**AQUEOUS-STREAM URANIUM-REMOVAL
TECHNOLOGY COST/BENEFIT AND
MARKET ANALYSIS**

**U.S. DEPARTMENT OF ENERGY
OAK RIDGE OPERATIONS**

Prepared for

OFFICE OF TECHNOLOGY DEVELOPMENT

By

KAPLINE ENTERPRISES, INC.

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FOREWORD

KapLine Enterprises, Inc. (KEI) prepared this study in response to a request from Johnny Moore, Technical Programs Officer for the Department of Energy's (DOE) Oak Ridge Operations (ORO). Purchase Order DE-AP05-94OR37915, which is dated December 23, 1993, specifies the terms and conditions for this project. The Statement of Work for the study was developed to address issues in a memorandum (dated August 27, 1993) from Jeffrey S. Walker, DOE Office of Technology Development (Washington). This memo asked ORO to gather information for determining the merit of funding beyond the current task for the uranium biosorption project.

CHAPTER 1. INTRODUCTION

PURPOSE

The primary purpose of this report is to present information that was gathered by KEI in order to help DOE determine the merit of continued biosorption research funding. However, in the event that funding is continued, it is also intended to help the researchers in their efforts to develop a better uranium-removal process. This report: 1) provides a comparison of DOE sites that may utilize aqueous-stream, uranium-removal biosorption technology, 2) presents a comparison of the biosorption and ion exchange processes, and 3) establishes performance criteria by which the project can be measured. It also attempts to provide focus for biosorbent ground-water-remediation research and to ask questions that need to be answered.

GOALS

The following goals are based on tasks listed in the Statement of Work submitted to KEI by DOE's Oak Ridge Operations.

Market Quantification: This study will identify the potential size of the DOE market for biosorbent-based, aqueous-stream uranium-removal technologies. It will also compare the domestic and German markets for uranium-removal technologies applied to uranium-containing aqueous waste streams.

Technology Identification: This report will identify available technologies for removing uranium from aqueous streams in the following categories: biosorbent based; non-biological sorbent based (i.e., ion-exchange or chelating resins, activated carbon, etc.); and non-sorbent based (i.e., reverse osmosis, organic and inorganic membrane, precipitation, extraction, etc.).

Frequency of Technology Implementation: For the three groups of uranium-removal technologies, this report will discuss the frequency of implementation within DOE for environmental management water treatment applications with appropriate rationale for use.

Economic Analysis: The study will compare material, capital equipment, and operating costs for the three groups of aqueous-stream uranium-removal technologies. It will also compare their operating efficiencies.

SCOPE AND FORMAT

This report is primarily a study of the U.S. market for technologies that remove uranium from aqueous streams, but it also addresses the international market--particularly for Germany. Because KEI's access to international market information is extremely limited, the material presented in this report represents a best effort to obtain this data. Although uranium-contaminated aqueous streams are a problem in other countries as well, the scope of this report is primarily limited to the U.S. and Germany for two reasons: 1) Germany is the country of the biosorbent-CRADA partner and 2) time constraints.

It is important to note the limited time frame that was allowed for completion of this study: December 23, 1993, to March 1, 1994. This period included a three-week DOE internal-

review period. As a result of these time constraints, information is presented in this report as it was obtained from the source material. In particular, note that economic information from the EPA was not updated from 1991 dollars. This type of analysis is quite complicated and generally relies on computer modeling programs that have been specifically developed for this purpose. The EPA has access to such a program, which was used by this agency to develop the cost estimates that are presented in this report.

As mentioned above, the purpose of this report is: 1) to compare DOE sites that will be able to utilize the uranium-biosorption technology, 2) to compare the economics of the uranium-biosorption process with other technologies, and 3) to determine the performance criteria by which the project will be measured. Note that item (1) is addressed in Chapter 4, while (2) and (3) are addressed in Chapter 6. In addition to meeting these specific goals, this report is a comprehensive reference document that quantifies the DOE water-treatment and public-municipality markets and describes water-treatment technologies, with a focus on uranium-contaminated water. The following topics are addressed in this study:

- Uranium overview and its occurrence in ground and surface waters (Chapter 3).
- The need for uranium-removal technologies, i.e., the uranium-contaminated water market in the U.S. and Germany (Chapter 4).
- Uranium-removal technologies (Chapter 5).
- Cost/benefit analysis (Chapter 6).
- Waste-disposal regulations overview (Appendix 2).
- General water-treatment technology discussion (Appendix 3).
- Sample site analyses: Oak Ridge Reservation, Fernald Plant (Appendices 4 and 5).
- Oak Ridge water treatment facilities (Appendix 4).
- Potential sources of future ground water contamination (Appendix 6).
- Important contacts: DOE (Appendix 7), EPA (Appendix 8), report participants (Appendix 9).
- List of references (Appendix 10).

METHODOLOGY

KEI gathered information on technologies and the U.S. market by: 1) reviewing the secondary literature and 2) interviewing DOE and EPA personnel (primarily by telephone). Information on the German market was provided by one German contact who responded to a fax sent by KEI. This fax was sent to several potential German sources, but only one responded. Fortunately, this source was extremely helpful and provided an overview of the German market and access to a confidential study that was performed by a Canadian consulting firm for the German government. As a result, KEI obtained access to some Canadian and European market information as well.

DISCLAIMER

This work was performed by KEI on a best-effort basis only and, therefore, KEI assumes no liability for its inability to obtain requested information. In particular, information regarding international markets is often extremely difficult to obtain. The materials generated by KEI as a result of this research are not legal or accounting documents and some of the information is speculative. Although KEI intends the work to be as reliable as possible and professional in nature, KEI assumes no liability for the information that is provided or for its use. KEI assumes no liability for loss or damage that occurs as a result of reliance on this information or any material developed from it. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

CHAPTER 2. EXECUTIVE SUMMARY

Ground water and its quality are not yet regulated like other environmental media [e.g., surface water by National Pollutant Discharge Elimination System (NPDES) and air by the Clean Air Act]. Consequently, there are no mandated ground water quality criteria. However, the U.S. EPA has determined that uranium, radium-226 and -228, radon, gross alpha, and beta and photon emitters are of health concern at certain levels of exposure.

The EPA Office of Drinking Water is developing national primary drinking water regulations for naturally occurring and man-made radionuclides, including uranium. The *Federal Register* (Vol. 56, No. 138, Thursday, July 18, 1991) discusses the proposed rules changes, which sets the water standard for uranium at 20 ug/L (i.e., 20 ppb or 13 pCi/L).

Since 1985, the EPA has conducted several detailed cost/benefit analyses on radionuclide removal, with the most recent in 1991. KEI incorporated these EPA costs estimates in this report. EPA is currently updating the 1991 estimates, but the report is still in the draft stage. KEI was able to obtain limited information (specifically regarding the elimination of ion exchange as a Best Available Technology) from this report with the agreement not to cite. As a result, this reference is not included in the List of References.

MARKET

Uranium is a naturally occurring radioactive contaminant that occurs both in ground and surface water. It is believed to cause bone cancer and other cancers in humans at high exposure levels. At lower exposure levels, the risk of cancer is reduced. The EPA also believes uranium can be toxic to the kidneys. As a result of these health issues, public pressure is becoming a major driving force in ground water remediation efforts, particularly for DOE.

DOE REMEDIATION

The following DOE offices have defined problem units for uranium-contaminated ground waters: Albuquerque, Fernald, Nevada, Oak Ridge, Rocky Flats, Richland, and Savannah River. Only two offices have specified uranium-contaminated surface water problem units, Oak Ridge (onsite at K-25) and Savannah River. Although soil (and related materials such as sludge, sediments, and buried materials) contamination is outside the scope of this project, sites with uranium-contaminated soil may experience ground water contamination in the future, if they are not already. All of the offices that report soil contamination also have contaminated ground water with one exception—Idaho, which only reports soil contamination.

PUBLIC WATER SUPPLIES

According to a 1991 study performed for the EPA, it is estimated that 718,000 people using public water supplies are exposed to uranium at levels exceeding 20 ug/L, with combined upper and lower 95 per cent confidence bounds of 26,000 and 1,559,000. Practically all of the population predicted to have drinking water exposure above this limit are served by 1,446 small and medium ground water supplies. According to the study, however, these population exposure estimates are probably overestimates of exposure levels as a result of using ground water data as the basis for the surface water occurrence distributions.

NEW TECHNOLOGIES

New technologies are being evaluated for removing uranium from aqueous streams. These technologies include activated alumina, biofloculants, biosorbents, and electrodialysis.

ACTIVATED ALUMINA

Limited experimental studies have shown that activated alumina is capable of achieving good removal of uranium from drinking water. This treatment has a very high capacity for concentrating radionuclides.

BIOFLOCCULANT

A biofloculant is a biological-based material that, when added to a dispersion of solids in a liquid, brings the fine particles together to form flocs. A biofloculant that removes uranium and other radionuclides from waste has been developed by Indian (New Delhi) scientists. The product is derived from the seeds of *Strychnos potatorum*, a tree found growing in forests in the state of Andhra Pradesh. It is said to be capable of removing cadmium, mercury, gold, silver, cobalt, copper, nickel, and other toxic heavy metals as well. The product reportedly has a very high affinity for uranium.

BIOSORBENT

According to the Oak Ridge National Laboratory (ORNL) researchers, biosorbents offer the advantage of selectivity for uranium as opposed to Group I and II elements (i.e., calcium, iron, magnesium, potassium, and sodium), which are common constituents of untreated water. These elements do not quickly saturate the biosorbent as they do ion-exchange resins. A precipitation step is often incorporated prior to ion exchange treatment in order to solve this problem. The biosorbent, however, is quickly saturated by transition elements, particularly iron, which might also require a precipitation step.

ELECTRODIALYSIS

It has been reported that electrodialysis, a membrane process that uses direct electrical current to separate dissolved ions from water, should be able to achieve an estimated *in situ* uranium rejection rate of 80 per cent in mining waters. In drinking waters, it is predicted that the method is as effective as reverse osmosis. KEI identified two DOE projects that are evaluating this treatment process, one for cesium removal and the other for nitrates.

BEST AVAILABLE TECHNOLOGIES

Technologies are judged to be Best Available Technology (BAT) based upon the following factors: high removal efficiency, general geographic applicability, cost, reasonable service life, compatibility with other water treatment processes, and the ability to bring all of the water in a system into compliance. Until recently, the EPA felt that coagulation/ filtration, ion exchange, lime softening, and reverse osmosis met the requirements of the Safe Drinking Water Act (SDWA) as BAT for uranium removal. These technologies have demonstrated effective uranium removal, are currently available, have been installed in

public water supplies, and are compatible with other water treatment processes in different regions. Table 1 lists the removal rates for these technologies and for biosorbents. The actual rate, however, depends on factors such as influent concentration and pH.

TABLE 1
URANIUM-REMOVAL EFFICIENCIES (PER CENT)

TECHNOLOGY	EFFICIENCY, %
Biosorbent ¹	Not available
Ion exchange	65-99
Reverse osmosis	98-99.4
Lime softening	85-99
Coagulation/filtration	80-95

¹ Technology developed specifically for acidic pH conditions of 2-3 (uranyl ion form) as opposed to typical ground water pH levels, 6-8 (uranyl carbonate form). In order to make a fair comparison with BAT removal efficiencies and economics, the researchers must modify the current biosorbent material in order to make it selective for uranyl carbonate.

Source: EPA, ORNL, and KEI

FREQUENCY OF USE IN PUBLIC TREATMENT FACILITIES

Note that a new EPA proposal being drafted eliminates ion exchange as a BAT. While this recommendation affects public water treatment facilities, it should have limited impact on DOE's usage of the technology for ground water remediation. However, it is expected to have a significant impact on public facilities. Based on this new recommendation, the EPA anticipates the following distribution of use of BATs by the public water supplies for radionuclide removal: lime softening (40%), coagulation/filtration (30%), and reverse osmosis (30%).

FREQUENCY OF USE IN DOE TREATMENT FACILITIES

KEI identified 37 DOE treatment facilities that either have technologies in place that can potentially be used for uranium removal or have plans to build them. Of these 37 systems, 15 (41%) listed chemical precipitation; 14 (38%) ion exchange; 13 (35%) activated carbon; and 2 (5%) reverse osmosis. The following technologies were listed by a single system (<3%): actinide separation, adsorption, flocculation, and liquid extraction. Note that some of the systems may have listed more than one technology.

URANIUM-REMOVAL ISSUES

Based on conversations with EPA sources, some issues should be carefully addressed when developing new uranium-removal technologies. These issues include: 1) the chemical form of the uranium, 2) disposal problems caused by sorbent's high capacity for uranium, 3) soluble versus non-soluble uranium, and 4) interactions with other contaminants. The second issue is primarily directed toward municipal water treatment facilities versus DOE systems, which have disposal methods and facilities for stabilized low-level radioactive wastes. Nevertheless, DOE is still affected by disposal costs of these materials.

RELATIONSHIP BETWEEN PH AND CHEMICAL FORM

While the biosorbent CRADA calls for treating uranyl nitrate, which is present in water as free uranyl cation, UO_2^{2+} , U.S. ground waters are typically contaminated with anionic uranyl carbonate complexes. The carbonate complexes occur as a result of the pH range (6-10) of these waters. Sources indicate that uranium is present as the free uranyl ion only at pH 5 and below. According to the EPA, the soluble carbonate complexes that are the predominant species present in natural waters are primarily $\text{UO}_2(\text{CO}_3)_2^{2-}$ and $\text{UO}_2(\text{CO}_3)_3^{2+}$. At higher pHs and in carbonate-free water, the following cationic hydroxide complexes can be formed: $\text{UO}_2(\text{OH})^+$, $(\text{UO}_2)_2(\text{OH})_2^{2+}$, and $(\text{UO}_2)_3(\text{OH})_5^+$. Pacific Northwest Laboratory has done some work on geochemical speciation modeling that may help address this issue. Note, however, that all analytical test results obtained by KEI report uranium in mg/L or pCi/L, but do not indicate the form.

HIGH URANIUM CAPACITY

The Nuclear Regulatory Commission (NRC) requires processes that generate materials with >0.05 wt.% uranium content to be licensed to generate "source materials." As a result, disposal issues may determine whether a sorbent-based uranium-removal system is regenerated frequently, resulting in large volumes of dilute liquid waste (which is often simply released to the surface waters), or recharged with new sorbent before the 0.05 wt.% limit is reached with the old sorbent being disposed of as solid waste. It is this issue that is the driving force behind the EPA's debate on whether to eliminate ion exchange from the list of BATs for public water systems.

SOLUBLE URANIUM VERSUS NON-SOLUBLE

A major issue when evaluating water-treatment technologies is the chemical form of the uranium, which can be either dissolved in the water or adsorbed to colloidal clay particles. According to an EPA source, one of the major problems with the use of removal technologies such as ion exchange is that their use is based on the assumption that all of the uranium is in a soluble form. This source believes this is not a valid assumption because uranium adsorbs onto colloidal clay particulates (i.e., facilitated transport) that may not be trapped by the ion exchange treatment.

INTERACTIONS WITH OTHER CONTAMINANTS

Another potential complication with uranium removal is that there are many combinations of uranium species as a result of the fact that compounds such as carbonates and nitrates react with other contaminants in the water. Compound-class mixtures formed by radionuclides such as uranium include: 1) metals-radionuclides, 2) metals/radionuclides-organic acids, 3) metals/radionuclides-complexing agents, 4) metals/radionuclides-ketones, and 5) metals/radionuclides-organic acids/complexing agents-ketones/chlorinated hydrocarbons.

COSTS AND BENEFITS

One of the goals of this study is to identify U.S. applications where biosorbent can potentially be used and the costs and benefits associated with those applications. The primarily application identified by KEI is ground water treatment. These waters are typically contaminated with uranyl carbonate (pH 6-8). However, if the merit of continued biosorbent funding is to be based on KEI's analysis, it is important to remember that the current technology was developed specifically for acidic conditions (pH 2-3) in order to remove uranyl ion and its cationic hydroxide complexes.

Because of this, KEI believes that, in order to make a fair comparison with Best Available Technologies (BATs), the researchers must first modify or replace the current biosorbent material in order to make it effective in the higher pH ground water application. This new material should then be compared with an anionic ion exchange resin, such as Dowex 21K, that is commonly used to treat uranium-contaminated ground water. Because of the focus on low pH conditions, the ion exchange resins tested by the researchers to date have been cationic resins that are known to be ineffective for removing uranium from ground water.

