Integrating Modeling and Monitoring to Provide Long-Term Control of Contaminants - 9478

Thomas Fogwell
Weiss Associates, 5801 Christie Ave., Suite 600, Emeryville, CA 94608 (USA)

ABSTRACT

An introduction is presented of the types of problems that exist for long-term control of radionuclides at DOE sites. A breakdown of the distributions at specific sites is given, together with the associated difficulties.

A paradigm for remediation showing the integration of monitoring with modeling is presented. It is based on a feedback system that allows for the monitoring to act as principal sensors in a control system. Currently the establishment of a very prescriptive monitoring program fails to have a mechanism for improving models and improving control of the contaminants. The resulting system can be optimized to improve performance. Optimizing monitoring automatically entails linking the monitoring with modeling. If monitoring designs were required to be more efficient, thus requiring optimization, then the monitoring automatically becomes linked to modeling. Records of decision could be written to accommodate revisions in monitoring as better modeling evolves. The technical pieces of the required paradigm are already available; they just need to be implemented and applied to solve the long-term control of the contaminants.

An integration of the various parts of the system is presented. Each part is described, and examples are given. References are given to other projects which bring together similar elements in systems for the control of contaminants. Trends are given for the development of the technical features of a robust system.

Examples of monitoring methods for specific sites are given. The examples are used to illustrate how such a system would work. Examples of technology needs are presented. Finally, other examples of integrated modeling-monitoring approaches are presented.

INTRODUCTION

Sir David King, Chief Science Advisor to the British government and Cambridge University Professor, stated in October 2005, "The scientific community is considerably more capable than it has been in the past to assist governments to avoid and reduce risk to their own populations. Prime ministers and presidents ignore the advice from the science community at the peril of their own populations." Some of these greater capabilities can be found in better monitoring techniques applied to better modeling methods. These modeling methods can be combined with the information derived from monitoring data in order to decrease the risk of population exposure to dangerous substances and to promote efficient control or cleanup of the contaminants.

Typical sources of contaminants at DOE sites, including releases of radioactive substances, derive from past practices which resulted in intentional injections into deep wells, unlined landfills and burial grounds, underground storage tanks, discharges to percolation cribs, trenches, and French drains, and direct discharges to the soils outside certain facilities. In some cases, when the discharges were intentional, the quantities were regulated so as to avoid filling all vadose zone void spaces to the groundwater. As such, many of these discharges either have not yet reached the groundwater, have recently reached the groundwater, or have slowly contaminated the groundwater. The Hanford site alone compared to the US nuclear weapons complex accounts for 42% of the total curies, 60% of the high level waste, 25% of the waste storage and release sites, 80% of the spent fuel, and 25% of the buried solid waste. It is estimated that the total tank leak volume for the Hanford Site has been on the order of 3.8 M liters. The estimates of the solid waste are 710,000 cubic meters of low level and transuranic waste, containing 6 million curies (1998).

The remediation activities at these sites consist of characterization, remedial actions, and monitoring. All these activities are optimized to produce a total cost of these activities which is minimized with respect to present probable value and subject to the constraints imposed by regulations, safety requirements, exposure risks, and uncertainties at all levels. To date there has not been an adequate paradigm developed and accepted by the both the regulatory community and the responsible parties to facilitate the use of monitoring data in the models used to evaluate performance. This means that compliance monitoring programs are not in general designed and the data are not used to support and enhance confidence in models after site characterization has been acquired. Much more monitoring information could be used to improve models. Many of the sites that are under RCRA closure requirements have very prescriptive monitoring programs that fail to have mechanisms for improving the site models. If monitoring designs were required to be more efficient, thus requiring optimization, then the monitoring would automatically become linked to modeling. Second, records of decision should be written to accommodate revisions in monitoring as better modeling evolves. There needs to be a change in the accepted paradigm. The technical pieces of the required paradigm already exist. This paper is dedicated to offering an approach, which shows how the existing tools can be used to produce a system to integrate monitoring with modeling. The basic approach is to establish a control system with feedback loop as the method for using monitoring data to improve model reliability. The active elements in the control are the remediation activities carried out at the sites.

PARADIGM and its ELEMENTS

The fundamental concept for the new paradigm is the feedback control system. In this system the monitoring data serves as sensor input, the site model serves as the system model, and remediation activities serve as the responses to changes in the input data. The actual system, together with its responses, is approximated by the site model. A diagram showing the various elements of such a feedback control is shown in the following figure:

