	ASTM	MaDEP	TPHCWG	ATSDR	RIVM	New Zealand
Additivity effects	Not recommended	Precautionary approach, based on addition of hazard quotients across fractions	Precautionary approach, based on addition of hazard quotients across fractions	Precautionary approach, developing index of concern based on addition of hazard quotients across fractions for compounds affecting same target organs or systems	Precautionary approach, based on addition of hazard quotients across fractions	Additivity of excess lifetime cancer risk for non-threshold substances. Precautionary approach as ASTDR
Application approach	Use of RBCA 3-tiered approach. Lookup tables for Tier 1 and increasing use of site-specific information in Tier 2 and 3.	3 methods used, with generic standards for Method 1 and increasing use of site-specific information for methods 2 and 3. Approach is not tiered as Method is selected prior to assessment	Use of RBCA 3-tiered approach. Lookup tables for Tier 1 and increasing use of site-specific information in Tier 2 and 3.	Use of RBCA 3-tiered approach. Lookup tables for Tier 1 and increasing use of site-specific information in Tier 2 and 3.	Use of tiered approach, moving from generic guidelines to less conservative values site-specific	Use of tiered approach, moving from generic guidelines to less conservative values site-specific
Recommended analysis	No specific method of analysis	Use Vapour Petroleum Hydrocarbons (VPH) and Extractable Petroleum Hydrocarbon (EPH) methods developed by MaDEP. Target analytes reported in the analyses	Direct method. Indicator compounds not reported	Direct method. Indicator compounds not reported	Single analytical method (NEN 5733) recommended. Indicator compounds not reported.	Based on API "Method for Characterization of Petroleum Hydrocarbons in Soil." Chemicals of concern not reported.

Item	ASTM	MaDEP	TPHCWG	ATSDR	RIVM	New Zealand	NSW
Other comments	Consideration given to aesthetic characteristics like odour when identifying "chemicals of concern."	Address issues of 'public welfare' such as odour and staining, through the use of ceiling limits for soil concentrations.				Aesthetic issues such as odour identified as a consideration on a site-by-site basis.	

ASTM: American Society of Testing Materials
MaDEP: Massachusetts Department of Environmental Protection
TPHCWG:
ATSDR: Agency for Toxic Substances and Disease Registry, Public Health Service, U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES,
RIVM: The National Institute of Public Health and Environmental Protection, Netherlands
TPHCWG : Total Petroleum Hydrocarbon Criteria Working Group
New Zealand: New Zealand Ministry of Environment
NSW: New South Wales Environment Protection Authority