Nevertheless, in order to demonstrate the current biosorbent's performance with a representative water sample, the researchers conducted tests using Y-12 waste water on the biosorbent and selected cationic ion exchange resins. The water sample tested (pH 8.9) contained 5.6 ppm U, 0.5 ppm Fe, and a complex mixture of Ni, Na, Cl, SO₄, etc. Although the removal was only around 5 per cent, the biosorbent performed at least as well as the other cationic materials.

Based on a biomass cost of \$50/kg (supplied by the researchers), KEI estimates the biosorbent cost to be \$52/ft³. Of this, materials make up 42/ft³ of the cost and foam-fabrication cost through a custom-foam fabricator is assumed to be \$10/ft³. Industry sources indicate that this is a high-end cost for fabrication. Note also that the biosorbent-materials cost used in this analysis is based on a bench-scale process that uses high-purity chemicals. Actual materials costs for a production-scale process should be lower. However, this analysis did not take into account many of the other factors that affect biosorbent product cost. According to the biosorbent researchers, however, the final sales price should actually be less than for ion-exchange resin. Because of the uncertainties in the actual biosorbent cost, KEI assumed three different biosorbent prices (\$52, 100, 200/ft³) in order to show the effect of sorbent price on water treatment costs.

While sorbent price plays a significant role in water treatment economics, other factors must also be considered. Kinetics and the resulting efficiency must also be taken into account in order to get the true economic picture. Kinetics and efficiency play an important role in costs associated with plant operation as well as spent-sorbent storage and disposal costs.

The factors that greatly affect biosorbent water treatment costs are: 1) grams uranium adsorbed per gram biomass cells or grams uranium adsorbed per gram total sorbent, 2) grams biomass cells per gram of foam, and 3) biomass materials costs. Each of these factors can be controlled to some degree.

- 1) Biosorbent research suggests that the grams of uranium adsorbed per gram biomass cells is a function of the kind of cells used (i.e., *pseudomonas aeruginosa*, *pseudomonas atlantica*). Cell capacity can be increased by pretreatments and matrix capacity can potentially be increased by changing some free functional groups or active sites, which are grafted in the base matrix.

- 2) The current biosorbent foam is 39 wt.% biomass cells. According to W.R. Grace, the foam prepolymer manufacturer, it can be theoretically load to 80 wt.%. The researchers, however, have not attempted to produce such a foam. Nevertheless, KEI made an estimate of how a higher loading would affect treatment costs assuming three different assumed prices. These calculations indicate that cell loading affects treatment costs dramatically.
- 3) Biomass materials cost makes up almost 90% of the total biosorbent materials cost used in these calculations. Anything that can be done to decrease the \$50/kg cost for the biomass will improve the economics. Note that, while the biomass and biosorbent costs used to determine the \$52/ft³ estimate are based on bench-scale production quantities, the ion exchange prices included in this report are actual sales prices from a distributor. This comparison is necessary due to the lack of better data.

Table 2 provides a summary of the results of KEI's economic analysis. Note that the number of gallons of water treated by the biosorbent can, theoretically, be improved significantly by increasing the cell loading from 39 to 80 wt.%. This increased throughput results in dramatically better biosorbent economics in terms of cost per gallon of water treated.

TABLE 2
ECONOMIC ANALYSIS RESULTS SUMMARY

	BIOSORBENT (Anion Removal, Y-12 Water)	BIOSORBENT (Cation Removal, Uranyl Nitrate)	BENCHMARKS (Anionic/Cationic Ion Exchangers ¹)
ECONOMIC ANALYSIS RESULTS			
Gal. water treated/ft ³ sorbent before regeneration or disposal (estimated)	37; 362 ²	58; 575	17,756/1,860
Treated water cost, \$/gal			0.0093/0.21
39 wt.% biosorbent (\$52/ft ³ , 100, 200)	1.42, 2.73, 5.46	0.895, 1.72, 3.44	
80 wt.% biosorbent (\$52/ft ³ , 100, 200)	0.14, 0.28, 0.55	0.090, 0.17, 0.35	
Treated water cost plus \$100/ft ³ for immediate disposal of spent sorbent, \$/gal.			0.0149/0.26
39 wt.% biosorbent	4.15, 5.46, 8.19	2.62, 3.44, 5.16	
80 wt.% biosorbent	0.42, 0.55, 0.83	0.26, 0.35, 0.52	
Treated water cost plus storage (\$35/ft ³) at K-25 and disposal (\$100/ft ³) of spent sorbent after 10 years of storage, \$/gal.			0.035/0.45
39 wt.% biosorbent	13.7, 15.0, 17.8	8.64, 9.46, 11.2	
80 wt.% biosorbent	1.39, 1.52, 1.80	0.87, 0.96, 1.13	

¹ Dowex 21K (\$166/ft³) with Y-12 water/Duolite C-467 (\$384/ft³) with uranyl nitrate solution.

² 39 wt.%; 80 wt.%.

Source: KEI

Note the effect of sorbent material cost on the cost per gallon. If the biosorbent costs \$52/ft³, the cost is \$1.42/gallon of water treated with 39 wt.% material compared to \$0.14/gallon for 80 wt.%. However, if the sorbent price is \$200/ft³, the treatment cost using 39 wt.% biosorbent rises to \$5.46/gallon as opposed to \$0.55/gallon for 80 wt.%.

Table 2 also shows the effect of storage and disposal costs on treatment cost. Assuming \$52/ft³, the cost per gallon of water treated jumps from \$1.42/gallon to \$4.15/gallon for 39 wt.% biosorbent and \$0.14/gallon to \$0.42/gallon for 80 wt.% when costs for immediate disposal are added. If the biosorbent cost is \$200/ft³, the cost per gallon of water treated jumps from \$5.46/gallon to \$8.19/gallon for 39 wt.% biosorbent and \$0.55/gallon to \$0.83/gallon for 80 wt.% when costs for immediate disposal are added.

If this material is stored for 10 years prior to storage, the cost jumps again. Assuming \$52/ft³, the cost per gallon of water treated jumps from \$4.15/gallon to \$13.7/gallon for 39 wt.% biosorbent and \$0.42/gallon to \$1.39/gallon for 80 wt.%. If the biosorbent cost is \$200/ft³, the cost per gallon of water treated jumps from \$8.19/gallon to \$17.8/gallon for 39 wt.% biosorbent and \$0.83/gallon to \$1.80/gallon for 80 wt.%. Although KEI assumed the cost of disposal will be the same in 10 years, this is probably not a valid assumption. This will result in even higher treatment costs than are estimated here.

Note the effect that the higher cell loading has on the overall treatment cost. Because the 80 wt.% material treats much more water, resulting in significantly less sorbent to dispose, the economics are dramatically better.

KEI discovered a commercially available patented foam (Forager Sponge) that can potentially remove uranium in the cationic form. This material sells for \$95/ft³, but note that its use for uranium removal has not been demonstrated. The manufacturer estimates the cost of treating water with this technology, which can supposedly adsorb 50-200 g cation/ft³ sponge, to be less than \$0.001 to \$0.02/gal. If the sponge is not regenerated, the cost is estimated to be in the range of \$100-300 per pound of metal removed. In comparison, KEI estimates that 80 wt.% biosorbent with a loading of 2.13 mg U/g cells (0.0293 lb.U/ft³ biosorbent) costs \$1,775/lb. **cationic** uranium removed assuming the biosorbent costs \$52/ft³ and \$6,826/lb. cation if it costs \$200/ft³. Duolite C-467 costs \$4,021/lb. cation assuming \$384/ft³. Based on ORNL test results (using adjusted uranium loading), the cost for Dowex 21K (\$166/ft³) is \$184 per pound of **anionic** uranium removed.

CONCLUSIONS AND RECOMMENDATIONS

The benefit of developing biosorbent technology is the possibility of developing a sorbent that generates less solid waste during ground water remediation efforts. This benefit becomes even more important as the cost of storing and disposing uranium-contaminated sorbents increases. However, KEI believes that before a decision regarding continued funding can be made, further development is necessary in order to evaluate and resolve the research issues that were identified in this study.

Because the research conducted thus far has focused on low pH applications, KEI recommends the focus be shifted to developing a biosorbent that removes uranium in higher pH conditions. Because the current biosorbent removes cations, it cannot be used as is for remediation of typical ground waters. This conclusion is supported by preliminary testing with Y-12 waste water.

The possibility of increasing the quantity of uranium adsorbed through cell pretreatments and a higher weight per cent of cells should be explored in order to improve removal efficiency. It would also be interesting to see a comparison of Forager Sponge performance with that of the biosorbent.

Although uranium-contaminated water is a problem at the DOE sites identified in this report, other contaminants are generally present as well. DOE, other government agencies such as the Department of Defense, and private industry all have a need for technologies that remove other contaminants, including metals such as cesium, chromate, lead, plutonium, radium, strontium, and thorium; tritium; PCBs; radon and radon "daughters"; VOCs; and SVOCs. As a result, KEI recommends that the current test plan be broadened to include additional testing to determine exactly what other contaminants the biosorbent will remove and how the interaction of these materials affect performance. This testing is also important to the DOE's uranium-removal application because of the potential for interference as a result of chemical interactions. Table 3 summarizes issues identified by KEI that should be addressed by the biosorbent researchers.

TABLE 3
BIOSORBENT RESEARCH ISSUES

- Can the biosorbent be modified to remove uranyl carbonate as opposed to the free uranyl ion, which the current biosorbent removes? [Note: The researchers indicate they have recently isolated microorganisms from a uranium-carbonate leaching mine that will probably work.]
- Can the adsorbence characteristics of the cells be improved through pretreatments?
- Can the foam matrix support 80 wt.% cell loading and what is the actual incremental cost of adding more cells?
- What are the biosorbent foam performance parameters and kinetics in a packed-bed column (i.e., minimum/ maximum uranium concentrations that can be effectively treated, minimum/maximum flow rates, potential for clogging, regeneration characteristics, etc.) How do these parameters compare with other Best Available Technologies?
- What contaminants besides uranium can be removed by biosorbent technology?
- How does the presence of other contaminants such as PCB, VOCs, metals, etc., affect the uranium-removal performance of the sorbent?
- Does the biosorbent remove colloidal forms of uranium that are carried through a facilitated transport mechanism?
- How does the biosorbent compare to the Forager Sponge?

Source: KEI

CHAPTER 3: URANIUM OVERVIEW

OCCURRENCE IN NATURE

Uranium is not as rare as was once believed. Widely distributed in the Earth's crust, uranium occurs to the extent of about 0.0004%, making the metal more plentiful than mercury, antimony, or silver. Before World War II, uranium was of interest only to the chemists and physicists who studied the element as they would any other substance. With the advent of the nuclear age, uranium now occupies a key position in nuclear weapons and nuclear energy.

ISOTOPES

Natural uranium has three isotopes: the most abundant is U-238 (99.276%), occurring with U-235 (0.718%) and U-234 (0.0056%). There are 14 isotopes in all, each radioactive. Except for neptunium and plutonium, uranium is the heaviest atom found in nature. Each of the naturally occurring isotopes of uranium are radioactive and decay by specific nuclear transformations. Each of the resulting thorium isotopes is also radioactive. The U-238 isotope decay begins a series of nuclear transformations, called the uranium series, that ends with the non-radioactive lead isotope, Pb-206.

U-238, the abundant isotope of uranium, is not fissionable, but will form plutonium-239 as a result of bombardment by neutrons in a reactor. U-235 is the readily fissionable isotope of uranium. U-235 was the energy source used in the original atomic bomb. Its half-life is 7.13×10^8 and its critical mass is about 33 pounds. U-235 is present in natural uranium only to the extent of 0.7% and can be separated from it by any of these methods: the gaseous diffusion processing using uranium hexafluoride, the gas centrifuge process, and the electromagnetic separation method. Uranium hexafluoride is volatile and, in the absence of water, chemically stable. Fractional diffusion of large volumes of this compound was used to separate U-235 from U-238 for use in the atomic bomb. U-234 is a natural isotope of uranium with half-life of 2.48×10^5 years. It is separated by extraction with triethylphosphine oxide.

CHARACTERISTICS AND PROPERTIES

Uranium is a heavy, radioactive metal and is the 92nd element in the periodic table and a member of the actinide series. Its atomic weight is 238.029 and its chemical symbol is U. Uranium metal is a dense, silvery solid that is ductile and malleable. It is a poor conductor of electricity and forms solid solutions (for nuclear reactors) with molybdenum, niobium, titanium, and zirconium. Uranium is a highly toxic, radioactive material. Its TLV, including metal and all compounds as uranium is 0.2 mg/m^3 of air. It is a dangerous fire risk because, in the powder form, it ignites spontaneously in air.

Uranium is a strongly electropositive element and is easily oxidized. When a massive sample of uranium is exposed to air, the surface is oxidized and protects the rest of the metal from oxidation near room temperature. The massive metal will burn in air at 700°C ($1,292^\circ\text{F}$), and finely divided uranium is pyrophoric, igniting spontaneously in air.

In its chemical compounds, uranium exhibits four common oxidation states +3, +4, +5, and +6. Uranium reacts readily with most non-metals and dissolves slowly in dilute mineral

acids. The metal dissolves rapidly in oxidizing acids, such as nitric acid, yielding (in nitric acid) uranyl nitrate. Much of the aqueous chemistry of uranium is dominated by the uranyl ion and its derivatives. It is also attacked by water and peroxides but is inert to basic solutions or alkalis. Green tetravalent uranium and yellow uranyl ion (UO_2^{++}) are the only species that are stable in solution.

ORES

Uranium is never found in its elemental state but rather is always combined with other elements in about 150 known minerals. There are several important uranium ores, including uraninite, pitchblende (essentially UO_2), and carnotite (a complex oxide containing potassium and vanadium as well). No deposits of concentrated uranium ore have been discovered. As a result, uranium must be extracted from ores containing less than 0.1 per cent uranium. The largest quantities of uranium ore are mined from the Blind River area of Canada. Other significant uranium deposits have been found in South Africa, Australia, France, and the United States (Colorado and Utah). The historic vein deposits at Jachymov, Bohemia, in the present-day Czech Republic, were supplemented by the discovery of uranium-bearing sandstones in the U.S. U.S. resources of uranium oxide in the 1970s were estimated at 150,000-175,000 tons. There is about the same amount in Canada.

DEPOSITS

More than 99 per cent of the uranium now being mined in the U.S. comes from sedimentary deposits in New Mexico, Wyoming, Texas, Colorado, and Utah. These deposits apparently formed when uranium-bearing ground water encountered chemically reducing conditions in sedimentary beds and precipitated reduced (+4) uranium minerals, principally uraninite and coffinite.

Oxidized uranium may also precipitate by interaction with primary vanadium minerals, forming the ore minerals carnotite and tyuyamunite. These deposits, typically tabular bodies enclosed in reduced sandstone and concordant with the sedimentary structure of the sandstone, represent a subsurface "wave" or moving interface between oxidizing and reducing conditions.

Approximately 90 per cent of the remaining uranium minerals are uranyl compounds. These minerals form mainly by alteration of primary ore minerals in petmatites and veins or by precipitation from evaporating uranium-bearing ground water. Almost half of the uranyl minerals are arsenate minerals, phosphate minerals, or vanadate minerals. The number of waters of hydration may vary in a given mineral species, as in the zeolites. Two structural series are recognized, corresponding to various cations replacing calcium in autunite and in metaautunite. Other uranyl minerals include silicates such as uranophane, carbonates such as rutherfordine, and sulfates such as zippeite.

PROCESSING

Uranium mills extract uranium from ores that contain only 0.01 to 0.3 per cent U_3O_8 . Uranium mills, typically located near uranium mines in the western U.S., are usually in areas of low population density. The product of the mills is shipped to conversion plants, where it is converted to volatile uranium hexafluoride (UF_6), which is used as feed to uranium enrichment plants.

Process Description

Because it is necessary to use low-grade ores in the production process, substantial and complex processing of these ores is required to obtain pure uranium. Usually it is necessary to preconcentrate the ore by grinding and by flotation or similar processes. A chemical leaching process separates the uranium from the ore. There are two basic leaching processes: 1) acid leaching for ores with low lime content and 2) alkaline or carbonate leaching for ores with high lime content.