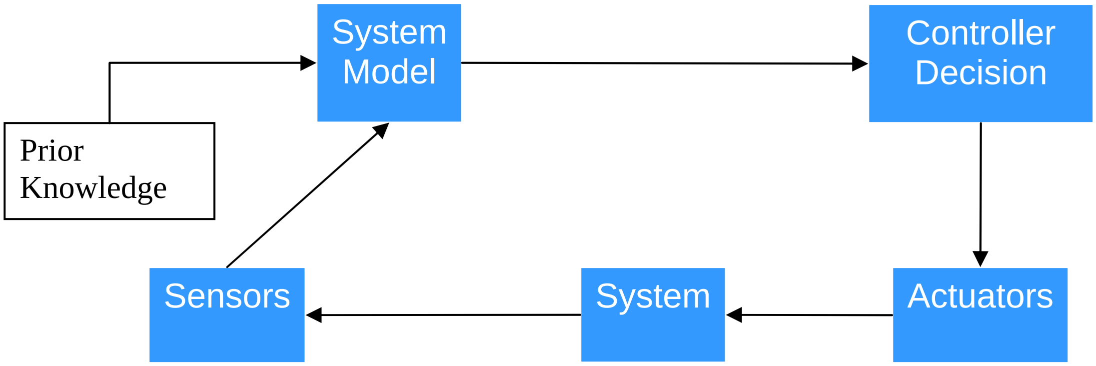


Fig. 1: Feedback Loop Control System

A more detailed illustration of such a control system is given in Figure 2. This shows how decisions can be made based on input data from the monitoring information. These decisions involve risk analyses, cost analyses, and most importantly, uncertainty analyses.

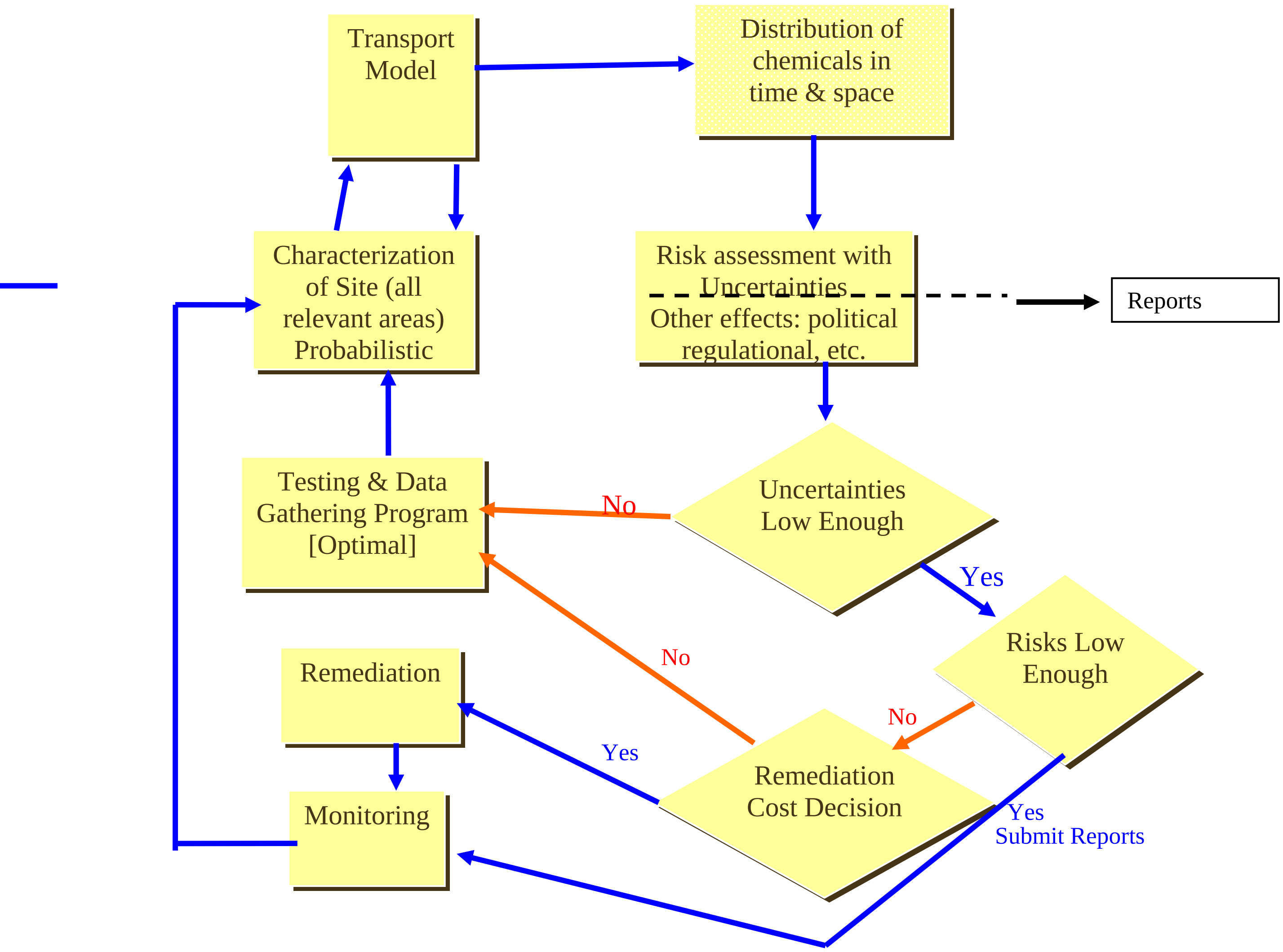


Fig. 2: Monitoring and Remediation Decision Schematic

The system to be modeled consists of the various components of the DOE site in question and would focus on the remediation of high-risk waste sites, shrinking the contaminated areas, reducing natural and artificial recharge through the waste areas, implementing effective groundwater remedies, and integrating groundwater monitoring. The mechanisms of transport from the various sources to a possible receptor population would include atmospheric convection, vadose zone transport, groundwater migration, and surface water migration, such as the Columbia River in the case of the Hanford Site. In producing the model of the system, attention should be paid to the applicable features, events, and processes (FEP) of the site. A systematic approach based on these elements has been a keystone of the high-level nuclear waste repository programs for several countries. A modified version of this approach has been developed for the Hanford Site. In order for the model of the system to be reliable, it should be able to predict as much of the history of the site as is known. This means that the parameters and features must be selected to conform as closely as possible to the known attributes of the site.

