# UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, OFFICE OF RADIATION AND INDOOR AIR INTEGRATED APPROACH FOR SITE REMEDIATION

Robert S. Dyer
US Environmental Protection Agency
US EPA, 401 M Street SW
Washington, DC, USA, 20460

Kelly Nix and Larry Coe
S. Cohen & Associates, Inc.
1355 Beverly Road
McLean, Virginia, USA, 20101

## ABSTRACT

The United States faces major challenges in addressing the degradation of the country's environment resulting from contamination by radioactive and mixed waste materials. The primary goals of the U.S. Environmental Protection Agency, Office of Radiation and Indoor Air's (ORIA) environmental programs are to develop the technical basis for cleanup standards for sites contaminated with radionuclides; to provide ongoing technical support to EPA regions, U.S. government agencies, and international institutions or foreign governments in the characterization and mitigation of critical environmental radiation remediation problems; and to develop and/or explore existing remediation technologies for volume reduction and the recycling of contaminated soils and materials.

ORIA applies an integrated approach to remediation of sites and materials that are contaminated with radioactive or mixed radioactive and hazardous materials. This approach can be applied to a wide variety of radiation contamination problems such as contaminated surface water, ground water, soils, and sediments, as well as contaminated metals. The five components of the approach are Monitoring and Site Characterization, Radiation Assessment Data System, Risk Assessment/Risk Indicators, Sample Characterization to Select a Remedial Technology, and Remedial Design. The poster presents actual examples of contamination problems addressed by ORIA to describe the process.

## MONITORING AND SITE CHARACTERIZATION

In the evaluation of remedial alternatives, data are needed to: determine the amount and distribution of contaminated materials such that the remediation costs can be estimated; define radionuclide inventories at the site prior to and following each remediation option; forecast individual and occupational doses associated with the implementation of each alternative; predict radionuclide concentrations in each of the principal pathways of exposure before and following each option; and project individual and population doses prior to and following each remedial option. Accordingly, the types of monitoring data required for site characterization include: direct radiation exposure rate; radionuclide concentrations in air, water, soil and food; removable and fixed surface contamination; vertical and horizontal soil contamination profiles; and radon levels and flux measurements.

A Quality Assurance Plan is prepared for each project involving collection and analysis of samples. Each plan includes details on sampling methods, criteria, locations, handling requirements, chain-of-custody requirements, analysis procedures, holding times, quality assurance requirements for splits and blanks, and data reporting requirements. Site data are subjected to quality assurance/quality control (QA/QC) procedures.

Barrows Field Park in Glen Ridge, New Jersey (1) provides an example of ORIA's characterization projects. Barrows Field contains soil and debris contaminated with radium. *In-situ* measurements were performed in a grid with 3 meter spacings over an area of 1000 square meters and to a depth of three meters to estimate the volume of contaminated soil and the level of contamination. Soil "hot spots" with Ra-226 activity above 200 pCi/g (7.4 Bq/g) were identified for excavation and offsite disposal, while soil with Ra-226 activity between 15 pCi/g (0.55 Bq/g) and 200 pCi/g was identified for remediation using a soil washing system. This monitoring was performed using a collimated down-looking radiation detector. Depth profiles were constructed using radiation measurements taken inside metal tubes (2.5 cm O.D.) below ground level using a NaI(Tl) detector at depths up to three meters. Several soil areas containing greater than 200 pCi/g were identified using this technique. The volume of soil containing 15-200 pCi/g of Ra-226 activity was estimated to be about 600 cubic meters. (A graphic representation of the Barrows Field site and a 3-D radioactivity distribution are provided in the poster.)

At all radioactively contaminated sites, many situations exist for potential radiation exposure or contamination of personnel working on site characterization, remediation, and compliance activities. EPA is developing and implementing an Agency-wide Radiation Safety and Health Protection Program for its employees. This effort is being managed jointly by ORIA and the Office of Administrations' Safety, Health, and Environmental Management Division. EPA's objective is to provide worker safety and health protection on the job by keeping exposure to ionizing radiation as low as reasonably achievable. Among the unique aspects of this program is a provision for integrating internal doses (committed effective dose equivalents determined from area monitoring and, where appropriate, bioassay) and doses derived from field exposure to radon above 8 pCi/L (.3 Bq/l) into the employee's cumulative exposure record for dose management purposes.