In the acid leaching process, the preconcentrated ore is leached with hot nitric-sulfuric acid mixture to bring the uranium compounds into solution. The leach solution is chemically treated to remove the uranium product. Most mills that use the acid leaching process follow with solvent extraction, a process where the uranium product is separated from the solution by an organic solvent and is then separated from the solvent by a stripping and precipitation operation. Some mills absorb the solution onto an **ion-exchange** resin. The mills that use the alkaline or carbonate leaching process add a caustic to the leach solution, resulting in the precipitation of sodium diuranate.

In order to produce the oxide, sulfate is precipitated from the solution with barium carbonate and uranyl nitrate is extracted with ether. After reextraction into water, it is heated to drive off nitric acid, leaving uranium trioxide. The latter is reduced with hydrogen to the dioxide. Uranyl nitrate may also be converted to other uranium compounds or reduced to yield the pure metal. The oxide may also be prepared from uranium hexafluoride by treating with ammonia diuranate and is recovered from phosphoric acid. In either case, the product is dried in large ovens and packaged in 55-gallon drums.

Emissions and Waste

Milling

The primary method of removing uranium dust from the exhaust gas is the wet scrubber. Wet scrubbers remove dust particles by impacting them with water droplets. The most common type of wet scrubber is the orifice scrubber, which has a removal efficiency of 93.6 per cent. Also common is the impingement scrubber, which has a removal efficiency of 97.9 per cent. The venturi scrubber, used infrequently, has a removal efficiency of 99.5 per cent but requires more energy to operate than the other two. The removal efficiencies presented are those cited by the NRC for these applications (NRC79). Baghouses are frequently used to remove dust from the crushing and packaging area exhaust, which have a rated removal efficiency of 99.9 per cent. They are not suitable for cleaning the dryer off-gas because of the high temperature and moisture content.

Tailings

After the uranium product is separated from the ore in the leaching process, the residual ore (mill tailings) is pumped as a slurry to a surface impoundment area or tailings pile. A tailings pile, typically 100 hectares in area, is surrounded by an embankment of impervious material. The liquid portion of the slurry is partially recovered and recycled by some mills and is allowed to evaporate at other mills. The solid tailings are made up of a sand fraction (particles from 38 to 200 mesh) and a slime fraction (particles smaller than 200 mesh).

An active tailings pile contains wet and dry areas. The slurry feed pipe is moved around the impoundment area to keep the pile level; therefore, the pile has a pond area where the slurry is fed while the rest of the pile is drying out. As sections of the pile dry, the tailings become a source of windblown dust. Control of pile dust is similar to control of dust from the ore storage pile--spraying with water or by discharging the slurry from multiple discharge points instead of one. Alternative methods for surfaces that are not being added to or disturbed is to put a chemical stabilizer on the surface of the pile or to use an asphalt spray.

REPROCESSING

Uranium is used as fuel in nuclear reactors. Eventually, the chain reaction of uranium oxide enriched with U-235, which is used to fuel nuclear reactors, will stop due to the accumulation of nuclear fission products. Before this point is reached, the fuel assembly is removed and the fuel must either be disposed of or reprocessed to remove the radioactive fission products. It is estimated that if the spent nuclear fuel were reprocessed, 30 per cent less uranium ore would need to be mined for a given amount of power.

APPLICATIONS

Before the advent of nuclear energy, uranium had some practical uses. It had been suggested for filaments of lamps. A small tube of uranium dioxide, UO_2 , connected in series with the tungsten filaments of large incandescent lamps used for photography and motion pictures, tends to eliminate the sudden surge of current through the bulbs when the light is turned on, thereby extending their life. Compounds of uranium such as uranyl nitrate have been used in photography for toning and in the leather and wood industries as stains and dyes. Uranium salts have been used as mordants of silk or wool. In making special steels, a little ferrou uranium has been utilized, but its value is questionable in this application. Such alloys have not proved commercially attractive.

In the production of ceramics, sodium and ammonium diuranates have been used to produce colored glazes. It has been used as a coloring agent for glass, in which it produces a yellow-green color (vaseline glass). Uranium carbide has been suggested as a good catalyst for the production of synthetic ammonia. Uranium salts in small quantities are claimed to stimulate plant growth, but large quantities are clearly poisonous to plants. Uranyl acetate is used in dry copying inks, as a bacterial oxidation activator, and as a reagent in analytical chemistry. Because of its great density, the metal is used in inertial guidance systems, counterweights and ballast, and as a shielding material.

Only with the advent of controlled nuclear fission in 1942 did uranium become an important commodity. By far the most important use of uranium lies in its application for nuclear energy. This use, in fact, has so increased the value of uranium as to eliminate its use for many of the applications mentioned above. Uranium oxide, enriched with U-235, is the fuel used in nuclear reactors.

OCCURRENCE IN GROUND AND SURFACE WATER

SOURCES

Uranium occurs in ground and surface water both naturally and as a result of government activities such as uranium mining and milling and nuclear research. Ground water contamination from uranium mining and milling operations generally results from the infiltration of mine, mill, and other plant effluents. The discharge of mine effluents to streams and seepage from tailing ponds has also caused ground water contamination. Seepage from stockpiled mill tailings may also contribute uranium to the ground water and the release of radionuclide contaminants from disposal sites for uranium mill tailings has received growing attention from federal regulatory agencies (Generic Environmental Impact Statement on Uranium Milling, U.S. Nuclear Regulatory Commission, NU-REG-0511, 1979).

ABUNDANCE

The relative abundance of the three uranium isotopes in water can vary somewhat from the relative abundance of the isotopes in crustal materials, although even in those cases U-238 remains by far the predominant isotope present by weight. The activity of a given mass of uranium (i.e., the number of alpha emissions per unit time) depends upon the amount of each isotope present. The greater the relative abundance of the more rapidly decaying U-234 and U-235, the higher the activity will be.

CHEMICAL FORM/WATER pH

A study of radioactivity in water, both naturally occurring and artificially produced, revealed that the chemistry and the geologic distribution of uranium are such that identifiable concentrations occur in most waters (R.C. Scott and F.C. Baker, *Data on Uranium and Radium in Ground Water in the U.S.—1954 to 1957*, U.S. Geological Survey Professional Paper 426, U.S. Government Printing Office, 1962.) Uranium and radium may often occur together in natural waters.

When exposed to more oxidizing conditions near the Earth's surface, the uranium-containing minerals and the inter granular phases in igneous rocks are readily oxidized to the highly soluble +6 valence state, and uranium is mobilized in surface water and ground water. Geologists theorize that in the oxygen-free atmosphere of early Precambrian time (more than 2.3 billion years ago) oxidation did not occur, and uraninite and brannerite grains accumulated as detrital placer deposits in Precambrian quartz-pebble conglomerates. Large uranium resources of this type, which may also contain gold, are found in Canada, South Africa, and Brazil.

Much of the oxidized uranium in solution ultimately reaches the oceans. Although the uranium in sea water amounts to only 0.002 parts per million, it may be selectively removed and incorporated in marine phosphorite deposits, adsorbed by clay minerals, or incorporated in the carbonate skeletons of organisms such as corals. Marine phosphorites constitute large uranium resources in the U.S., Africa, Brazil, and the Mediterranean region. In Florida, these low-grade deposits are mined extensively for their phosphate, which makes recovery of the uranium feasible. Some lignites and marine black shales also contain enough uranium to be considered resources.

Uranium in water can occur both in dissolved forms and attached to suspended particles. According to Ron Wilhelm, Section Chief, EPA Office of R&D, Radionuclide Studies, one of the major problems with the use of removal technologies such as ion exchange is that their use is based on the assumption that all of the uranium is in a soluble form. He feels that this is not a valid assumption because uranium adsorbs onto colloidal clay particulates (i.e., facilitated transport) that are not trapped by the ion exchange process.

Another major issue when evaluating water-treatment technologies is the chemical form of the uranium, which can be either dissolved in the water or adsorbed to colloidal clay particles. The predominant species of uranium present in water involve the uranyl ion, UO_2^{2+} , which forms stable complexes with phosphate and carbonate. Jonathan Blount, a geochemist for Roy F. Weston (a consulting firm), indicates that uranium is present as the free uranyl ion only at lower pHs (less than 5). At typical drinking water pHs (6-10), it is present as uranyl carbonate. According to the EPA's Tom Sorg, the soluble carbonate complexes that are the predominant anion species present in natural waters are primarily $\text{UO}_2(\text{CO}_3)_2^{2-}$ and $\text{UO}_2(\text{CO}_3)_3^{2+}$. At higher pHs and in carbonate-free water, the following cationic hydroxide complexes can be formed: $\text{UO}_2(\text{OH})^+$, $(\text{UO}_2)_2(\text{OH})_2^{2+}$, and $(\text{UO}_2)_3(\text{OH})_5^+$. Pacific Northwest Laboratory has done some work on geochemical speciation modeling that may help address this issue. Note, however, that all analytical test results obtained by KEI report uranium in mg/L or pCi/L but do not indicate the chemical form.

STANDARDS, DETECTION, AND MEASUREMENT

In addition to comparing results against background levels for substances in the environment, environmental monitoring results are often compared to standards or guidelines. These standards set concentration limits for specific substances in a medium. According to the *Fernald Environmental Report for 1992*, standards and guidelines are always set lower than the lowest concentration known to cause illness or injury to humans or the environment. (NOTE: The use of the word **always** in this sentence is misleading; it is more accurate to use the word **theoretically**. The EPA now considers treatment cost versus the benefit to society as a major factor when setting these guidelines.)

U.S. EPA is responsible for setting standards for substances in drinking water throughout the U.S. National Primary Drinking Water Standards are enforceable by federal law. However, in the absence of a U.S. EPA standard for a particular substance, guidelines are set by other agencies such as DOE and the Nuclear Regulatory Commission. These guidelines, however, are only applicable to DOE- or NRC-governed sites.

In 1990, the only standard for uranium in drinking water was a DOE guideline of 30 parts per billion or 20 pCi/L. Past site reports have used this reference for comparison. However, in 1991, U.S. EPA proposed a standard for uranium in drinking water of 20 ug/L (20 ppb) or 13.5 pCi/L.

Usually, uranium levels in water and other environmental samples are measured and reported only in terms of total uranium by mass, without specification of either the chemical form(s) or the relative abundance of the isotopes present. It is possible to estimate the corresponding radioactivity for these data by applying an "activity-to-mass" conversion factor. Frequently, a conversion factor of 0.68 pCi/ug (assumes that the three isotopes are present at levels corresponding to the crustal abundance percentages) is used to estimate the activity of uranium in a sample that has been measured as total uranium by mass.

However, that assumption does not appear to be valid for uranium in water and the actual factor is higher than 0.68 pCi/ug because of the shorter half-life of U-234.

In drinking water, as it is regulated by EPA, the determination of concentrations of natural radioactivity begins with the measurement of the gross alpha particle activity which, using current analytical techniques, measures the total of all alpha emitters except radon. This measurement is used as a screening technique. If the gross alpha particle activity is less than 5 pCi/L, the uranium concentration is not of concern. If the gross alpha is greater than 15 pCi/L, further tests to determine the uranium concentration should be made. The first step in the determination of natural radioactivity is to measure uranium activity and to subtract its activity from the gross alpha particle activity and determine whether it is greater or less than 15 pCi/L. Uranium activity of 10 pCi/L is equivalent to approximately 0.015 mg/L of uranium.

CHAPTER 4: THE NEED FOR URANIUM-REMOVAL TECHNOLOGIES: THE URANIUM-CONTAMINATED-WATER MARKET

U.S. OVERVIEW

According to *Cleaning Up the Nation's Waste Sites: Markets and Technology Trends* (U.S. EPA, Solid Waste and Emergency Response, EPA 542-R-92-012, April 1993), the national cleanup market is divided into eight segments: Department of Energy (DOE), National Priorities List (NPL or Superfund), Resource Conservation and Recovery Act (RCRA) corrective action, Underground Storage Tanks (UST), Department of Defense (DOD), other federal agencies, states, and private parties. Each of the eight markets has a substantial amount of work left to accomplish. Some programs expect to take 30 years to complete the remediation of known sites. Most of these programs will cost tens of billions of dollars, while the DOE cleanup may cost hundreds of billions. Contaminants common to most of these programs include solvents, petroleum products, and metals. Examples of specialized wastes include munitions and explosives at DOD sites and radioactive material at DOE installations. This section provides an overview of the number of U.S. sites where cleanup activities are being undertaken and the important issues related to these sites.

DEPARTMENT OF ENERGY

DOE is responsible for cleaning up more than 100 major installations and other locations in 33 states and Puerto Rico under its Environmental Restoration Program. Most of the cleanup effort is occurring at 64 DOE installations and other locations managed under the Remedial Actions Program (RAP).

NATIONAL PRIORITIES LIST: SUPERFUND

Superfund is a federal program, administered by EPA under CERCLA (as amended) to clean up the nation's worst abandoned hazardous waste sites. Currently, over half of all investigations and almost 75 per cent of all cleanups are being implemented by responsible parties, with EPA or state oversight. EPA's database lists 36,814 potentially hazardous sites. Of these, 1,235 sites are listed on the National Priorities List (NPL or Superfund). Superfund remedies call for the treatment of waste on-site and treatment of soil without excavation.

At the Superfund sites, volatile organic compounds (VOCs) are the most common contaminant groups, followed by metals, and semi-volatile organic compounds (SVOCs). Chlorinated VOCs are by far the most common organic contaminant, followed by non-chlorinated VOCs, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), and phenols. The most common metal is lead, followed by chromium, arsenic, and cadmium. EPA estimates that 80 per cent of NPL sites will need remediation of contaminated ground water, 74 per cent for soil, 15 per cent for sediments, and 10 per cent for sludge.

About 26 million cubic yards (indicated by EPA to be a conservative estimate) of soil, sludge, and sediment need to be cleaned up at the Superfund sites, which includes 20.5 million cubic yards of waste containing metals alone or in combination with other contaminants; 13.9 million cubic yards of VOCs alone or in combination with other contaminants; and 7.25 million cubic yards of SVOCs. The largest quantities of contaminated material are found at

sites used to manufacture primary metal products and metal plating sites--14 million and 8.9 million cubic yards, respectively.

The greatest need for new technologies at Superfund sites appears to be for metals in soil and treatment of ground water in place, without pumping to the surface.

RESOURCE CONSERVATION AND RECOVERY ACT

Approximately 5,100 hazardous waste treatment, storage, and disposal facilities (TSDFs) are potentially subject to corrective action under the Resource Conservation and Recovery Act (RCRA). Approximately 80,000 pre-existing "solid waste management units" are located at TSDFs. Between 1,500 and 3,500 of the regulated TSDFs will require corrective action.

Some of the most prevalent wastes, many of which are similar to those found at Superfund sites, are corrosive and ignitable wastes, heavy metals, organic solvents, electroplating waste, and waste oil.

The site owners or operators are responsible for the necessary corrective action, with oversight by EPA or a state. One EPA analysis suggests that the weighted average cost per facility is \$7.2 million. However, this is likely to change when final regulations are issued.

UNDERGROUND STORAGE TANK

Underground Storage Tanks (USTs) containing petroleum products or hazardous chemicals are also regulated under RCRA. Approximately 91 per cent of USTs contain petroleum products (66% of which are gasoline and 21% diesel fuel) and 2 per cent contain hazardous materials.

Approximately 295,000 UST sites, containing at least 56 million cubic yards of soil and debris, require cleanup. There is an average of almost three USTs per site. Studies indicate that the cost to clean up one site ranges from \$2,000 to over \$400,000. Tank owners are responsible for remediation under state UST programs.

DEPARTMENT OF DEFENSE

DOD is responsible for the cleanup of facilities contaminated as a result of training, industrial, or research activities. Policy is determined centrally under the Defense Environmental Restoration Program (DERP), but each service is responsible for its own installation. DOD has identified 17,660 potentially contaminated sites located at 1,877 DOD installations and 6,786 formerly used defense sites (FUDs). Of these, 7,000 will require cleanup.

The most common contaminants are similar to those at non-defense industrial facilities: petroleum products, solvents, metals, pesticides, and paints. Some sites also contain more unusual wastes, such as unexploded ordnance or low-level radioactive materials.

The following are DOD's estimates of the typical quantities of contaminated soil for 9 of its 20 standard site categories, which range from 500 to 9,500 cubic yards of contaminated soil per site: disposal pit/dry wells (2.2 million cubic yards), storage areas (2.1 million cubic yards), underground storage tanks (1.6 million cubic yards), and fire/crash training areas (1.2 million cubic yards).