FUNCTIONING of the SYSTEM

Decisions to be Made

In focusing on the elements of the feedback control system, it is important to evaluate what decisions are to be made. In the case of the Hanford Site, as a site that contains most of the features of other DOE sites, the decisions revolve around a strategy that limits the migration of contaminants to the Columbia River, while staging the cleanup effort in such a way as to meet budget constraints in any given year. In order to accomplish this goal with a reasonable approach, the Site was divided into 24 zones based on geographical area. Each zone represented the area where a certain historical activity took place that resulted in the contamination in that area. The result was a map that partitioned the site into the zones of these activities. The regulatory agencies greatly influenced the final zone boundaries. The resulting zones were then prioritized according to the types of contaminants they contained, the potential impact of these components on the Columbia River, and the less tangible evaluation of how valuable a given zone would be in sequencing it in a way that provided necessary experience for other zones. The results of this partitioning are given in the following table.

CLOSURE ZONE See Figures 1-1 through 1-3)	**Number of Locations Requiring Closure[1]**	**Future Groundwater Contamination Concerns**	**Intrusion Concerns (TRU Waste Residuals)**	**Radiological Cleanup Operations Concerns**
Zone does not support Hanford cleanup operations				
U Plant Zone	103	^{99}Tc, U, ^{129}I	U	-
Non Radioactive Disposal Waste Landfill and BC Cribs (NRDWL/BC) Control Zone	37	^{99}Tc, ^{129}I	-	-
PUREX Zone	224	^{129}I, H_3	Pu	Pu, Cs, Sr
Plutonium Finishing Plant (PFP) Zone	133	Pu, CCl_4	Pu	Pu
C Farm Zone	53	^{99}Tc	Pu	Pu, Cs, Sr
B Farm Zone	119	^{99}Tc, U, ^{129}I	Pu	Pu, Cs, Sr
T Farm Zone	144	^{3}H, ^{99}Tc, ^{129}I	Pu	Pu, Cs, Sr
618-10 & 11 Zone	4	^{3}H	-	Pu, Cs, Sr
Fast Flux Test Facility Zone	90	-	-	-
Semi-Works Zone	48	-	Pu	Pu, Cs, Sr
200 West Ponds Zone	37	U	Pu	-
Zone supports Hanford cleanup operations & opportunities exist to alter plans and allow earlier cleanup				
B Plant Zone[4]	205	^{90}Sr, ^{137}Cs, Pu	-	Cs, Sr
East Ponds Zone[5]	72	^{99}Tc, ^{90}Sr, ^{129}I	-	-
Zone supports Hanford cleanup operations				
Reduction Oxidation (REDOX) Zone[6]	141	^{129}I, ^{3}H	Pu	Pu, Cs, Sr
T Plant Zone	184	^{3}H, CCl_4	Pu	Pu, Cs, Sr
Waste Management Zone	87	^{99}Tc, U	Pu	Pu
S/U Farms Zone[7]	155	^{99}Tc, U	Pu	Pu, Cs, Sr
Environmental Restoration Disposal Facility (ERDF)	64	-	-	-
Waste Treatment Plant and A Farm (WTP/A Farm) Zone	234	^{3}H, ^{99}Tc	Pu	Pu, Cs, Sr
Solid Waste Zone[8]	48	-	Pu	Pu
Immobilized Low Activity Waste (ILAW) Zone	3	^{99}Tc, U, ^{129}I	-	-
200 East Administrative Zone	145	-	-	-
200 Area Effluent Treatment Facility (ETF) Zone	11	-	-	-
Canister Storage Building (CSB) Zone	13	-	-	-

Table 1: Closure Zone Priorities

The evaluation of risk was based on prediction of the migration of Technetium-99 and Uranium past the boundaries of the zone. The model of the Site performed these calculations, which included release mechanisms, transport in the vadose zone, and finally transport in the groundwater. Two scenarios were evaluated. The first was for anticipated consequences of not carrying out any remediation. The second was for the anticipated consequences of reducing vadose zone infiltration by the use of impermeable barriers covering the areas of contamination. The following tables show the results of these calculations. The first shows the results for Tc-99, while the second shows the results for uranium.