EPA has set an administrative dose level of 500 millirem (5 mSv) for its workers. Worker safety and health will be maintained through an Agency-wide program, incorporating appropriate directives and standardized practices and procedures for radiation safety and health. The latter includes: training and education; monitoring and dosimetry (personal and environmental); medical surveillance and medical and health consultation; and a state-of-the-art management information system. The program will offer performance based interactive PC training tools as well as classroom training (including video-conferencing) to insure that workers are well-prepared for duty in radiation areas. To date, the program has been implemented in four EPA regions. The remainder of the Agency is expected to be included by 1994. After Agency-wide implementation, EPA intends to offer this program as a model to States and other Federal agencies and for use in the private-sector and international arena.

## RADIATION ASSESSMENT DATA SYSTEM (RADS)

Site characterization and assessment results in spatially and temporally complex data that varies in format and type. Data required is extensive and likely to include base maps, hydrogeologic maps, aerial photographs, well locations, sample locations, well logs, pump tests, and laboratory analyses. Graphic presentation of data is important for both communicating and analyzing this data.

ORIA has developed a prototype Radiation Assessment Data System (RADS) to input, manage, analyze, and present site characterization and assessment data. RADS is a graphic application system that provides data management and analysis tools for assessing, modeling and monitoring radioactive waste sites and identifying potential remediation alternatives. The system is comprised of core data management software linked to a set of integrated application tools to create a computerized site management system. RADS is built on an environmental resource management applications module that integrates GIS; computer aided design; scientific data management; relational database management; imaging; statistics; architectural, engineering and construction applications; geologic and geophysical interpretation capabilities; groundwater flow and solute transport models; and radiation dose models.

RADS provides an integrated approach to radiation dose modeling by providing the required computer tools on a single platform. Models, such as RESRAD and PRESTO, can aid in radiation dose modeling and facilitate the efforts of health physicists in quantifying the risks of long term radiation exposure. However, the models require correct input from a variety of disciplines including meteorology, geology and hydrogeology. Because the model user frequently does not possess expertise in each of the required disciplines, the default values provided with the computer model are usually chosen. This can result in an oversimplified and sometimes incorrect representation of the environment that calls into question the validity of the dose model results. RADS addresses this problem by providing powerful GIS, geological, and surface modeling tools on the same platform as the radiation dose models. This system makes available to the dose modeler an interactive 3-dimensional view of the environment. RADS does not eliminate the need for expert input into the exercise. It simply makes the information developed and provided by discipline experts more available to the dose modeler. Because dose models frequently require one-dimensional input, RADS provides a Monte Carlo simulator to reduce the range of values found in the environment within a given area to a single statistically valid value. RADS also includes the Berkeley Interactive Statistical System to aid in the post-modeling analysis of results. (A listing of RADS capabilities is presented in the poster.)

Shallow geophysical surveys conducted to characterize contaminated sites include a variety of procedures and techniques. A single survey can include data from ground penetrating radar, electromagnetic surveys, magnetometer readings, and shallow seismic and spontaneous potentials. The rationale for applying such a wide range of procedures is that a single geophysical technique may be unsuitable for a particular area or there may be excessive environmental noise in the vicinity. The anticipated result of conducting several types of surveys is that an analysis of the combined results will cancel some of the ambiguity. RADS takes this concept a step further and provides a platform whereby the results of several seemingly non-related survey techniques can be physically combined through mathematical algorithms to produce an unique view of the subsurface. In effect, one survey procedure is used as a filter to cancel some or all of the noise in another survey procedure. A further enhancement of the qualitative geophysical data is attained by combining the survey data model with sophisticated 3-dimensional geological, civil engineering, and surface modeling packages to produce a quantitative model of the subsurface. This model can then be used to estimate volumes of waste and provide a 3-dimensional control grid for remedial activities at a site. (An example of this modeling technique is provided in the poster, where the results from an electromagnetic induction survey are overlayed on results from a ground penetrating radar survey to show the potential locations of radioactive waste burial at RW Site 09, George Air Force Base.)