OTHERS

Other federal agencies, such as the Departments of Agriculture and Interior, are responsible for cleaning up waste sites on property owned or formerly owned by agencies. At least 350 sites have been identified by 16 agencies as needing remediation. Sites vary from illegal drug operations to landfills and abandoned mines.

States are responsible for assessing and cleaning up sites not being addressed by the federal Superfund nor the UST and RCRA corrective action programs. Many states have created cleanup programs patterned after the federal Superfund program. Three states—New York, New Jersey, and Michigan—account for about 80 per cent of available state Superfund funds. EPA estimates that over 19,000 state sites require additional evaluation or action beyond a preliminary assessment. Wastes at these sites are typical of industrial facilities and include organic chemicals, metals, and solvents.

In addition to sites remediated under state and federal programs, an unknown number of sites are being remediated independently by the private sector. These cleanups result from efforts of companies to limit their potential future liabilities or from new requirements for environmental evaluations as a prerequisite for real estate transactions. Because these cleanups are not conducted under a specific federal or state cleanup program, no information is available on the number of sites or the amount of remediation work that may be needed.

DEPARTMENT OF ENERGY

According to the EPA (EPA 542-R-92-012, April 1993), assessment and characterization activities have yet to be completed at nearly two-thirds of the installations, including most of the major installations such as Rocky Flats, Colorado; Oak Ridge Reservation, Tennessee; Savannah River, South Carolina; and Hanford Reservation, Washington. The EPA reports that the total number of identified DOE sites grows as assessment and characterization activities continue. The DOE, however, reports that the number of identified sites has stabilized.

CONTAMINATED SITES

At the time of the EPA study, 23 DOE sites on 16 installations and other locations were listed on the NPL. DOE has lead responsibility in the cleanup of these sites. DOE is also involved in the remediation of four other NPL sites--Maxey Flats, Kentucky; Shpack Landfill, Massachusetts; South Valley Site, New Mexico; and Monticello Uranium Mill, Utah. These are EPA-lead sites for which DOE shares financial responsibility with other responsible parties. Note that DOE installations tend to be much larger than most DOD and other non-DOE Superfund sites.

Many installations contain more than one area of contamination, with each area requiring different types of remedies. DOE estimates that remediation may be required at about 4,000 individual contaminated areas or sites covering more than 26,000 acres at these DOE installations and non-DOE sites. Based on estimates for a small number of installations, the quantity of contaminated material at individual sites in the RAP can range from 200 to 3.3 million cubic yards.

Table 4 lists some of the DOE installations (based on EPA data) that may potentially need to be remediated for uranium contamination or are currently under remediation. Note that a much more detailed analysis of the DOE sites (based on DOE data, which are probably more accurate than the EPA data covered below) is presented in Table 4. In each of the cases listed below, KEI believes uranium is a ground water or soil contaminant. This list includes: 1) sites where uranium contamination is definite, 2) those where low-level radioactive (rad) waste and/or mixed waste (which may include uranium) are present, and 3) sites that have not yet been characterized that may be contaminated with uranium. Soil is included in this listing because of the potential for secondary-waste cleanup applications and future ground water contamination as a result of leaching.

TABLE 4
POTENTIAL URANIUM-CONTAMINATED DOE INSTALLATIONS
(BASED ON EPA DATA)

DOE INSTALLATION	STATE	RELEVANT MATRIX	TYPE OF WASTE
Aliquippa Forge*	PA	Soil	Uranium
Argonne National Laboratory--West	ID	Soil	Mixed waste
Argonne National Laboratory--East	IL	Soil, ground water	Low-level mixed wastes, low-level radioactive waste
Ashland Oil Co. #1 and #2	NY	Soil	Uranium
Brookhaven National Laboratory	NY	Soil, ground water, surface water	Not listed
Center for Environmental Research	PR	Not initiated	Not initiated
Central Nevada Test Site	NV	Not initiated	Not initiated
Colonie Interim Storage	NY	Soil	Uranium
Du Pont & Co.	NJ	Soil	Uranium
Energy Technology Engineering Center	CA	Soil, ground water	Low-level radioactive waste
Fernald Environmental Management Project	OH	Soil, ground water	Low-level radioactive waste
Gassbuggy Site	NM	Not initiated	Not initiated
Gnome-Coach Site	NM	Not initiated	Not initiated
General Motors	MI	Soil	Low-level radioactive waste
Hazelwood (Latty Ave.)*	MO	Soil	Uranium
Inhalation Toxicology Research Institute	NM	Soil, ground water	Low-level radioactive waste
Kauai Test Facility	HI	Unknown	Unknown
Linde Air Products	NY	Soil	Uranium
Los Alamos National Laboratory	NM	Soil	Low-level radioactive waste
Mallinckrodt, Inc. (St. Louis, downtown)	MO	Soil	Uranium

DOE INSTALLATION	STATE	RELEVANT MATRIX	TYPE OF WASTE
Maywood	NJ	Soil	Uranium
Middlesex Sampling Plant*	NJ	Soil	Uranium
Mound Plant	OH	Soil, ground water	Radioactive waste
New Brunswick Laboratory	NJ	Soil	Uranium
Niagara Falls Storage Site	NY	Soil	Uranium
Oak Ridge Reservation	TN	Soil, ground water, surface water	Uranium
Pinellas Plant	FL	Soil, ground water	Low-level wastes
Princeton Plasma Physics Laboratory	NJ	Soil, ground water	Unknown
Rocky Flats Plant	CO	Soil, ground water, surface water	Low-level mixed wastes
Seaway Industrial Park	NY	Soil	Uranium
Shoal Site	NV	Not initiated	Not initiated
St. Louis Airport Site	MO	Soil	Uranium
St. Louis Airport Storage	MO	Soil	Uranium
Vicinity Properties			
Ventron*	MA	Soil	Uranium
W.R. Grace & Co.	MD	Soil	Uranium
Wayne/Pequannock	NJ	Soil	Uranium
Weldon Spring	MO	Soil, ground water	Uranium

* In progress

Source: Compiled by KEI from *Cleaning Up the Nation's Waste Sites: Markets and Technology Trends*, U.S. EPA, Solid Waste and Emergency Response (OS-110W), EPA 542-R-92-012, April 1993.

EPA data on NPL sites without RODs is also available, but is not summarized here. This data did not indicate specifically whether uranium is a contaminant; it only gave the general contaminant classification, "metal."

Thirty-five of the installations currently requiring remediation by DOE are being addressed under two specialized subsets of the RAP: the Uranium Mill Tailings Remedial Action (UMTRA) and the Formerly Utilized Sites Remedial Action Program (FUSRAP).

Uranium Mill Tailings Remedial Action

The UMTRA Project provides for stabilizing and controlling uranium mill tailings at inactive mills. The tailings resulted from the production of uranium between the early 1950s and the early 1970s. In addition to the primary UMTRA sites, many private residential and commercial properties are being remediated under the project. These "vicinity" properties are contaminated because tailings were used as fill for construction and landscaping, or were carried by the wind to open areas. DOE is working to complete surface remediation work at all the remaining sites by 1998 when Congressional authorization for the project expires. In addition, ground-water restoration is required at some sites and is expected to begin in 1998 and continue through 2014. Refer to Chapter 3, which discusses uranium processing. Table 5 lists uranium mill sites in the U.S.

As of December 1988, of 27 uranium mills in the U.S. licensed by the NRC or Agreement States, 4 were operating (all currently decommissioned according to Harry Anthony of URI, Inc.), 8 were on standby, 14 were being decommissioned, and 1 had been built but never operated. The 4 operating mills had a capacity of 9,600 tons of ore per day. In 1981, when 21 mills were operating, approximately 50,000 tons of ore per day were processed. The 8 mills on standby could resume operations, but the 14 mills that are being decommissioned will never operate again. The status descriptions used in this document are not necessarily the same as the license definitions. Umetco's Uravan mill is listed as on standby; however, since the mill's tailings impoundment is being reclaimed, the mill is considered to be decommissioned for the purpose of this assessment. Ownership of a few of these mills has changed since 1988 as well.

TABLE 5
URANIUM MILLS LICENSED BY THE U.S. NUCLEAR
REGULATORY COMMISSION AS OF DECEMBER 1988

LICENSEE	COMMON NAME	LOCATION	RATED ^a CAPACITY	STATUS ^b	PROCESS ^c
American Nuclear Corp.		Gas Hills, WY	950	3	1,5
Anaconda	Bluewater	Bluewater, NM	6000	3	1,3
Atlas Minerals	Moab	Moab, UT	1400	3	2,3
Bear Creek Uranium Co.	Bear Creek	Converse Co., WY	2000	3	1,3
Bokum Resources		Marquez, NM	2000	4	1,3
Chevron Resources Co.	Panna Maria	Panna Maria, TX	2500	1 ^d	1,3
Conoco-Pioneer		Falls City, TX	3400	3	1,3
Cotter Corp.	Canon	Canon City, CO	1200	2	1,3
Dawn Mining Co.	Dawn	Ford, WA	450	3	1,3
Exxon	Ray Point	Ray Point, TX	---	3	---
Exxon Minerals	Highland	Converse Co., WY	3200	3	1,3
Homestake Mining Co.	Homestake	Grants, NM	3400	1 ^d	4,6
BP American	L-Bar	Seboyeta, NM	1600	3	---

LICENSEE	COMMON NAME	LOCATION	RATED ^a CAPACITY	STATUS ^b	PROCESS ^c
Minerals Exploration	Sweetwater	Sweetwater Co., WY	3000	2	1,3
Pathfinder Mines	Lucky Mc	Gas Hills, WY	2500	2	1,3
Pathfinder Mines	Shirley Basin	Shirley Basin, WY	1700	1 ^d	1,3
Petrotomics	Petrotomics	Shirley Basin, WY	1500	3	1,3
Plateau Resources	Shootaring	Shootaring Cnyn, UT	750	2	1,3
Quivira	Ambrosia	Ambrosia Lake, NM	---	2	---
Rio Algom	La Sal	La Sal, UT	750	2	4,6
TVA	Edgemont	Edgemont, SD	---	3*	---
Umetco Minerals Corp.	Gas Hills	Gas Hills, WY	1400	3	1,5
Umetco Minerals Corp.	White Mesa	Blanding, UT	2000	1 ^d	1,7
Umetco Minerals Corp.	Uravan	Uravan, CO	1300	2**	1,3
UNC Mining & Milling	Church Rock	Church Rock, NM	3000	3	1,3
Western Nuclear Inc.	Split Rock	Jeffrey City, WY	1700	3	1,3
Western Nuclear Inc.	Sherwood	Wellpinit, WA	2000	2	1,3

Status Code:

1 = Facility operating as of 12/88.

2 = Facility on standby.

3 = Facility is, or is being, decommissioned.

4 = Facility built, never operated.

Process Codes:

1 = Acid leach

4 = Carbonate leach

7 = Column ion exchange

2 = Alkaline leach

5 = Eluex

3 = Solvent extraction

6 = Caustic precipitation

Data Sources:

(a) Tons of ore/day (Jo81).

(b) Personal communication with Dale Smith, USNRC, Denver, Colorado.

(c) From Ri81.

(d) Harry Anthony (URI, Inc.) indicated that these mills have been decommissioned.

* Decommissioning and long-term stabilization complete.

** Per public comment by Umetco, the mill is being maintained on standby although the tailings impoundment is being reclaimed.

A reviewer of this report questioned why the uranium mill at Lakeview, Oregon is not listed.

Source: *Risk Assessments-Environmental Impact Statement-NESHAPS for Radionuclides, Background Information Document, Vol.2*, U.S. EPA, Office of Radiation Programs, EPA/520/1-89-006-1, Sept. 1989.

Formerly Utilized Sites Remedial Action Program

The Formerly Utilized Sites Remedial Action Program (FUSRAP) involves the cleanup or control of sites owned or leased by DOE or other government agencies as well as privately owned commercial and residential property where there is residual radioactive material. Radioactive-material-contaminated buildings at more than 20 sites and about 1.6 million cubic yards of soil need to be remediated under FUSRAP. Decontamination and Decommissioning (D&D) involves about 500 facilities slated for cleanup by 2019 and as many as 500 additional facilities.

DOE PROBLEM UNIT DESCRIPTIONS

The problem descriptions presented in this section were gathered through the following keyword searches of the *Technology Needs Crosswalk Report* (1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993): "uranium and surface water," "surface water and rad and metals," "uranium and ground water," "ground water and rad and metals," "uranium and soil," "soil and rad and metals," "biotechnology," "ion exchange," "membrane," "precipitation," "reverse osmosis," and "uranium and disposal." A search on the word "Germany" was also performed, but it was not one of the keywords included in the database.

The "hits" are listed below by keyword. Table 6 groups the hits by Field Office. Table 7 lists all of the keywords that apply to each of the technologies. The numbering system used in this section is consistent with that used in the *Crosswalk* database. For example, POR004 refers to problem unit 4, which is monitored by the Oak Ridge Field Office. (Refer to Appendix 1 for a list of the field office abbreviations.) In the listing below, the numbers in parentheses indicate which other searches include that particular problem unit or technology. For example, POR004 can be found under "uranium AND surface water" (Search 1A) and "surface water AND rad AND metals" (Search 1B).

1A. Uranium AND surface water

POR004 (1B), 015 (1B), 028, 039 (1B)

1B. Surface water AND rad AND metals

PAL014

PCH026, 030 (2B), 051 (2B)

POR004 (1A), 015 (1A), 023, 039 (1A)

PSR021A

2A. Uranium AND ground water

PAL001

PFN045 (2B), 054

PNV020 (2B,6)

POR002 (2B), 017, 022 (2B), 029 (2B,4,6), 030 (2B), 036 (2B)

PRF003 (2B), 006 (2B), 010 (2B)

PRL017 (2B), 029 (2B)

2B. Ground water AND rad AND metals

PAL001 (2A)
PCH024, 026, 027, 030, 035, 037, 051
PFN045 (2A), 054 (2A)
PID004, 005, 013, 022
PNV020 (2A,6), 021
POR002 (2A), 022 (2A), 029 (2A,4,6), 030 (2A), 031, 036 (2A)
PRF003 (2A), 006 (2A), 010 (2A), 014B, 016, 019
PRL017 (2A), 025, 029 (2A)
PSF010
PSR009, 011, 012, 015, 017, 023

3A. Uranium AND biotechnology

No problem unit hits--only technologies.

3B. Biotechnology

No problem unit hits--only technologies.

4. Uranium AND soil

PAL011, 012, 018, 047 (6)
PCH017
PFN040 (6), 043 (6), 044 (6), 051, 055 (6)
PID011
PNV019 (6)
POR001 (6), 003 (6), 009, 012, 015 (1), 021, 027 (6), 029 (2A,6), 032, 033 (6), 035, 037
PRF004, 009 (6), 011
PRL015, 016, 021, 023, 026 (6)
PSR011 (6), 016

4B. Soil AND rad AND metals

PCH024, 027, 030, 037, 051
PRF014
(Too many hits to list all)

5A. Uranium AND reverse osmosis

No problem unit hits--only technologies.

5B. Reverse osmosis

No problem unit hits--only technologies.

6. Uranium AND disposal

PAL047 (4)
PFN040 (4), 043 (4), 044 (4), 046, 047, 055 (4), 056
PNV019 (4), 020
POR001 (4), 003 (4), 006, 008, 011, 027 (4), 028, 029 (2A,4), 033 (4)
PRF004, 005, 009 (4)
PRL007, 014, 026 (4)
PSR011 (4)

7. Membrane

No problem unit hits--only technologies.

8A. Uranium AND ion exchange (No hits)

8B. Ion Exchange

No problem unit hits--only technologies.

9A. Uranium AND precipitation (No hits)

9B. Precipitation

No problem unit hits--only technologies.