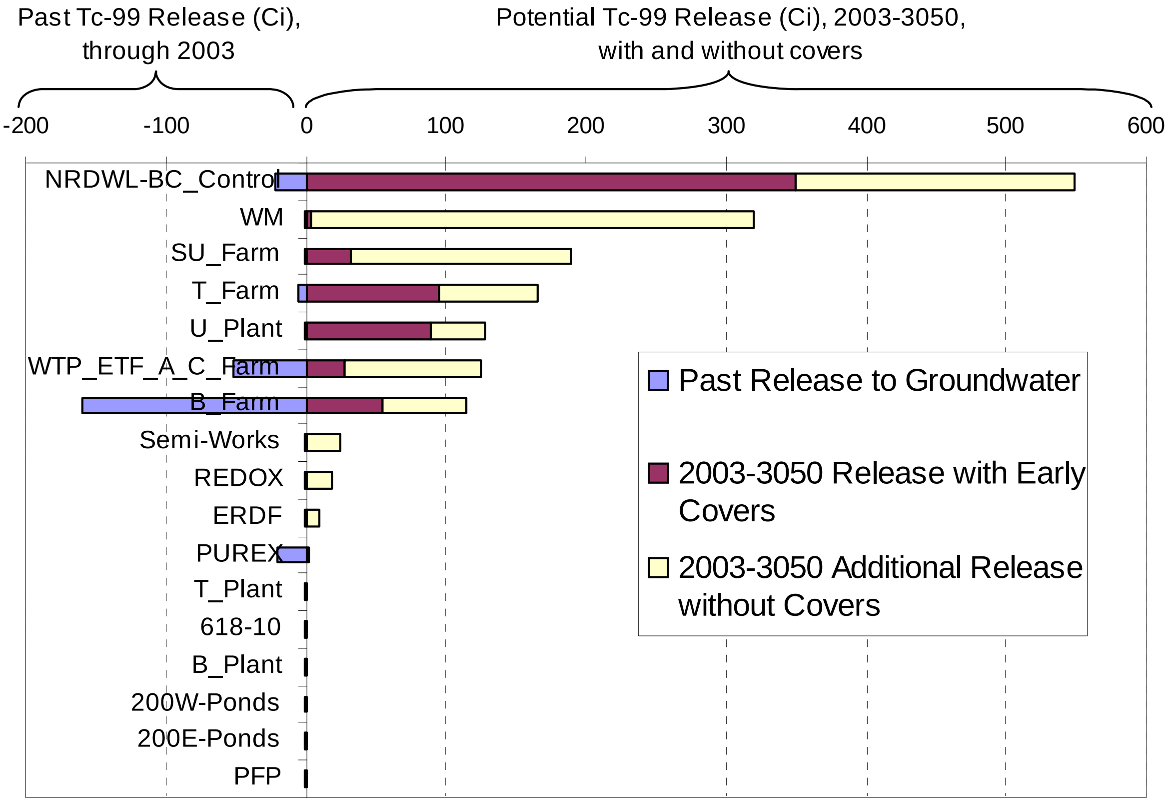


Chart 1: Tc-99 release under the scenarios of no action and caps, including past releases.

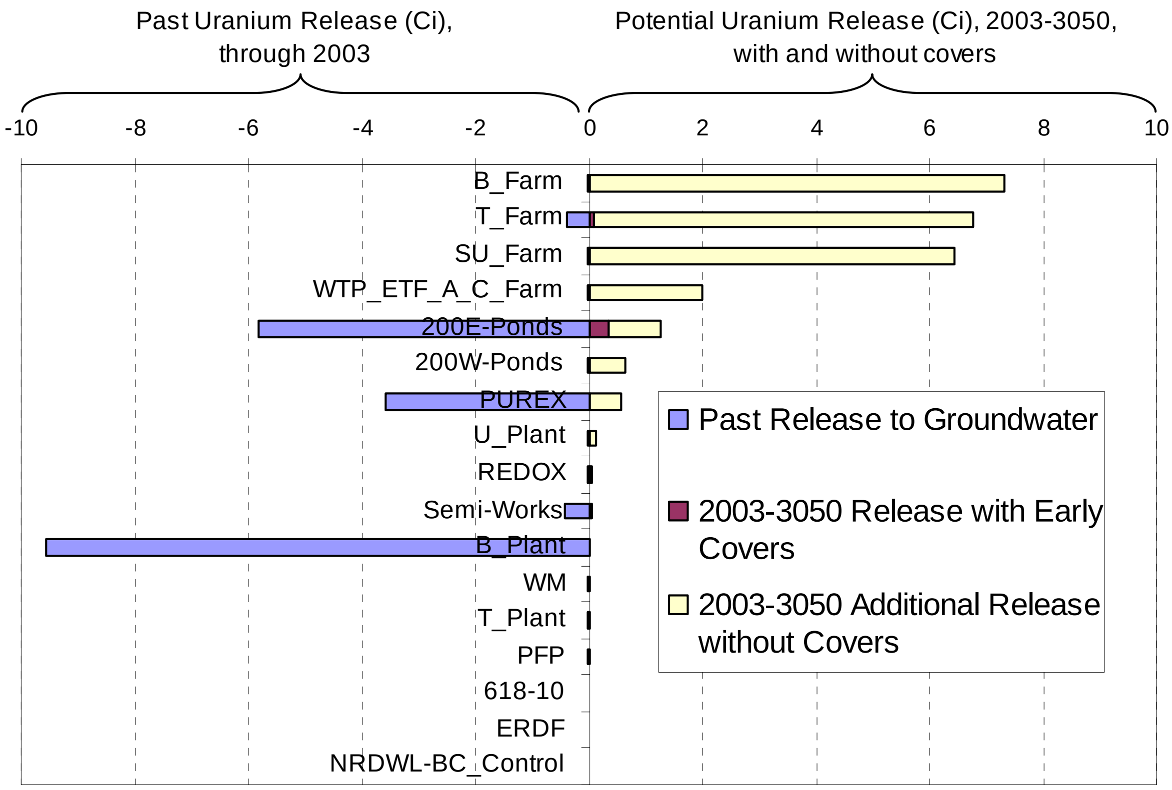


Chart 2: Uranium release under scenarios of no action and caps, including past releases.