## RISK ASSESSMENT/RISK INDICATORS

ORIA routinely applies environmental models in supporting the development of new standards and guidelines and in determining compliance with applicable regulations and guidelines. In general, the purpose of the these assessments is to quantify the actual or potential radiological impacts of human activities on human health and the environment. Evaluations include radiation doses and risks to individual members of the public and remedial workers, and cumulative radiation doses and risks to the population in the vicinity of a site under expected and transient conditions and following accidents. Doses and risks are evaluated for a site in its current condition and during and following a broad range of feasible alternative remedies.

### Examples of Risk Assessments/risk Indicators

**Low Level Radioactive Waste Burial Ground**: ORIA performed a baseline radiological risk assessment, including pathway analysis, at the former Maxey Flats low level radioactive waste disposal site in Morehead, Kentucky (2). The pathways included direct radiation exposure, inhalation, drinking water, and the food chain for a broad spectrum of radionuclides, primarily byproduct material. The results revealed that, for individuals living adjacent to the site, the ingestion of tritium in ground water is the limiting pathway. The effective dose equivalent for this pathway was determined to be 50 mrem/y (0.5 mSv/y) representing a risk range of $10^{-3}$ - $10^{-4}$. The site is currently undergoing remediation to prevent tritiated water from leaving the site. (A three-dimensional isopleth showing groundwater contamination from radioactivity is shown in the poster.)

**Cytogenetic Techniques**

ORIA has supported research in the use of the marine polychaete Halicize as an ecological risk indicator (3). Cytogenetic techniques are being used to assess the impact of chronic and acute sub-lethal radiation exposure in an aqueous environment. ORIA has focused on potential impacts from past U.S. ocean disposal activities. These studies focus on the changes to the DNA of a cell following exposure to radiation. The intent is to correlate DNA damage with impacts on reproductive success. The goal of this project is to develop cytogenetic methods for assessing the biological impact of radiation exposure, as these techniques are easier than traditional methods that follow generations of an organism. Since many ecologists view biological impact in terms of reproductive success, not DNA damage, the correlation of DNA damage assessment techniques and observed biological inhibition is important. (Chromosomal aberrations identified in the Halicize study are displayed in the poster.)

**Biological Dosimeter**

Under a U.S. - Poland Science and Technology Agreement, radiation exposure levels in aquatic organisms, as determined by Electron Paramagnetic Resonance (EPR) spectrometry of calcareous material, are being investigated as a reliable indicator for estimating dose to individual organisms (field biological dosimeter). EPR can quantify the production of point defects within biological materials from radiation. The concentration of defects is proportional to the amount of radiation the material has been exposed to and these defects are cumulative over time. This study focuses on the effects of radionuclides deposited in Eastern Europe as a result of the Chernobyl accident. (The procedure using the EPR technique is outlined in the poster.)

## SAMPLE CHARACTERIZATION TO SELECT A REMEDIAL TECHNOLOGY

Contaminated sites have unique characteristics that are identified through monitoring and site characterization. Remedial system design, however, is dependent upon the characteristics of the specific radionuclides and the host matrix. This is especially true for soils where the relationship of the radionuclide with the soil is very complex. Before a specific cleanup technology can be implemented, samples from each site must be collected and characterized. ORIA conducts bench-scale laboratory testing to characterize the particle sizes and mineralogical and radioactivity distributions of contaminated soils. ORIA has developed a characterization protocol, published as an EPA Superfund Directive, for soils contaminated with radioactivity and has demonstrated the necessity of characterization data for selecting an applicable cleanup process (4).

This innovative soil characterization process has demonstrated that radium and thorium contaminated soils collected from specific sites can be significantly remediated by a soil washing process that includes initial wetting and scrubbing, energetic attrition, and hydroclassification. ORIA's experience with test soils has shown that as much as 80 percent of a contaminated soil can be remediated solely through the use of physical methods. Physical separation techniques and pertinent operational equipment components needed to fully identify particle behavior have been tested at the bench-scale level. These bench-scale studies consist of both particle separation and liberation techniques. Particle separation techniques include sizing, settling velocity, specific gravity, magnetic properties and flotation. Particle liberation techniques include washing, scrubbing, surface debonding and attrition.