10. Germany (No hits)

TABLE 6
PROBLEM UNIT SUMMARY

FIELD OFFICE	PROBLEM UNITS
Albuquerque	PAL001, 011, 012, 014, 018, 047
Chicago	PCH017, 024, 026, 030, 035, 037, 051
Idaho	PID004, 005, 011, 013, 022
Fernald	PFN040, 043, 044, 045, 046, 047, 051, 054, 055, 056
Nevada Test Site	PNV019, 020
Oak Ridge Operations	POR001, 002, 003, 004, 006, 008, 009, 011, 012, 015, 017, 021, 022, 023, 027, 028, 029, 029, 030, 031, 032, 033, 035, 036, 037, 039
Rocky Flats	PRF003, 004, 005, 006, 009, 010, 011, 014B, 016, 019
Richland	PRL007, 014, 015, 016, 017, 021, 023, 025, 026, 029
San Francisco	PSF010
Savannah River	PSR009, 011, 012, 016, 017, 021A, 023

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

TABLE 7
PROBLEM UNIT KEYWORD SUMMARY

PU ID	CROSSWALK KEYWORDS
PAL001	LLW, ammonia, automated, characterization, ex situ, ground water, in situ, metals, monitoring, nitrates, ponds, rad, treatment, uranium, wasteform
PAL011	LLW, TRU, automated, characterization, field operation, metals, mixed waste, monitoring, non-intrusive, organics, plutonium, rad, real-time, remote, soil, uranium
PAL012	LLW, PCB, automated, characterization, explosives, field operation, mercury, metals, mixed waste, monitoring, non-intrusive, oils, organics, rad, real-time, remote, soil, uranium
PAL014	LLW, TRU, access difficulty, automated, characterization, explosives, field operation, metals, mixed waste, monitoring, non-intrusive, organics, rad, real-time, remote, soil, surface water
PAL018	LLW, characterization, explosives, in situ, metals, mixed waste, plutonium, rad, soil, treatment, uranium
PAL026	LLW, burial grounds, characterization, containment, ground water, iron, manganese, metals, monitoring, organics, ponds, rad, sediments, surface water, tritium
PAL047	LLW, containment, disposal, explosives, metals, rad, retrieval, soil, uranium
PCH017	LLW, asbestos, burial grounds, characterization, metals, mixed waste, monitoring, rad, soil, thorium, uranium
PCH024	LLW, TRU, characterization, disposal, drums, ex situ, ground water, immobilization, metals, rad, separation, soil, stabilization, tanks, treatment, volume reduction
PCH026	LLW, burial grounds, characterization, containment, ground water, iron, manganese, metals, monitoring, organics, ponds, rad, sediments, surface water, tritium
PCH027	LLW, burial grounds, characterization, concrete, containment, ground water, metal objects, metals, monitoring, organics, rad, soil
PCH030	LLW, above ground, below ground, characterization, containment, disposal, drums, ex situ, ground water, metal objects, metals, monitoring, organics, ponds, rad, retrieval, sediments, soil, strontium-90, surface water, tanks, transportation, treatment, tritium
PCH035	LLW, PCB, TCE, ex situ, ground water, in situ, metals, mixed waste, organics, rad, retrieval, separation, treatment, volume reduction
PCH037	LLW, characterization, ground water, metals, organics, rad, soil, tritium
PCH051	LLW, characterization, ground water, metals, rad, soil, surface water
PFN040	LLW, automated, burial grounds, characterization, concrete, containment, disposal, ex situ, immobilization, metal objects, mixed waste, monitoring, rad, real-time, retrieval, separation, sludges, soil, stabilization, transportation, treatment, uranium, volume reduction, wasteform
PFN043	LLW, PCB, characterization, containment, disposal, ex situ, fly ash, immobilization, metals, organics, rad, retrieval, separation, soil, stabilization, treatment, uranium, volume reduction
PFN044	LLW, PCB, TCE, access difficulty, containment, disposal, field operation, in situ, metals, mixed waste, organics, rad, separation, soil, treatment, uranium, volume reduction
PFN045	LLW, TCE, containment, ex situ, field operation, ground water, metals, mixed waste, organics, rad, real-time, treatment, uranium

PU ID	CROSSWALK KEYWORDS
PFN046	D&D, LLW, asbestos, characterization, concrete, disposal, metal objects, rad, real-time, separation, uranium, volume reduction
PFN047	LLW, above ground, characterization, disposal, drums, metal objects, mixed waste, rad, real-time, separation, tanks, uranium, volume reduction
PFN051	HLW, LLW, berm, ex situ, field operation, immobilization, metals, rad, soil, stabilization, treatment, uranium
PFN054	LLW, ex situ, ground water, metals, organics, rad, retrieval, separation, treatment, uranium, volume reduction
PFN055	LLW, containment, disposal, ex situ, immobilization, rad, retrieval, soil, stabilization, treatment, uranium
PFN056	LLW, disposal, immobilization, metals, mixed waste, rad, separation, sludges, stabilization, uranium, volume reduction
PID004	LLW, TCE, ex situ, ground water, metals, mixed waste, organics, rad, treatment, tritium
PID005	LLW, ground water, metals, monitoring, rad, tritium
PID011	HLW, access difficulty, containment, immobilization, in situ, metals, mixed waste, nitric acid, plutonium, rad, soil, stabilization, sulfuric acid, treatment, uranium
PID013	LLW, ground water, immobilization, in situ, metals, mixed waste, rad, stabilization, treatment, tritium
PID022	LLW, TCE, ex situ, ground water, metals, organics, rad, treatment, tritium
PNV019	HLW, LLW, TRU, automated, characterization, containment, disposal, ex situ, field operation, immobilization, in situ, metals, mixed waste, monitoring, organics, rad, real-time, remote, retrieval, separation, soil, stabilization, treatment, uranium, volume reduction
PNV020	HLW, LLW, TRU, access difficulty, automated, characterization, containment, disposal, ex situ, field operation, ground water, immobilization, in situ, metals, monitoring, plutonium, rad, real-time, remote, retrieval, separation, stabilization, transportation, treatment, tritium, uranium, volume reduction, wasteform
PNV021	LLW, automated, characterization, disposal, ex situ, field operation, ground water, metals, mixed waste, monitoring, organics, rad, real-time, remote, treatment, tritium
POR001	LLW, PCB, TCE, TRU, access difficulty, burial grounds, characterization, containment, disposal, ex situ, field operation, in situ, metals, mixed waste, monitoring, oils, organics, rad, real-time, remote, retrieval, separation, soil, transportation, treatment, uranium, volume reduction
POR002	LLW, PCB, TCE, TRU, asbestos, automated, characterization, field operation, ground water, in situ, metals, mixed waste, oils, organics, rad, real-time, treatment, uranium
POR003	LLW, PCB, TCE, TRU, access difficulty, asbestos, automated, disposal, field operation, metals, mixed waste, oils, organics, rad, retrieval, soil, uranium
POR004	LLW, TCE, characterization, field operation, metals, monitoring, organics, rad, real-time, surface water, uranium
POR006	D&D, LLW, PCB, TRU, access difficulty, asbestos, automated, buildings, characterization, concrete, disposal, ex situ, field operation, in situ, metal objects, metals, mixed waste, oils, organics, rad, real-time, remote, retrieval, separation, transportation, treatment, uranium, volume reduction
POR008	D&D, LLW, PCB, TRU, asbestos, characterization, concrete, disposal, metal objects, organics, plutonium, rad, remote, tritium, uranium

PU ID	CROSSWALK KEYWORDS
POR009	LLW, PCB, automated, characterization, field operation, metals, non-intrusive, organics, rad, real-time, remote, soil, uranium
POR011	LLW, PCB, above ground, asbestos, automated, characterization, disposal, drums, field operation, mixed waste, monitoring, non-intrusive, organics, rad, real-time, remote, sludges, tanks, uranium
POR012	LLW, PCB, access difficulty, automated, characterization, field operation, metals, non-intrusive, organics, rad, real-time, remote, soil, uranium
POR015	LLW, PCB, above ground, above-ground debris, automated, characterization, concrete, drums, ex situ, field operation, metal objects, metals, mixed waste, monitoring, organics, ponds, rad, real-time, retrieval, sediments, sludges, soil, surface water, tanks, treatment, uranium
POR017	LLW, automated, characterization, field operation, ground water, monitoring, non-intrusive, organics, rad, real-time, remote, uranium
POR021	HLW, LLW, TRU, asbestos, characterization, containment, ex situ, field operation, immobilization, in situ, metals, organics, rad, remote, retrieval, soil, stabilization, treatment, tritium, uranium
POR022	HLW, LLW, characterization, field operation, ground water, metals, monitoring, organics, rad, separation, tritium, uranium, volume reduction
POR023	HLW, LLW, PCB, TRU, characterization, containment, field operation, immobilization, metals, monitoring, non-intrusive, rad, retrieval, sediments, stabilization, surface water, tritium
POR027	LLW, PCB, TCE, characterization, disposal, ex situ, field operation, in situ, metals, mixed waste, organics, rad, real-time, retrieval, soil, treatment, uranium
POR028	TCE, automated, containment, disposal, field operation, immobilization, in situ, monitoring, organics, real-time, retrieval, sediments, separation, stabilization, surface water, transportation, treatment, uranium, volume reduction
POR029	LLW, PCB, TCE, automated, burial grounds, characterization, containment, disposal, ex situ, field operation, ground water, immobilization, in situ, metals, mixed waste, monitoring, non-intrusive, organics, rad, remote, retrieval, soil, stabilization, treatment, uranium
POR030	BETX, LLW, TCE, automated, characterization, ex situ, ground water, in situ, metals, mixed waste, monitoring, non-intrusive, phthalates, plutonium, rad, real-time, treatment, uranium
POR031	BETX, DNAPL, LLW, automated, characterization, disposal, ex situ, ground water, in situ, metals, monitoring, non-intrusive, organics, phthalates, rad, real-time, treatment
POR032	LLW, PCB, characterization, containment, ex situ, immobilization, in situ, metals, mixed waste, monitoring, organics, ponds, rad, retrieval, sediments, separation, soil, stabilization, treatment, uranium, volume reduction
POR033	BETX, LLW, PCB, TCE, characterization, containment, disposal, ex situ, immobilization, in situ, metals, monitoring, organics, rad, retrieval, soil, stabilization, treatment, uranium
POR035	LLW, PCB, burial grounds, characterization, concrete, containment, creosote, metal objects, metals, mixed waste, non-intrusive, organics, rad, remote, sludges, soil, uranium
POR036	DNAPL, LLW, PCB, TCE, TRU, access difficulty, automated, bedrock, characterization, field operation, ground water, metals, nitrates, organics, ponds, rad, real-time, uranium

PU ID	CROSSWALK KEYWORDS
POR037	LLW, PCB, TCE, TRU, characterization, field operation, metals, monitoring, organics, rad, real-time, soil, uranium
POR039	LLW, PCB, automated, characterization, field operation, metals, monitoring, organics, rad, real-time, surface water, uranium
PRF003	LLW, TRU, characterization, ex situ, field operation, ground water, in situ, metals, monitoring, organics, ponds, rad, real-time, treatment, uranium
PRF004	LLW, TRU, americium, burial grounds, characterization, containment, disposal, ex situ, field operation, immobilization, metals, monitoring, organics, plutonium, ponds, rad, real-time, retrieval, soil, stabilization, transportation, treatment, uranium
PRF005	LLW, TRU, burial grounds, characterization, disposal, ex situ, field operation, metals, monitoring, organics, plutonium, rad, real-time, retrieval, transportation, treatment, uranium, waste
PRF006	LLW, TCE, TRU, americium, characterization, ex situ, field operation, ground water, in situ, metals, monitoring, organics, plutonium, ponds, rad, real-time, retrieval, treatment, uranium
PRF009	LLW, TRU, americium, characterization, containment, disposal, ex situ, field operation, immobilization, in situ, monitoring, plutonium, rad, real-time, retrieval, soil, stabilization, transportation, treatment, uranium
PRF010	D&D, LLW, TRU, characterization, ex situ, field operation, ground water, high security area, in situ, metals, mixed waste, monitoring, nitrates, organics, ponds, rad, real-time, treatment, tritium, uranium
PRF011	D&D, LLW, characterization, ex situ, field operation, high security area, in situ, metals, mixed waste, monitoring, nitrates, organics, ponds, rad, real-time, retrieval, soil, treatment, uranium
PRF013	burial grounds, characterization, ex situ, field operation, ground water, metals, mixed waste, monitoring, non-intrusive, organics, rad, real-time, retrieval, treatment, tritium
PRF014B	HLW, TRU, americium, characterization, ex situ, field operation, ground water, high security area, metals, mixed waste, monitoring, organics, plutonium, ponds, rad, real-time, retrieval, treatment
PRF016	LLW, TRU, characterization, ex situ, field operation, ground water, high security area, metals, mixed waste, monitoring, organics, ponds, rad, real-time, remote, treatment
PRF019	LLW, characterization, ex situ, field operation, ground water, metals, mixed waste, monitoring, organics, ponds, rad, real-time, remote, retrieval, treatment
PRL007	LLW, TCE, burial grounds, characterization, disposal, ex situ, immobilization, mixed waste, nitrates, non-intrusive, organics, pesticides, rad, real-time, retrieval, separation, stabilization, treatment, uranium, volume reduction, waste
PRL014	HLW, LLW, TRU, automated, below ground, characterization, containment, disposal, drums, ex situ, field operation, immobilization, in situ, metals, mixed waste, nitrates, nitrites, organics, phosphates, plutonium, rad, real-time, remote, retrieval, separation, sludges, stabilization, tanks, treatment, uranium, volume reduction, wasteform
PRL015	HLW, LLW, TRU, characterization, immobilization, in situ, metals, mixed waste, nitrates, non-intrusive, organics, plutonium, ponds, rad, real-time, soil, stabilization, treatment, tritium, uranium

PU ID	CROSSWALK KEYWORDS
PRL016	HLW, LLW, TRU, access difficulty, characterization, immobilization, in situ, metals, mixed waste, nitrates, non-intrusive, organics, pesticides, plutonium, rad, real-time, soil, stabilization, treatment, tritium, uranium
PRL017	HLW, LLW, characterization, ex situ, ground water, in situ, metals, nitrates, non-intrusive, organics, plutonium, rad, real-time, retrieval, treatment, tritium, uranium
PRL021	LLW, access difficulty, characterization, immobilization, in situ, metals, nitrates, non-intrusive, plutonium, rad, real-time, soil, stabilization, treatment, tritium, uranium
PRL023	HLW, LLW, TRU, burial grounds, characterization, immobilization, in situ, metals, nitrates, non-intrusive, organics, plutonium, rad, real-time, soil, stabilization, treatment, tritium, uranium
PRL025	LLW, TRU, access difficulty, ammonia, ground water, in situ, metals, mixed waste, monitoring, nitrates, organics, ponds, rad, sludges, treatment
PRL026	LLW, PCB, characterization, disposal, ex situ, immobilization, metals, non-intrusive, organics, pesticides, ponds, rad, real-time, retrieval, separation, soil, stabilization, treatment, uranium, volume reduction
PRL029	LLW, PCB, characterization, copper, ground water, in situ, metals, nitrates, non-intrusive, rad, real-time, retrieval, treatment, uranium
PSF010	LLW, ground water, in situ, metals, nitrates, organics, rad, treatment, tritium
PSR009	LLW, automated, characterization, ex situ, field operation, ground water, in situ, metals, mixed waste, nitrates, ponds, rad, treatment, tritium
PSR011	LLW, access difficulty, characterization, disposal, immobilization, metals, mixed waste, nitrates, non-intrusive, rad, real-time, remote, retrieval, soil, stabilization, tritium, uranium
PSR012	D&D, HLW, LLW, characterization, containment, field operation, ground water, in situ, metals, mixed waste, nitrates, non-intrusive, rad, real-time, remote, treatment, tritium
PSR014	LLW, TRU, automated, burial grounds, characterization, concrete, containment, disposal, field operation, ground water, immobilization, in situ, metal objects, metals, mixed waste, non-intrusive, organics, rad, real-time, remote, retrieval, soil, stabilization, treatment, tritium
PSR015	LLW, TRU, burial grounds, characterization, containment, ex situ, field operation, ground water, metals, monitoring, non-intrusive, organics, plutonium, rad, real-time, treatment, tritium
PSR016	LLW, americium, automated, characterization, containment, field operation, immobilization, in situ, inorganics, metals, mixed waste, monitoring, non-intrusive, organics, plutonium, ponds, rad, real-time, remote, separation, soil, stabilization, treatment, tritium, uranium, volume reduction
PSR017	LLW, characterization, containment, disposal, ground water, metals, monitoring, non-intrusive, ponds, rad, real-time, retrieval, sewer, soil
PSR021A	LLW, characterization, metals, organics, plutonium, rad, real-time, surface water
PSR023	HLW, LLW, TRU, access difficulty, automated, burial grounds, characterization, containment, drums, ex situ, field operation, ground water, in situ, metals, mixed waste, nitrates, non-intrusive, organics, ponds, rad, real-time, tanks, treatment, wetlands

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

Problem Overview

Table 8 presents an overview of the physical setting of each problem unit, the technologies available to treat the problem, problem uniqueness, and other comments from the Technology Needs Assessment (from the *Crosswalk* database) that KEI felt were relevant to this report.