An analysis of the details of the releases as they would occur over time reveals that many of these zones have peak periods of release beyond the zone boundaries at different times. By comparing the releases over time and by comparing the two scenarios of no action vs. action, the relative effectiveness of the actions can be evaluated. Thus, it becomes clear, for example, that the NRDWL-BC Control Area is the area that achieves the greatest reduction in risk of contamination from Tc-99. Because of its high mobility Tc-99 is taken as a constituent of prime concern for the Site. The following chart shows the relative effectiveness of remediation actions for the various zones.

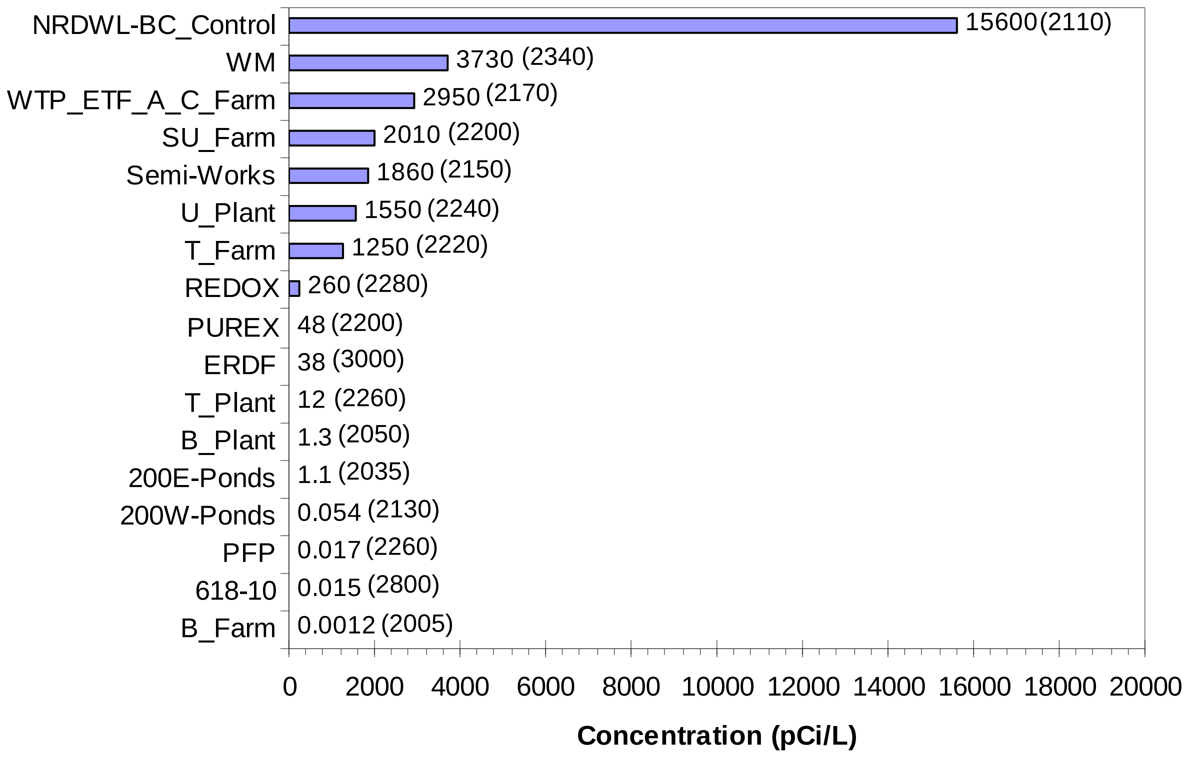


Chart 3: Maximum reduction in Tc-99 due to covers, and the year in which this maximum occurs.

The following is a summary of other actions considered for remediation:

- Removal and disposal actions
  - Moving contaminated material
    - Phyto-remediation of strontium-90
  - Vitrification of wastes
  - Grouting of wastes
  - Excavation of waste and removal of materials to WIPP
  - Pump and treat groundwater
    - Increase capacity with EC Soil vapor extraction
    - Six-phase heating Enhanced volatilization of chlorinated hydrocarbons

- Immobilization of contaminants left in place
  - Sequestration of contaminants through a chemically reactive zone
    - In-Situ Redox Manipulation (ISRM), vertical and horizontal
    - Near shore strontium-90 infiltration barrier
    - Micron-sized elemental iron injection
  - direct application of reacting chemicals
    - Calcium polysulfide injection
    - Bio-reduction of chromium
    - Polyphosphate injection for uranium
    - Bio-degradation of carbon tetrachloride

- Reduce or eliminate water flux to groundwater
  - Caps on landfills (enhanced design capabilities)
  - Desiccation

Monitoring and Data Input

There are various places on the Site that benefit from vadose zone instrumentation in order to achieve the most effective monitoring and characterization. They include waste sites (cribs and trenches), tank farm sites, canyon buildings (reactor buildings), disposal facilities (ERDF and IDF), liquid effluent retention facilities, and low-level burial grounds. Hanford has over 1600 liquid and solid waste sites, including 12 tank farms and some 200 Burial Sites covering over 800 Acres. Uncertainties in field-scale performance require long-term data to demonstrate performance. In order to insure long-term data reliability, robust, long-lived monitoring technologies are required. Uncertainties in performance and stewardship can impact long-term post closure care of covers. Careful planning and installation of monitoring systems will be needed. The Field Lysimeter Test Facility has been in operation at Hanford for many years. It provides valuable information about infiltration characteristics of the Site.