ORIA has performed soil characterizations at a number of contaminated sites to demonstrate the applicability of this approach. For example, uranium contaminated soil samples from the Weldon Spring, Missouri National Priority List (NPL) site were characterized to determine the effectiveness of soil washing and physical separation techniques on the soil. The characterization process revealed that the uranium activity at the Weldon Spring site was not associated with any one particle size range, and, therefore, the particle size distribution of the soil proved to be unsuitable for remediation using physical separation techniques. On the other hand, characterization of radium/thorium contaminated soils from the Maywood Chemical Company FUSRAP site in New Jersey indicated that the soil could be successfully remediated using soil washing and physical separation methods to recover as much as 80 percent of the soil. (Particle size distributions and photomicrographs of contaminated soil samples from the Weldon Spring and Maywood sites are depicted in the poster.)

Although all samples can be characterized, not all lend themselves to remediation for reasons external to the sample matrix. For certain types of contaminated media, such as large bodies of water, remediation is not practical. Characterization to determine the extent and effect of such contamination is necessary; however, no remedial options are presently available. Radiation contamination found in the Black Sea as a result of the Chernobyl accident is one such example. ORIA has collected and analyzed core sediment samples from the Black Sea for radionuclides (Cs-134 and Cs-137), heavy metals (e.g. Cr, Pb, Zn, Cd), and mineral composition to determine health and ecological risks to the region. Preliminary findings revealed elevated levels of Cs-134 and Cs-137 near the mouth of the Danube River, although no significant concentrations of cesium were detected in the deeper waters of the northern Black Sea. Further research is planned to consider dispersion patterns of the contamination to construct transport and exposure models; however, pollution prevention options are the only practical approaches being considered at this time.

## REMEDIAL DESIGN

The remedial design phase builds on the characterization phase to establish and evaluate remedial alternatives. There are a limited number of remedial solutions for radioactive soil. The most promising solution, in terms of cost and human health and environmental benefit, is soil washing without chemical extractive additives followed by particle size separation. The soil washing/separation principle is liberation of the radioactive components from the soil matrix by physical techniques, separation and disposal of the radioactive components and return of the nonradioactive (washed) soil material to the site. Radioactive constituents must be separated by exploiting differences in the physical characteristics of the particles. Properties which can be utilized for separation include particle size, shape, density, conductivity, hardness, and hydrophobicity.

ORIA's VORCE (Volume Reduction/Chemical Extraction) soil washing system was designed based on laboratory tests that demonstrated that radionuclide contaminants in most soils are not evenly distributed among the various soil particle sizes (gravel, sand, silt and clay), but are usually found in a particular size fraction, typically, but not exclusively, in the clay and/or silt fractions. These fine particles are liberated from the coarse particles and separated using physical methods that employ soil screening and hydroclassification based primarily on soil particle size. Additional separation can be achieved by taking advantage of differences in other physical properties, such as particle density, in specific instances. The radium isotopes focused upon in these studies were not solubilized to produce an aqueous by-product requiring further treatment.

A full-scale pilot plant has been assembled to test soil washing as a viable remediation option, specifically as the process may apply to the radium-226 and thorium-230 contaminated soils found at the Montclair/Glen Ridge site in New Jersey. (An artist's sketch and an actual photograph of the pilot plant are shown in the poster.) Bench scale tests demonstrated that the volume of soils, containing about 10 to 40 pCi/g (approximately 0.4 - 1.5 Bq/g) radium-226, can be reduced by 60 percent (5). In the first test of the VORCE pilot plant at the US EPA National Air and Radiation Environmental Laboratory in Montgomery, Alabama, the validity of the hydroseparation principles were confirmed at the full-scale level. Treatment of 10 pCi/g soil produced a product of 6 pCi/g, representing 40 percent of the starting material. The plant was modified to expand its applicability to a wider range of particle size separation, and the second testing phase was completed in September 1992. Results from the phase II test indicate that 54 percent of the 40 pCi/g soil was remediated to approximately 13 pCi/g (.4 Bq/g). (Results of the particle size separation from the Phase II test and the percent of soil recovered are graphically displayed in the poster.)