**TABLE 8
DOE PROBLEM OVERVIEW**

PU ID	PHYSICAL SETTING	AVAILABLE TECHNOLOGIES	PROBLEM UNIQUENESS	COMMENTS
PAL001	Natural surface & subsurface soils, Seepage/evap. pond/trench/crib	Pump and treat, passive flushing with institutional control, ion exchange, precipitation	New program started to comply with EPA ground water regulations under 40CFR-192. Large volume.	Ion exchange or precipitation systems produce voluminous quantities of waste that contain RRM and hazardous metals (for ex situ cleanup).
PAL011	Not listed	All remediation technologies are viable.		Discrete sites include tanks, sumps, pits, chambers, dry wells, former reactor.
PAL012	Natural surface & subsurface soils.	*	Explosives widely scattered or concentrated in subsurface. Risk: near surface contamination subject to weathering, erosion, and intermittent run-off events.	
PAL014	Natural surface & subsurface soils. Hard to access/high-use areas	*	Past releases of discharge water has contaminated adjacent canyon sediments. Some concern by local environmental organizations. Risk: potential pathway via canyon erosion/run-off.	Much of the contamination is over the sides of canyons; soils and rocks are contaminated; sampling could involve hanging people over the side of the canyons to collect samples.
PAL018	Natural surface & subsurface soils.	*	Many sites on withdrawn BLM land, public would like returned for use. Volume high. Hundreds of acres must be surveyed to find a limited number of very small pieces of high explosives, U-238, Be, Pb.	Will start characterizing some sites in 1993, but not complete until 2001. Expect very large volumes. Better defined problem will reduce quantities to be treated.
PAL047	Not listed	*	Two sites potentially contain depleted uranium.	
PCH017	Burial ground/buried material	*	There is a potential for migration to ground and surface waters.	

PU ID	PHYSICAL SETTING	AVAILABLE TECHNOLOGIES	PROBLEM UNIQUENESS	COMMENTS
PCH024	Natural surface & subsurface soils, contained in tanks/drums	Extraction and above-ground treatment of potentially contaminated ground water.	Out of use storage tanks, operating underground lines from reactors.	
PCH026	Burial ground/ buried material	*	Impacted ground water is in a sole-source aquifer.	
PCH027	Burial ground/ buried material	*	Landfill is source of contamination of sole-source aquifer.	
PCH030	Natural surface & subsurface soils, contained in tanks/drums above ground, contained in tanks/drums below ground, seepage/evap pond/trench/ crib	Pump and treat by spray aeration.	Source of contamination of sole-source aquifer.	
PCH035	Not listed	Until identification and quantification of ground water contamination is complete, uncertain about appropriate techniques.	The physical proximity of potential sources complicates identification of a contaminant-source relationship.	
PCH037	Natural surface & subsurface soils	*		
PCH051	Natural surface & subsurface soils	*		
PFN040	Burial ground/ buried material	Vitrification, solidification, soil washing, and water treatment.		Large volume of waste.
PFN043	Not listed	*		
PFN044	Hard to access/ high-use areas	*		
PFN045	Natural surface & subsurface soils	Containment, pump and treatment.	Contaminated perched water is potentially a mixed waste.	Soil under buildings contains high levels of uranium.
PFN046	Not listed	*		
PFN047	Contained in tanks/drums, above ground	*		

PU ID	PHYSICAL SETTING	AVAILABLE TECHNOLOGIES	PROBLEM UNIQUENESS	COMMENTS
PFN051	Berm	Soil washing, solidification.	Dense clay soils may make contaminant removal difficult.	
PFN054	Natural surface & subsurface soils	Extract and treat with ion exchange or reverse osmosis.	Sole-source aquifer for drinking water.	
PFN055	Natural surface & subsurface soils	*	Volume of contaminated soil exceeds 1E6 cu. yd.	
PFN056	Not listed	*	Sludge will result from OU5-1 ground water treatment.	
PID004	Not listed	*	Depth to 61 meters.	
PID005	Not listed	*	Injection well is the source. Located in perched system that discharges to major aquifer. Volume approx. 12E6 gal.	
PID011	Hard to access/high-use areas	*	Contaminants associated with a high-level tank farm and are present in fractures in the underlying basalt.	
PID013	Not listed	*	Injection well. Rad activity of 375 Ci/yr. with an injection rate of 1,500,000 gal./day. Plugged.	
PID022	Not listed	Pump and treat using air stripping with carbon adsorption. Pump and treat technologies produce waste--some mixed in the filters. Disposal can be a problem.	The contaminated aquifer is the major source of municipal and agricultural water for central and southern Idaho. Volume is millions of acre-feet.	VOCs are currently being treated in the aquifer at Test Area North. Treatment technologies for the tritium and chromium may generate more waste and be a greater risk than not treating.
PNV019	Natural surface & subsurface soils	*	Large aerial extent (1350 sq. mi.), great depths (water table at 800-2000 feet), high concentrations, unknown regulatory driver (RCRA/CERCLA), ongoing nuclear testing.	

PU ID	PHYSICAL SETTING	AVAILABLE TECHNOLOGIES	PROBLEM UNIQUENESS	COMMENTS
PNV020	Natural surface & subsurface soils, hard to access/high-use areas	*	Deep water table 800-2000 feet, only 100 proposed wells to characterize 1350 sq. mi., regulatory agency acceptance of methods in question, complex geohydrology, no method for dealing with H3 in ground water. Multi-ple aquifers including thick regional carbonate aquifer.	While removal of contaminated water is technologically feasible, the volumes of pumping required and depths to water may preclude the feasibility of removal. Withdrawal of water with reinjection would not address problem. Injection of rad water is expressly prohibited in Nevada.
PNV021	Natural surface & subsurface soils	Pump and treat at Tatum Dome may be applicable but not at other sites.		
POR001	Burial ground/ buried material, hard to access/ high-use areas	Pump and treat.	Potential for radioactive contaminated vaults that are buried under buildings.	
POR002	Natural surface & subsurface soils	Pump and treat.		Pump and treat results in ground water that may/may not be disposable.
POR003	Natural surface & subsurface soils, hard to access/high-use areas	*	Adjacent to a river that has high recreational use.	
POR004	Not listed	*	Source for off-site contamination, which has resulted in lower property values downstream.	
POR006	Hard to access/high-use areas, buildings	*		
POR008	Not listed	*	High levels of TRU are located in areas of public access.	
POR009	Natural surface & subsurface soils	*	Near large populations, potential for contaminated coastal areas.	
POR011	Contained in tanks/drums, above ground	*	1000 drums of contaminated material.	

PU ID	PHYSICAL SETTING	AVAILABLE TECHNOLOGIES	PROBLEM UNIQUENESS	COMMENTS
POR012	Hard to access/high-use areas	*	600,000 cu. yd.	
POR015	Contained in tanks/drums, above ground; Seepage/evap pond/trench/crib, above ground debris	*	Quarry pit is a potential source of drinking water contamination.	
POR017	Natural surface & subsurface soils	*		
POR021	Not listed	*	Potential for explosive material. Trench locations & inventories unknown.	Need to keep ground water from buried wastes.
POR022	Not listed	*	Fractured flow, presence of illite which traps Cs137.	
POR023	Not listed	*	Potential for off-site migration of sediments.	
POR027	Not listed	*		
POR028	Natural surface & subsurface soils	*	Sediments have uranium concentrations 20 times background found in stream sediments.	
POR029	Burial ground/buried material	*	Pyrophoric U, PCB, oil, TCE, Tc-99 may have DNAPLs.	
POR030	Natural surface & subsurface soils	Pump and treat.	DNAPL identification and removal problems.	
POR031	Not listed	Pump and treat.	Separate phase moves without ground water gradient.	
POR032	Seepage/evap pond/trench/crib	*		
POR033	Natural surface & subsurface soils	*		
POR035	Burial ground/buried material	*	Pyrophoric materials, very sensitive areas, unique karst geologic environment.	

PU ID	PHYSICAL SETTING	AVAILABLE TECHNOLOGIES	PROBLEM UNIQUENESS	COMMENTS
POR036	Natural surface & subsurface soils, seepage/evap pond/trench/ crib, hard to access/high-use areas, bedrock	*	-	
POR037	Natural surface & subsurface soils	*		
POR039 PRF003	Seepage/evap pond/trench/ crib	Pump and treat with ion exchange for rads (which has yet to be proven for very low radiologic levels and sub-micron particle size) and UV/peroxide and/or activated carbon for organics.	Shallow water table with unlimited production capacity.	Analysis costs average \$3000 per sample for full suite radiologic analysis.
PRF004	Natural surface & subsurface soils, burial ground/buried material, seepage/evap pond/trench/ crib	*	Finely divided sub-micron particles of Pu, Am, U in soils.	Analysis costs \$3500 per media sample for full suite radiologic analysis.
PRF005	Natural surface & subsurface soils, burial ground/buried material	*	Burial trenches containing drums of U, Pu, and machining oil; pyrophoric uranium present; buried sanitary sewer sludge.	
PRF006	Seepage/evap pond/ trench/ crib	Pump and treat with granular activated carbon for removal organics and chemical precipitation/micropore filtration for radionuclides.	Pu, Am, U, TCE, PCE, CCl4	CCl4: 2300 ug/L; TCE > 10,000 ug/L; PCE > 10,000 ug/L; U: 28 pCi/L
PRF009	Natural surface & subsurface soils	*	Off-site windblown contamination, large aerial extent (several sq. mi.)	
PRF010	Seepage/evap pond/ trench/ crib, high-security area	Pumping to evaporation/distillation column.	12-15 acre plume.	

PU ID	PHYSICAL SETTING	AVAILABLE TECHNOLOGIES	PROBLEM UNIQUENESS	COMMENTS
PRF011	Seepage/evap pond/ trench/ crib, high-security area	*		
PRF013	Burial ground/ buried material	Same as PRF003.		
PRF014	Natural surface & subsurface soils, seepage/ evap pond/ trench/crib, high-security area	Same as PRF003. Costs are anticipated to be prohibitive.		
PRF016	Seepage/ evap pond/ trench/ crib, high-security area	Same as PRF003.		
PRF019	Seepage/ evap pond/ trench/ crib, high-security area	Same as PRF003.		
PRL007	Burial Grounds/ buried material	*		
PRL014	Contained in tanks/drums, below ground	*	HLW, LLW hazardous & mixed waste composed of sludges, sediments, & fluids from 149 single-shell tanks, 66 of which may leak. Significant amounts of Pu may exist. Explosion potential due to hydrogen build-up in tanks.	Volume: 37 million gallons. Greatest long-term risk to public health.
PRL015	Seepage/ evap pond/ trench/ crib, high-security area	*	87 cribs, 29 French drains, 63 trenches, 40 ponds, 9 injection wells, 66 leaking SSTs, 205 other spills, & 499 land disposal units.	Volume: 10E5 tons, vadose zone estimate 100-300 feet thick.
PRL016	Hard to access/ high-use areas	*	Same as PRL015.	
PRL017	Not listed	Pump and treat.	Several discrete plumes; may not contain mixed waste; depth to ground water 100-300 feet. Risk: Potential contamination of Columbia River.	Volume unknown, area 1 extent @ 300 sq km.
PRL021	Hard to access/ high-use areas	*	Same as PRL015.	

PU ID	PHYSICAL SETTING	AVAILABLE TECHNOLOGIES	PROBLEM UNIQUENESS	COMMENTS
PRL023	Burial ground/ buried material	*	Same as PRL015	
PRL025	Seepage/ evap pond/ trench/ crib, high- security area, hard to access/ high-use areas	*	Ground water, sludges, and sediments from 200 Area sanitary and lab sewers.	Low-level priority problem.
PRL026	Seepage/ evap pond/ trench/ crib	*	Soil & surface water from ponds, trenches, & cribs. One crib, 2 ponds, 30 leaks/spills.	Near Columbia River/city of Richland.
PRL029	Not listed	Pump and treat.	Problem not well defined. Aerial extent: U-1 sq. km, gross alpha=1.6 sq km, Co=0.6 sq km, nitrates=2.6 sq km.	In situ techniques that work are needed to speed up process & reduce costs if GW treatment is required.
PSF010 PSR009	Not listed Seepage/ evap pond/ trench/ crib	* Pump and treat (with reinjection). Pump and treat technology will not remediate H3 or nitrate, and possibly other contaminants, to concentrations appreciably less than the concentra- tions that natural flushing would achieve.	Volume is 110E06 gallons. Total volume of contami- nated ground water is approximately 3E9 gallons. Ground water discharges to onsite streams and deeper aquifers. Risks and hazards have been quantified and are estimated to be less than standard EPA points- of-departure.	May be difficult to inject water into low K water table unit, may increase vertical flow of contaminants into deeper units.
PSR011	Hard to access/ high-use areas	*	Hot spots from leads along a 4-mile sewer line, which is currently active.	
PSR012	Natural surface & subsurface soils	*	Contamination to 70 feet, vertical extent of ground water contamination unknown.	
PSR014	Burial ground/ buried material	*	Physically mixed waste. Area is 175 acres. Depth is 10-20 feet. GW is impacted.	
PSR015	Burial ground/ buried material	Pump and treat.		Contamination up to 200 feet deep. Exceeds normal range of immobilization technologies.
PSR016	Seepage/ evap pond/ trench/ crib	*	Volume—1000s of cubic yards	

PU ID	PHYSICAL SETTING	AVAILABLE TECHNOLOGIES	PROBLEM UNIQUENESS	COMMENTS
PSR017	Seepage/ evap pond/ trench/ crib	*	Ground water is contaminated.	
PSR021A	Not listed.	*		
PSR023	Natural surface & subsurface soils, burial ground/buried material, contained in tanks/ drums, seepage/ evap pond/ trench/ crib, hard to access/ high-use areas, wetlands	Pump and treat.	This problem encompasses several units. Whatever is done at one area must not adversely affect the other areas. It would be useful to build cleanup facilities near the area but must integrate the facility or make it modular so that it does not have to be rebuilt or moved several times.	

* Technologies relevant to this study were not discussed.

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

Contaminants

This section presents an overview of the problem units, including identification number and name, media, contaminants, and concentrations (where available). It also presents this information grouped by media (i.e., ground water, surface water, soil and related media, and other solid media). Contaminated soil and other solids are included here because KEI believes these materials will very likely contribute to the uranium contamination problem at some time in the future, either through ground water contamination or waste water that is contaminated through decontamination operations.

Overview

The information in Table 9 is listed alphanumerically by the Technology Needs Assessment Problem Unit (PU) ID number. Those not specifically listing uranium as a contaminant (indicated by an asterisk) are included because KEI believes they are likely to have it or are contaminated by components that may be potential candidates for removal by biosorbents.

The following DOE offices have defined problem units for uranium-contaminated ground waters: Albuquerque, Fernald, Nevada, Oak Ridge, Rocky Flats, Richland, and Savannah River. Only two offices have specified uranium-contaminated surface water problem units, Oak Ridge (onsite at K-25) and Savannah River. Although soil (and related materials such as sludge, sediments, and buried materials) contamination is outside the scope of this project, sites with uranium-contaminated soil may experience ground water contamination in the future, if they are not already. All of the offices that report soil contamination also have contaminated ground water with one exception—Idaho, which only reports soil contamination.