A special Hanford Prototype Barrier was constructed and well-instrumented on the Site. The monitoring program for the Prototype Barrier has provided valuable information about the performance of such remedial actions. The following is a schematic of the Barrier, together with information about some of the phenomena being monitored:

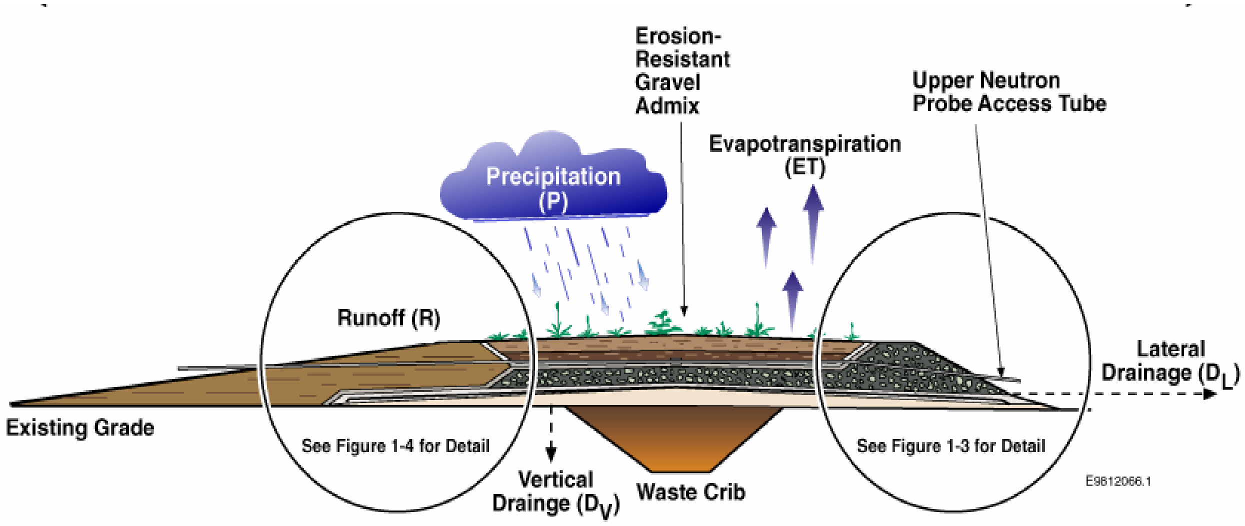


Fig. 3: Hanford Prototype Surface Barrier (vertical cross-section).

Current monitoring scope includes water balance monitoring, vegetation and animal use surveys, stability surveys, settlement, surface topography, and riprap side slope stability. The evaluation of this monitoring data gives valuable insights into which type of barrier would be most useful in the various applications on the Site. These include various types of evaporative transport barriers.

Various vadose zone monitoring techniques are employed, and others are being evaluated. In the category of moisture change monitoring we have neutron probes, time domain reflectometry [TDR], thermocouple psychrometer, electromagnetic induction [EMI], electrical resistivity tomography [ERT], and fiber optic cable. Direct moisture sampling methods include suction lysimeter, absorbent pads, sodium iodide gamma detector, basin lysimeter, and associated chemical analyses. Trends in developing technologies include more volume integrating methods, better sensitivity, and better remote sensing (less intrusive). The information derived from these monitoring activities is put together to enhance the model capabilities by refining the transport properties of the relevant radionuclides and better delineating the extent of contamination and inventories. Groundwater characterization focuses on the main constituents of Tc-99, Uranium, I-129, and carbon tetrachloride. Efforts have been made to optimize this activity to achieve greater efficiency. CPT pushes have been made, which give soil gas measurements for the carbon tetrachloride. The following figure shows concentrations with depth in various locations:

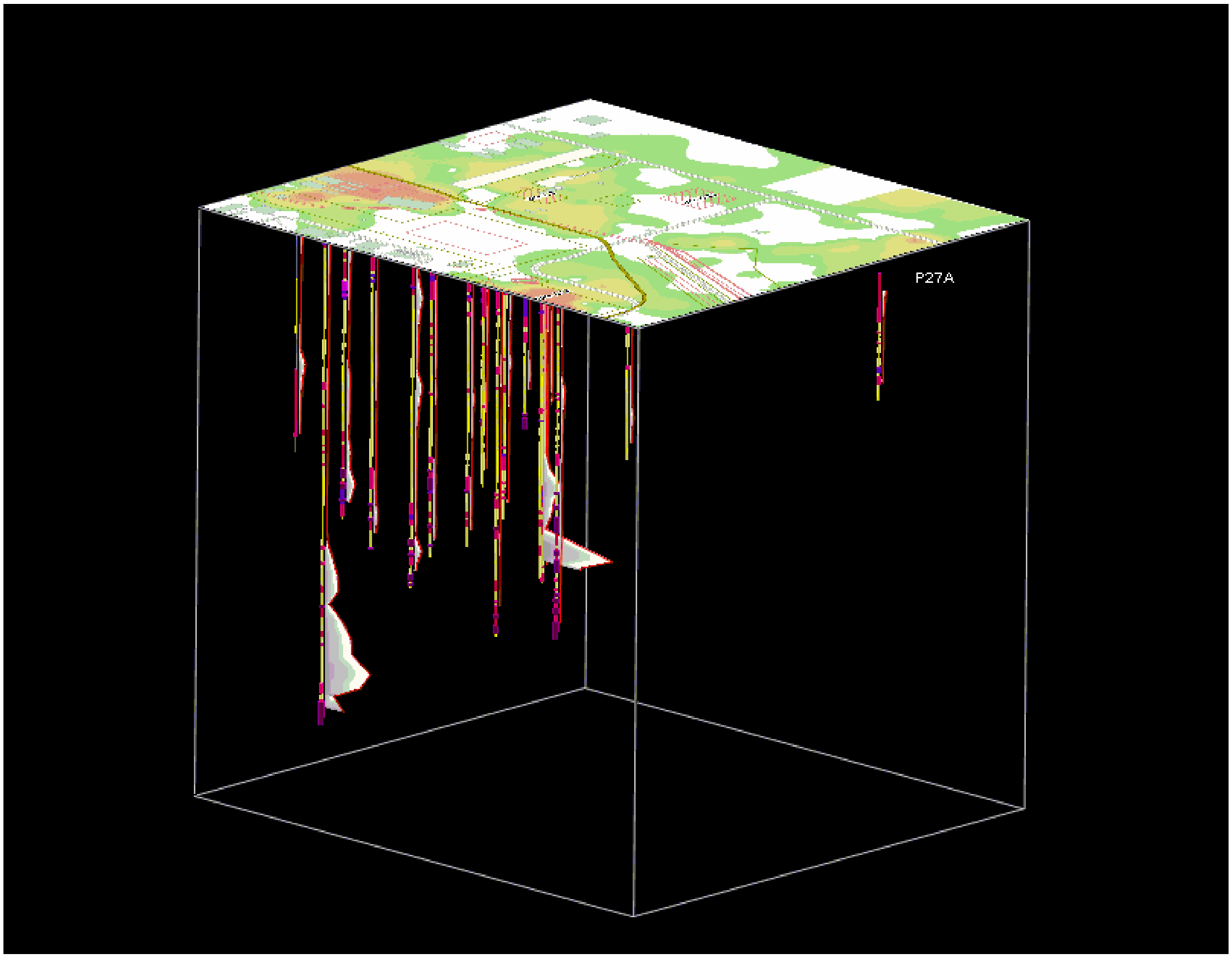
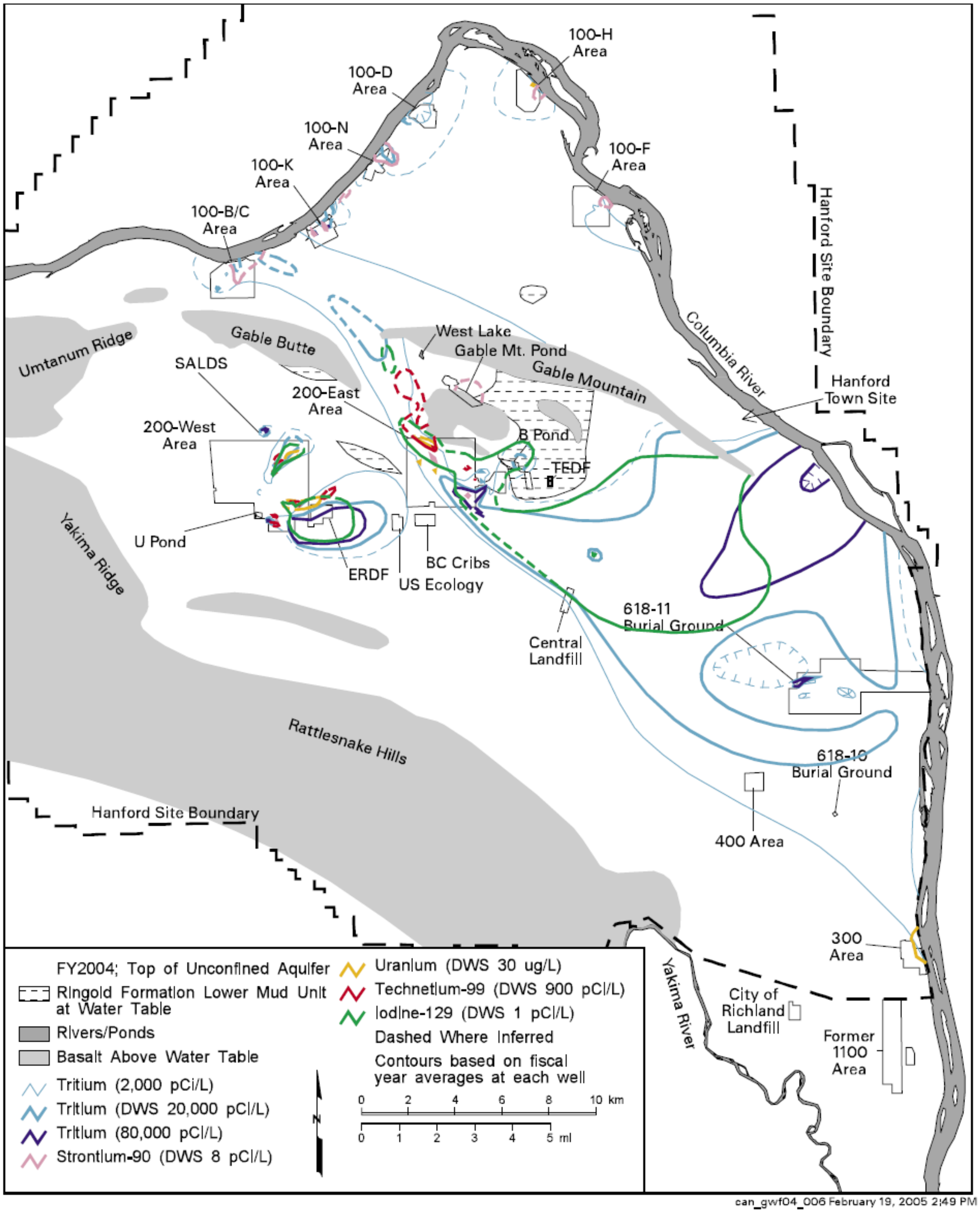