An important aspect of clean-up and site remediation is the decommissioning, decontamination, and disposal (DD&D) of contaminated materials such as building rubble, concrete, and radioactive scrap metal (RSM). Of particular interest are metals such as steel, aluminum, copper, and nickel, because of their inherent value. The U.S. Department of Energy (DOE) currently has about 1.5 million tons of scrap metal that is slightly contaminated with radioactivity (with a potential value in excess of $1 billion), and future generation from DD&D is estimated to be as high as some 90,000 tons per year.

ORIA has a cooperative program with DOE to evaluate the numerous problems and possibilities associated with the recycle of slightly contaminated scrap metal. This effort will seek to: assess the magnitude of DOE's contaminated metal inventories and estimate future scrap generation; evaluate past work done in this area both nationally and internationally in terms of technology development and economic analyses, protecting sensitive industries (e.g. electronics, photography), policy and law, public relations, and risk assessment; assess risks to public health and the environment through a variety of metal usage scenarios and models; estimate costs involved in recycling (processing, emission/effluent control, waste disposal, packaging/transportation and resale, as compared with virgin metal production costs); and consider the feasibility of preparing residual radioactivity guidance for the restricted and unrestricted release of RSM.

Phase II of the cooperative program with DOE will focus on technology selection and demonstration as it pertains to metal recycling and the implementation of a metal recycling program. ORIA is examining the feasibility of developing a pilot smelt plant for the D&D of Pu contaminated metal, which could provide substantial cost savings. The proposed project would attempt to convert transuranic (TRU, especially plutonium) contaminated metal waste to Low Level Waste (LLW) (below 100 nCi/g), and, thereby, reduce the high cost associated with TRU disposal. Varying degrees of decontamination could be achieved by smelting the contaminated metal under a variety of experimental parameters (time, temperature, slag composition and slag/metal ratio). Only the slag would then have to be disposed of as TRU waste.

## INTERNATIONAL INITIATIVES

Through a 1992 U.S. - Belarus Protocol of Intent, a cooperative initiative to examine cleanup alternatives for Chernobyl contamination on Belarussian territory has been enacted. Under this initiative, ORIA in cooperation with the World Bank performed an environmental audit of Chernobyl mitigation program activities underway in Belarus. The audit was based on a review of newly enacted laws, reports, studies, field audits, and interviews and targeted the following elements of the remediation program: population relocation, food and water interdiction, changes in agricultural practices, end-use of interdicted food, waste management, substitution of natural gas and electricity for contaminated solid fuels, and storage, disposition, and control of contaminated materials. Contaminated soil samples were collected for analysis to determine the applicability of the soil washing remedial approach used in the U.S. for selected contamination scenarios in cities such as Gomel. Future cooperative activities include evaluating, monitoring and characterizing techniques for remediating radiation contaminated soil and planning for a possible joint remediation technology demonstration.

## REFERENCES

1. MOSHO, G. D. and M.J. ROBINET, "Volume Estimate of Radium-Contaminated Soil in a Section of Barrows Field Park, Glen Ridge, New Jersey," ANL/ESH/TS-90/103, 1990.
2. KLUESNER, DAVID, MADELEINE NAWAR, and JOHN J. MAURO, "Baseline Risk Assessment of the Maxey Flats Disposal Site," Waste Management '92 Proceedings, March 1992.
3. HARRISON, FLORENCE L. and SUSAN L. ANDERSON, "Reproductive Success as an Indicator of Genotoxicity in the Polychaete Worm, Neanthes arenaceodentata," Marine Environmental Research, Vol. 28, 1989, p. 313-316.
4. EPA, "Characterization Protocol for Radioactive Contaminated Soils," EPA 9380.1-10FS, May 1992.
5. COX, CLINT, MIKE EAGLE, SCOTT HAY, MATTHEW GIFFORD, and WILLIAM RICHARDSON, "Testing of a Pilot Plant for the Remediation of Radioactive Contaminated Soil Using Particle-Size Separation Technology, International Symposium on Environmental Contamination in Central and Eastern Europe," Proceedings, October 1992.