TABLE 9
DOE PROBLEM UNIT CONTAMINANTS

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PAL001	UMTRA	Ground water	Heavy metals, U, Ra, molybdenum, arsenic, cadmium, selenium, nitrate, and ammonia	Relatively low for metals; high for TDS, nitrates and ammonia at some sites
PAL011*	Discrete sites	Soil	Organics, LLW, TRU, metals	Unknown
PAL012	Firing Sites	Soil	Metals, LLW, depleted U, PCB, organics, high explosives (TNT, PBX, RDX)	Widespread low level
PAL014*	Outfalls	Soil	Unknown	Unknown
PAL018*	Explosives/weapons test sites	Soil	Metals	Locally high
PAL047	Firing Sites	Soil	HE, metals, and possibly depleted uranium	Unknown

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PCH017	Chemical Disposal Site	Soil	LLW, metals (Th, U); inorganics (Cr, Hg, Tl, Th, U, CN, Be); asbestos	Low
PCH024*	Waste Concentration Facility Storage Tanks and Underground Pipelines	Metals (debris), potentially contaminated soil and ground water	LLW. The tanks previously held sludge from BGRR with mixed fission products (Cs137 and TRU).	Unknown
PCH026*	Current Landfill	Ground water, surface water, sediments	LLW, Fe, Pb, Mn, H3	Drinking water standards exceeded for Fe, Pb, Mn, H3, trichloroethane
PCH027*	Former Landfill	Soil, ground water	LLW	Unknown
PCH030*	Hazardous Waste Management Area--Soil	Soil	LLW, organics	Unknown
PCH035*	Sewage Treatment Plant	Ground water	Cs137, Ce137, Sr90, Co58, heavy metals, PCB, TCA, TCE	Unknown
PCH037*	Upland Meadow Marsh	Soil, ground water	H3, possible organics and metals in soil	H3 below NYS standard
PCH051*	Recharge Basin HN	Soil, ground water, surface water	Radionuclides, metals	Not provided
PFN040	Operable Unit 1	Buried material	U, Th, F, sulfates	Low-level waste
PFN043	Fly Ash Pile/ Southfield	Other	U, Th, Ra, PCBs, Pb, and other heavy metals	Unspecified
PFN044	Operable Unit 3	Soil	U, minor Th, PCBs, DCE, TCE, Pb	Low level
PFN045	Operable Unit 5	Perched ground water	U, minor Th, PCBs, DCE, TCE, Pb	Mostly 50,000-200,000 ug/L range; as high as 697,000 ug/L
PFN046	Operable Unit 3	Metals (debris)	U, Th, asbestos	Low level
PFN047	Operable Unit 3	Metals (debris)	U, Th	Low level
PFN051	Berm Soils	Soil	U, Th, Ra likely, possible Pb, As, Cr, Cd	Undetermined
PFN054	Operable Unit 5--Environmental Media	Ground water	U, metals, organics	U: 200 ppb; organics: less than MCLs
PFN055	Operable Unit 5--Environmental Media	Soil	LLW (U, Th, Tc)	64 pCi/g onsite (mostly U); 13 pCi/g offsite (mostly U)

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PFN056	Operable Unit 5-- Environmental Media	Sludges	LLW (U, Th, Tc)	None given
PID004*	TSF Injection Well (WAG 1)	Ground water	TCE, lead, Sr90, H3	TCE>0.5 mg/L, lead<0.5 mg/L, Sr90<470 pCi/L, H3<10,000 pCi/L
PID005*	TRA Perched Water (WAG 2)	Ground water	Cr6, H3	>100 ug/L (Cr); H3 over water quality standards
PID011	ICPP--High-Level Waste Tank Farm (WAG 3)	Soil	Cr, Hg, Ag, Cd, Se, I129, Sr90, Cs137, U234, Pu239, Pu241, sulfuric and nitric acids	Locally very high
PID013	ICPP--Injection Well and Casing Failure (WAG 3)	Ground water	H3, Co60, Cs137, Sr90, Cr, Hg, Ba, Ag, Cd, acids	Unknown
PID022*	Snake River Plain Aquifer (WAG 10)	Ground water	I129, H3, Sr90, CCl4, Cr(+6), TCE	Localized contamina- tion exceeds maxi- mum contaminant levels (MCLs)
PNV019	Underground Nuclear Test Locations	Soil	Sr90, Zr95, Nb95, Ru103, Sb124, I131, Ba140, Ce141, Ce144, Nd147, Te132, Cs136, Np239, U237, Pb, Be, heavy metals, organics	Classified, not fully identified. Millions of curies
PNV020	Underground Nuclear Test Locations	Ground water	Sr90, H3, Co60, Te99, Ru106, Sb125, I129, Ce144, Cs137, U234, Pu239, Ra226, Kr85	Classified, not fully identified. Millions of curies
PNV021*	Eight Off-Site Testing Locations	Ground water	H3, Cr, solvents	H3>Drinking Water Standards (DWS)
POR001	Buried Material in the K-25 Area	Buried material	TCE, U, Tc99, PCB, Th232, solvents, oils, heavy metals, toluene, asbestos	Unknown
POR002	Ground Water in the K-25 Area	Ground water	TCE, Cr3, Cr6, PCB, As, U, Tc99, Th, asbestos, oils, toluene, solvents, heavy metals, pentachlorophenol	TCE up to 36 mg/L; Pb ND to <0.5 mg/L at location K-1407B

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
POR003	Soil in the K-25 Area	Soil	TCE, U, Tc99, Se, Cr3, Cr6, Th, PCB, PCP, As, oils, toluene, asbestos, solvents, heavy metals, radioactive PCB	18 to 22 ppm chromate
POR004	On-site surface Water in the K-25 Area	Surface water	TCE, U, Tc99, solvents, heavy metals	U up to 231 pCi/L; Tc99 up to 526 pCi/L. Both at location K-1407J
POR006	D&D for all ORO Gaseous Diffusion Plants	Masonry (debris)	U, PCB, Cr, Tc, Pb, As, PCP, dioxin, asbestos, daughter products, oils	U trace to Class C
POR008	D&D for the X-10 Area	Masonry (debris)	U, Pu, TRU, PCB, H3, asbestos, biological contaminated radioactive waste, various radionuclides, daughter products	Very high concentrations. Hot cells > 100 nCi/g
POR009	Soil at Non-New Jersey FUSRAP Sites	Soil	U, Ra226, Th232, PCB, Pb, As, heavy metals, some RCRA waste	PCB: none to 100 ppm; heavy metals: background to <10,000 ppm; 70% by volume total activity 5 to 1000 pCi/g; 30% by volume total activity 1,000 to 200,000 pCi/g
POR011	Drums of Material at Non-New Jersey FUSRAP Sites	Process sludges	U, Ra226, Pb, As, PCB, asbestos	Not provided
POR012	Soil at New Jersey FUSRAP Sites	Soil	Th232, U, Ra226, As, heavy metals, PCBs	80% of volume, total activity 1,000 pCi/g; 20% of volume, total activity 100 to 10,000 pCi/g. Heavy metals 1,000 to 10,000 ppm. PCBs: ND to 100 ppm
POR015	Weldon Spring RAP Raffinate Pit Sludge/Quarry Bulk Waste	Sludge	U, Th230, Ra, heavy metals, nitroaromatics, PCBs	U up to 6,000 pCi/g; nitroaromatics up to 20,000 mg/kg. Ra up to 3,600 pCi/g; Th230 up to 270,000 pCi/g; As up to 6,271 (average 500) mg/kg; and Pb up to 644 (average 130) mg/kg

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
POR017	Weldon Spring RAP Quarry Ground Water	Ground water	U, nitroaromatics	U ~ 5000 pCi/L (average for 1990), sample location SW-1008 quarry pond
POR021	Buried Materials at X-10	Buried material	Cs137, Sr90, H3, U, Co60, Hg, Pb, Cr, Cd, heavy metals, I129, Tc99, TRU, asbestos, radioactive biological waste, some solvents	Up to millions of Curies, high concentrations
POR022	Ground Water at X-10	Ground water	H3, Sr90, Cs137, U, Co60, I129, Tc99, Pb, Hg, Cr, Cd, some solvents	H3 and organics > DWS; up to 1 uC/L H3; Sr: 10,000 uC/L
POR023*	On-site Sediments at X-10	Sediments	Cs137, PCB, Co60, As, Hg, Sr90, H3, TRU	Cs: 100,000 pCi/g; PCB: low ppm to 100 ppm; As: 5 to 10 ppm; Hg: >100 ppm
POR027	Soil at Portsmouth	Soil	PCB, U, TCE, Pb, UF6, petroleum products, heavy metals	PCB>200 ppm; TCE>200 ppm
POR028*	On-site and Off-site Surface Water at Portsmouth	Surface water	TCE, other VOC	TCE trace to 50 ppm
POR029	Buried Materials at Paducah	Buried material	TCE, Tc99, U, PCB, radioactively contaminated PCB	Unknown
POR030	On-site Ground Water at Paducah	Ground water	TCE, Tc99, BETX, As, Phthalates, U, Pu, DNAPLs	TCE: trace to thousands of ppm, up to 10%; Tc99: trace to thousands pCi/L
POR031*	Off-site Ground Water at Paducah	Ground water	TCE, Tc99, BETX, As, Phthalates	TCE: trace to hundreds of ppm; Tc99: trace to hundreds of pCi/L
POR032	Sediments at Paducah	Sediments	PCB, U, Cr	Unknown
POR033	Soil at Paducah	Soil	TCE, PCB, U, BETX, Cr, radioactively contaminated PCB, DNAPL	Unknown

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
POR035	Buried Material at Y-12	Buried material	PCB, U, Hg, Pb, Cr, Cd, Th232, Be, pyrophoric U, chlorinated solvents, creosote, heavy metals	Unknown
POR036	Ground Water at Y-12	Ground water	TCE, PCE, U, PCB, DNAPLs, Hg, Cd, Ni, nitrate, chlorinated solvents	TCE up to 760 ug/L at S-2 pond site; variable for other contaminants
POR037	Soil at Y-12	Soil	PCB, Hg, U, Th, Be, Pb, Cd, Cr, TCE, DNAPLs, chlorinated solvents, heavy metals, long-chain hydrocarbons, creosote	Not available
POR039	Surface Water at Y-12	Surface water	Hg, U, PCB, Cl, Cd, Ni	Unknown
PRF003	Hillside 881	Ground water	VOC, U, Se, Sr90, gross Alpha	VOC: 50,000 ppb; U < 59 pCi/L; Se < 3.2 mb/L; Sr90 < 5.6 pCi/L; gross alpha < 319 pCi/L
PRF004	903 Pad	Soil	Pu, Am, U, chlorinated solvents, Se	Up to 500 pCi/g plutonium at the outside lip of the pad
PRF005	903 Pad	Buried material	Pu, U, organics, metals	Pu at 55 pCi/L, U at 1.2×10^6 pCi/L; VOC: 100s ppb
PRF006	903 Pad	Ground water	Pu, Am, U, TCE, PCE, CCl4	CCl4: 2300 ug/L; TCE > 10,000 ug/L; PCE > 10,000 ug/L; U: 28 pCi/L
PRF009	Off-site	Soil	Pu, Am, U	< 1 to 7 pCi/g (state standard 0.9 pCi/g)
PRF010	Solar Evaporation Ponds	Ground water	Nitrates, trace VOC, organics, H3, U, sulfates, some heavy metals	Nitrates: 6,000 mg/L; U: 100 pCi/L; H3: 7,000 pCi/L within impoundments
PRF011	Solar Evaporation Ponds	Soil	Organics, U, nitrates, metals, sulfates	10 to 1,000 times background for metals
PRF013*	Existing Operating Sanitary Landfill	Ground water	Solvents, tritium source	Unknown

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PRF014*	700 Area	Soil, ground water	Acids, algicides, bases, Be, CCl4, chromate, caustics, fluorides, hydrocarbons, metals, nitrates, organics, solvents, and radionuclides	Unknown
PRF016*	Original Process Waste Lines	Ground water	Low-level rad, TRU, hazardous organics, heavy metals, mixed waste	Not provided
PRF019*	Remaining Problem Units	Ground water	Low-level rad, hazardous organics, heavy metals, mixed waste	Not provided
PRL007	100 Area Burial Grounds	Buried material	H3, Cr, Sr90, Tc99, U, Hg, nitrates, PCB, TCE. Many other contaminants in lower concentrations	Not listed
PRL014	200 Area Single Shell Tanks (SSTs)	Sludges	Al, Cr, F, Fe, FeCN, Mn, Ni, nitrites, nitrates, phosphates, OH, Cs137, Sr/Y90, Pu239, Am241, U238, C14, Tc99, and I129; TRUs present	1.2E08 curies
PRL015*	200 Area Cribs/ Liquid Disposal Units/Vadose Zone	Soil	Extensive list of metals, inorganics and organics, and radionuclides	Locally very high
PRL016*	200 Area Cribs/ Liquid Disposal Units/Vadose Zone	Soil	Extensive list of metals, inorganics and organics, and radionuclides	Locally very high
PRL017*	200 Area Ground Water	Ground water	Extensive list of metals, radionuclides, inorganics and organics	Maximums: H3, 5.36E06 pCi/L; Co60, 400 pCi/L; Sr90, 5740 pCi/L; Tc99, 41000 pCi/L; I129, 25 pCi/L; U, 2191 pCi/L; nitrates, 1360 ug/L

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PRL021*	200 Area Piping	Soil	Extensive list of metals, radionuclides, inorganics and organics	Locally high
PRL023*	200 Area Burial Grounds	Buried material	LLW (may be some HLW or TRU)	Varies
PRL025*	200 Area Waste Waters	Sludges, ground water	Organics, metals, TRU, LLW, ammonia, nitrates, mixed waste	Unknown
PRL026	300 Area Ponds/Trenches/Cribs/Vadose Zone	Soil	U, other radionuclides, metals, trace PCB	Unknown
PRL029	300 Area Ground Water	Ground water	U, Cu, nitrates	U, 255 pCi/L; nitrates, 30 ug/L; gross alpha, 50 pCi/L (see 300-FF-5 work plan)
PSF010*	Shallow Ground Water	Ground water	C14, Cr, nitrate, H3, chloroform, Ra226, dichloromethane	Unknown
PSR009*	New F&H Seepage Basin Ground Water	Ground water	H3, nitrate, Cd, Pb, Hg, Cs137, Sr90, Na	H3 to 30,000 pCi/ml, nitrate to 400 mg/L, Cd at 20 ug/L, Pb at 450 ug/L, Hg to 14 ug/L, Cs137 to 218 pCi/L, Sr90 to 2700 pCi/L
PSR011	F&H Inactive Process Sewer Lines	Soil, ground water	H3, Cd, Pb, Hg, U234, U238, I129, Tc99, Cs137, Sr90, Ra226, Np237, nitrate, chromium	High (tritium)
PSR012*	H Area and F Area Tank Farms	Ground water	HLW, H3, Hg, Cr, Ba, Ag, Pb, Sr90, Cs137, Tc99	Above background
PSR014*	Burial Ground Complex	Buried material	Hg, C14 on resin, TRU, organics, LLW, Ag, Pb, Cd, waste oil, solvent rags, H3 in crucibles	Up to very high locally (total 19E06 curies)
PSR015*	Burial Ground Complex--Ground Water	Ground water	H3, VOCs, metals, Pu239, Cs137, Sr90, TRU, other radioisotopes	High H3; Low VOC and metals

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PSR016	Miscellaneous Basins	Soil	U, Cs, Sr, Ag, As, Ba, Cd, Cr, Pb, Se, Hg, SO ₄ , Zn, Ni, Mn, Mg, Am, Ra, Th, Cl, Cu, Na	Above background
PSR017*	R-Area Seepage Basin	Soil, ground water	Sr90, Cs137	2700 Ci disposed in 1954 through 1964; half-decayed
PSR021A	Site Streams	Surface water	Cs137, Sr90, Pu, Co60, H3 from permit outfall, U (natural), other radionuclides; heavy metals and possibly chlorinated organics	Low
PSR023*	General Separations Area--Ground Water	Ground water	High- and low-level rad, TRU, hazardous organics, heavy metals, mixed waste, nitrate, VOCs	Not provided

* Does not specifically list uranium as a contaminant but are included because KEI believes they are likely to have it or are contaminated by components that may be potential candidates for removal by biosorbents.

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

Ground Water

The problem units listed in Table 10 resulted from a search of the *Crosswalk* database using the following keyword combinations: 1) uranium and ground water and 2) ground water and rad and metals. Also included are those units that were discovered as a result of other keyword searches but also met the criteria for this category. Those not specifically listing uranium as a contaminant are indicated by an asterisk.