Fig. 4: Active Soil Gas Measurements.

In addition to these kinds of measurements, extensive use has been made of electrical resistivity methods. These have been employed most effectively in the BC Cribs and Trenches area, where the existence of the Tc-99 plume is inferred from the lower resistivity of the higher water saturation associated with its discharge. The results of these various monitoring activities have resulted in approximate plume maps showing the locations of the various constituents of concern. The following map shows the radioactive constituents:



This map shows the distribution of radionuclides in groundwater at concentrations above drinking water standards during FY 2004 at the top of the unconfined aquifer.

Fig. 5: Radioactive Constituents of Concern.

Future monitoring development will include reducing the price of instrumentation and deployment of the technology, increasing reliability of the instrumentation, allowing current designs to incorporate future technology, better barrier design tools, optimizing monitoring activities, developing better standards, including more redundancy, and employing less intrusive techniques. These developments will enhance the use of monitoring in the modeling of the system, and thus, in the control of the contaminants. In order to enhance the capabilities of this feedback control system, improvements need to be made in characterization capabilities, transport properties, risk evaluations, monitoring capabilities, and cost reduction. Characterization issues include the following:

- Technetium – 99 – Difficult to analyze in radiation samples. Transport properties.
- Uranium – Transport properties. Chemical speciation.
- Carbon Tetrachloride – Inventory. Phase? Movement with water or without. Degradation questions. Transport properties.
- Access to locations in groundwater – limits numbers of samples and increases costs.
- Non-intrusive hydro-geological characterization of larger areas.
- Scaling issues.
- Data integration, consistency, and presentation.

Transport issues include the following:

- Uranium chemistry resulting in different transport properties.
- Carbon Tetrachloride sources and migration
- Flow patterns of groundwater over time. Effects of pump and treat, etc.
- Recharge through barriers and how they change over time.
- Vadose zone fate and transport (comparison to groundwater).
- How to accurately predict concentrations for far field from near field values. Particularly, technetium-99.
- Diffuse Chromium Plume. How to handle?

Risk issues include the following:

- What radiation levels cause ecological damage to certain species?
- Understand and provide means to quantify the impact of river contaminants on receptors.
- Dilution factor for river or characterization of salmon fry uptake.
- Can a history match be done to quantify risks?

Monitoring issues include the following:

- Optimization strategies for monitoring
- Unsaturated zone monitoring (better methodology).
  - What types of monitoring.
  - Types of instrumentation, detection methods, etc.
- Monitoring in long-term stewardship mode.
- Reduce monitoring costs.

Examples of Implementation of Similar Paradigms

HydroImage is a user-friendly hydrogeophysical characterization software package developed at Lawrence Berkeley National Laboratory. It integrates continuous geophysical data with limited borehole data to estimate hydrogeological parameters of interest in the subsurface was developed. The software package can be used to significantly enhance site conceptual models and improve design and operation of remediation systems.

Computational Environments for Integration of Geophysics and Reservoir Simulation is a joint development among Ohio State University, Rutgers, and the University of Texas at Austin. It was developed by funding support from the National Science Foundation for the enhanced use of computers in data assimilation. There is also a collaboration between INEL and PNNL. The end goal is to be able to click on a location or well and bring up geophysical (surface and borehole), as well as grain size distributions and estimated hydraulic properties as well as other properties. SAIC has developed an automated knowledge management and production integration system for oil fields and other applications.

CONCLUSIONS

The current technology is available to establish a robust control system with feedback loop as the method for using monitoring data to improve model reliability. This increased capability can then be used to make the best decisions for the cleanup of contaminated DOE sites. This is accomplished by using the feedback mechanism to change the model and update information as to the progress of the remediation effort. The resulting analysis can be used to improve the success of the remediation effort. Advances in monitoring technology are keys to improving the system performance. The trends in monitoring suggest greater robustness, greater accuracy, better volume-averaged methods, less intrusive methods, and decreasing costs.