TABLE 10
GROUND WATER PROBLEM SUMMARY

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PAL001	UMTRA	Ground water	Heavy metals, U, Ra, molybdenum, arsenic, cadmium, selenium, nitrate, and ammonia	Relatively low for metals; high for TDS, nitrates and ammonia at some sites
PCH024*	Waste Concentration Facility Storage Tanks and Underground Pipelines	Potentially contaminated ground water and soil; metals (debris)	LLW. The tanks previously held sludge from BGRR with mixed fission products (Cs137 and TRU).	Unknown
PCH026*	Current Landfill	Ground water, surface water, sediments	LLW, Fe, Pb, Mn, H3	Drinking water standards exceeded for Fe, Pb, Mn, H3, trichloroethane
PCH027*	Former Landfill	Ground water, soil	LLW	Unknown
PCH035*	Sewage Treatment Plant	Ground water	Cs137, Ce137, Sr90, Co58, heavy metals, PCB, TCA, TCE	Unknown
PCH037*	Upland Meadow Marsh	Soil, ground water	H3, possible organics and metals in soil	H3 below NYS standard
PCH051*	Recharge Basin HN	Ground water, surface water, soil	Radionuclides, metals	Not provided
PFN045	Operable Unit 5	Perched ground water	U, minor Th, PCBs, DCE, TCE, Pb	Mostly 50,000-200,000 ug/L range; as high as 697,000 ug/L
PFN054	Operable Unit 5--Environmental Media	Ground water	U, metals, organics	U: 200 ppb; organics: less than MCLs
PID004*	TSF Injection Well (WAG 1)	Ground water	TCE, lead, Sr90, H3	TCE>0.5 mg/L, lead<0.5 mg/L, Sr90<470 pCi/L, H3<10,000 pCi/L
PID005*	TRA Perched Water (WAG 2)	Ground water	Cr6, H3	>100 ug/L (Cr); H3 over water quality standards

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PID013*	ICPP--Injection Well and Casing Failure (WAG 3)	Ground water	H3, Co60, Cs137, Sr90, Cr, Hg, Ba, Ag, Cd, acids	Unknown
PID022*	Snake River Plain Aquifer (WAG 10)	Ground water	I129, H3, Sr90, CCl4, Cr(+6), TCE	Localized contamination exceeds maximum contaminant levels (MCLs)
PNV020	Underground Nuclear Test Locations	Ground water	Sr90, H3, Co60, Te99, Ru106, Sb125, I129, Ce144, Cs137, U234, Pu239, Ra226, Kr85	Classified, not fully identified. Millions of curies
PNV021*	Eight Off-Site Testing Locations	Ground water	H3, Cr, solvents	H3>Drinking Water Standards (DWS)
POR002	Ground Water in the K-25 Area	Ground water	TCE, Cr3, Cr6, PCB, As, U, Tc99, Th, asbestos, oils, toluene, solvents, heavy metals, pentachlorophenol	TCE up to 36 mg/L; Pb ND to <0.5 mg/L at location K-1407B
POR017	Weldon Spring RAP Quarry Ground Water	Ground water	U, nitroaromatics	U ~ 5000 pCi/L (average for 1990), sample location SW-1008 quarry pond
POR022	Ground Water at X-10	Ground water	H3, Sr90, Cs137, U, Co60, I129, Tc99, Pb, Hg, Cr, Cd, solvents	H3 and organics > DWS; up to 1 uC/L H3; Sr: 10,000 uC/L
POR029	Buried Materials at Paducah	Buried material	TCE, Tc99, U, PCB, radioactively contaminated PCB	Unknown
POR030	On-site Ground Water at Paducah	Ground water	TCE, Tc99, BETX, As, Phthalates, U, Pu, DNAPLs	TCE: trace to thousands of ppm, up to 10%; Tc99: trace to thousands pCi/L
POR031*	Off-site Ground Water at Paducah	Ground water	TCE, Tc99, BETX, As, Phthalates	TCE: trace to hundreds of ppm; Tc99: trace to hundreds of pCi/L
POR036	Ground Water at Y-12	Ground water	TCE, PCE, U, PCB, DNAPLs, Hg, Cd, Ni, nitrate, chlorinated solvents	TCE up to 760 ug/L at S-2 pond site; variable for other contaminants
PRF003	Hillside 881	Ground water	VOC, U, Se, Sr90, gross Alpha	VOC: 50,000 ppb; U < 59 pCi/L; Se < 3.2 mb/L; Sr90 < 5.6 pCi/L; gross alpha < 319 pCi/L

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PRF006	903 Pad	Ground water	Pu, Am, U, TCE, PCE, CCl4	CCl4: 2300 ug/L; TCE > 10,000 ug/L; PCE > 10,000 ug/L; U: 28 pCi/L
PRF010	Solar Evaporation Ponds	Ground water	Nitrates, trace VOC, organics, H3, U, sulfates, some heavy metals	Nitrates: 6,000 mg/L; U: 100 pCi/L; H3: 7,000 pCi/L within impoundments
PRF013*	Existing Operating Sanitary Landfill	Ground water	Solvents, tritium source	Unknown
PRF014*	700 Area	Ground water, soil	Acids, algicides, bases, Be, CCl4, chromate, caustics, fluorides, hydrocarbons, metals, nitrates, organics, solvents, and radionuclides	Unknown
PRF016*	Original Process Waste Lines	Ground water	Low-level rad, TRU, hazardous organics, heavy metals, mixed waste	Not provided
PRF019*	Remaining Problem Units	Ground water	Low-level rad, hazardous organics, heavy metals, mixed waste	Not provided
PRL017	200 Area Ground Water	Ground water	Extensive list of metals, radionuclides, inorganics and organics	Maximums: H3, 5.36E06 pCi/L; Co60, 400 pCi/L; Sr90, 5740 pCi/L; Tc99, 41000 pCi/L; I129, 25 pCi/L; U, 2191 pCi/L; nitrates, 1360 ug/L
PRL025*	200 Area Waste Waters	Ground water, sludges	Organics, metals, TRU, LLW, ammonia, nitrates, mixed waste	Unknown
PRL029	300 Area Ground Water	Ground water	U, Cu, nitrates	U, 255 pCi/L; nitrates, 30 ug/L; gross alpha, 50 pCi/L (see 300-FF-5 work plan)
PSF010*	Shallow Ground Water	Ground water	C14, Cr, nitrate, H3, chloroform, Ra226, dichloromethane	Unknown

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PSR009*	New F&H Seepage Basin Ground Water	Ground water	H3, nitrate, Cd, Pb, Hg, Cs137, Sr90, Na	H3 to 30,000 pCi/ml, nitrate to 400 mg/L, Cd at 20 ug/L, Pb at 450 ug/L, Hg to 14 ug/L, Cs137 to 218 pCi/L, Sr90 to 2700 pCi/L
PSR011*	F&H Inactive Process Sewer Lines	Ground water, soil	H3, Cd, Pb, Hg, U234, U238, I129, Tc99, Cs137, Sr90, Ra226, Np237, nitrate, chromium	High (tritium)
PSR012*	H Area and F Area Tank Farms	Ground water	HLW, H3, Hg, Cr, Ba, Ag, Pb, Sr90, Cs137, Tc99	Above background
PSR015*	Burial Ground Complex--Ground Water	Ground water	H3, VOCs, metals, Pu239, Cs137, Sr90, TRU, others	High H3; Low VOC and metals
PSR017*	R-Area Seepage Basin	Ground water, soil	Sr90, Cs137	2700 Ci disposed in 1954 through 1964; half-decayed
PSR023*	General Separations Area--Ground Water	Ground water	High- and low-level rad, TRU, hazardous organics, heavy metals, mixed waste, nitrate, volatile organics	Not provided

* Does not specifically list uranium as a contaminant but are included because KEI believes they are likely to have it or are contaminated by components that may be potential candidates for removal by biosorbents.

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

Surface Water

The problem units listed in Table 11 resulted from a search of the *Crosswalk* database using the following keyword combinations: 1) uranium and surface water and 2) ground water and rad and metals. Also included are those units that were discovered as a result of other keyword searches but also met the criteria for this category. Those not specifically listing uranium as a contaminant are indicated by an asterisk.

TABLE 11
SURFACE WATER PROBLEM SUMMARY

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PCH026*	Current Landfill	Surface water, ground water, sediments	LLW, Fe, Pb, Mn, H3	Drinking water standards exceeded for Fe, Pb, Mn, H3, trichloroethane
PCH051*	Recharge Basin HN	Surface water, soil, ground water	Radionuclides, metals	Not provided
POR004	On-site Surface Water in the K-25 Area	Surface water	TCE, U, Tc99, solvents, heavy metals	U up to 231 pCi/L; Tc99 up to 526 pCi/L. Both at location K-1407J
POR028	On-site and Off-site Surface Water at Portsmouth	Surface water	TCE, other VOC	TCE trace to 50 ppm
POR039	Surface Water at Y-12	Surface water	Hg, U, PCB, Cl, Cd, Ni	Unknown
PSR021A	Site Streams	Surface water	Cs137, Sr90, Pu, Co60, H3 from permit outfall, U (natural), other radionuclides; heavy metals	Low

* Does not specifically list uranium as a contaminant but are included because KEI believes they are likely to have it or are contaminated by components that may be potential candidates for removal by biosorbents.

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

Soil and Related Media (Sludge, Sediments, Buried Materials)

Problem units that resulted from a search of the *Crosswalk* database using the keyword combination "uranium and soil" can be found in Appendix 6. This appendix also includes related problem units that were identified through other keyword searches. Those not specifically listing uranium as a contaminant are indicated by an asterisk.

Other Solid Media

Refer to Appendix 6 for information regarding other solid media problem units that KEI believes may eventually result in contaminated ground water, surface water, or effluents. Note that most of these were obtained as a result of other keyword searches. KEI did not specifically attempt to identify sources of future contamination as this is beyond the scope of this project.

EXISTING DOE WATER TREATMENT FACILITIES

The document, *Conceptual Site Treatment Plan for Mixed Wastes on the U.S. DOE Oak Ridge Reservation*, includes 176 information sheets describing treatment units and technologies, either in use or planned, for several DOE sites including the Oak Ridge Reservation. Out of these 176 treatment systems, KEI identified 37 that listed at least one treatment technology that might be used to treat uranium. Some of them listed more than one. It appeared, however, that many do not actually remove uranium, particularly the activated carbon systems, which tend to target VOC removal from aqueous streams. A contact for each of these treatment systems is included in Appendix Table 7-5.

Out of 37 DOE treatment systems, 15 listed chemical precipitation; 14 ion exchange; 13 activated carbon; and 2 reverse osmosis. The following technologies were listed by a single information sheet: actinide separation, adsorption, flocculation, and liquid extraction.

TABLE 12
OVERVIEW OF SELECTED DOE ON-SITE TREATMENT SYSTEMS¹

DOE SITE	FACILITY	SYSTEM STATUS	SYSTEM	OTHER
Energy Technology Engineering Center	Radioactive Materials Disposal Facility	Existing ²	Ion exchange	Design capacity: 250 gal./day, approx. 9,000 gal. annually
Fernald Env. Man. Project	Plant 8 VOC Treatment System	Existing ²	Carbon adsorption	Design capacity: 23,862 m ³ /yr
Fernald Env. Man. Project	UMM Treatment Facility	Existing ²	Precipitation	Design capacity: 765 m ³ /yr. Operation suspended
Hanford Site	242-A Evaporator	Existing ²	Ion exchange	Design capacity: 11.4 m ³ /hr, tank waste only
Hanford Site	242-A/Purex Effluent Treatment Facility	Planned, approved	Ion exchange, reverse osmosis	Design capacity: 17 m ³ /hr
Hanford Site	Pu Finishing Plant Water Disposal	Existing ²	Carbon adsorption, ion exchange	Design capacity: 30,000 m ³ /yr
Hanford Site	Waste Receiving and Processing Facility	Planned, approved	Adsorption	Design capacity: 1,400 m ³ /yr

DOE SITE	FACILITY	SYSTEM STATUS	SYSTEM	OTHER
Idaho National Engineering Lab	INEL Waste Generator Treatment	Existing, operating	Ion exchange	Design capacity is developed and implemented on an as-needed basis.
Idaho National Engineering Lab	Mixed Low-level Waste Treatment Facility (MLLWTF)	Planned, unap-proved	Chemical precipitation	Design capacity: 60 m ³ /yr
Idaho National Engineering Lab	Portable Water Treatment System (PWTU)	Existing ²	Carbon adsorption, ion exchange	Design capacity: 187 m ³ /yr
Idaho National Engineering Lab	TAN 726-A Treatment	Existing ²	Ion exchange	Design capacity: 126 m ³ /yr
Lawrence Livermore National Lab	Area 514-1	Planned, approved	Carbon adsorption	Design capacity: 38,000,000 gal/yr; 147,000 m ³ /yr
Los Alamos National Lab	Hazardous Waste Treatment Facility	Planned, approved	Chemical precipitation	Design capacity: to be determined.
Oak Ridge K-25 Site	K-1232 Waste-water Treatment Facility	Existing ²	Chemical precipitation	Design capacity: 1,000,000 gal/yr; 0.8 m ³ /yr
Oak Ridge National Lab	Process Waste Treatment Plant	Existing, operating	Chemical precipitation, ion exchange	Design capacity: 200 gal/min; 397,789 m ³ /yr
Oak Ridge National Lab	Non-radiological Waste Treatment Plant	Existing, operating	Chemical precipitation, ion exchange	Design capacity: 760 gal/min; 1,511,941 m ³ /yr
Oak Ridge Y-12 Plant	Central Pollution Control Facility (CPCF)	Existing, operating	Carbon adsorption	Design capacity: 2,700,000 gal/yr; 10,227 m ³ /yr
Oak Ridge Y-12 Plant	Ground Water Treatment Facility	Existing, operating	Chemical precipitation, carbon adsorption	Design capacity: 2.5 mil gal/yr; 17,714 m ³ /yr
Oak Ridge Y-12 Plant	West End Treatment Facility	Existing, operating	Chemical precipitation	Design capacity: 2.5 mil gal/yr; 9,469 m ³ /yr; Excess capacity: 4.0 mil gal/yr
Paducah Gaseous Diffusion Plant	C-400-D Lime Precipitation Unit	Existing, operating	Chemical precipitation	Design capacity: 136 m ³ /yr. Closure planned.
Paducah Gaseous Diffusion Plant	Waste water Treatment System	Planned, unap-proved	Chemical precipitation	Funding rejected.
Portsmouth Gaseous Diffusion Plant	X-622 Ground Water Treatment Facility	Existing, operating	Carbon adsorption	Design capacity: 78,576 m ³ /yr
Portsmouth Gaseous Diffusion Plant	X-622T Ground Water Treatment Facility	Planned, approved	Carbon adsorption	Design capacity: 69,628 m ³ /yr

DOE SITE	FACILITY	SYSTEM STATUS	SYSTEM	OTHER
Portsmouth Gaseous Diffusion Plant	X-623 Ground Water Treatment Facility	Planned, approved	Carbon adsorption	Design capacity: 99,470 m ³ /yr
Portsmouth Gaseous Diffusion Plant	X-624 Ground Water Treatment Facility	Existing, operating	Carbon adsorption	Design capacity: 99,470 m ³ /yr
Portsmouth Gaseous Diffusion Plant	X-701E Ground Water Treatment Facility	Existing, operating	Carbon adsorption	Design capacity: 99,470 m ³ /yr
Portsmouth Gaseous Diffusion Plant	X-705 Decontamination Facility	Existing, operating	Ion exchange, liquid extraction	Design capacity: 150 m ³ /yr. Influent stream limited to uranium-bearing solutions from specific operations.
Rocky Flats Plant	Aqueous Pores Waste Treatment: Building 774	Existing, operating	Chemical precipitation	Design capacity: 1,819 m ³ /yr; 130,060 gal/hr.
Rocky Flats Plant	Mixed Residue Treatment	Planned, unapproved	Actinide separation	Not listed
Savannah River Site	F/H Area Effluent Treatment Facility	Existing, operating	Carbon adsorption, chemical precipitation, ion exchange, reverse osmosis	Present discharge: 16,000 m ³ /yr; Design capacity: 600,000 m ³ /yr; Permit 400,000 m ³ /yr
Savannah River Site	Hazardous Waste/Mixed Waste Disposal Facility	Planned, approved	Chemical precipitation	Design capacity: 1,432 m ³ /yr
Savannah River Site	M-Area Liquid Effluent Treatment Facility	Existing, operating	Chemical precipitation, flocculation	Design capacity: 38,000 gal/yr; 480 m ³ /yr
Savannah River Site	SRL Ion Exchange Treatment Probe, High Activity	Existing, operating	Ion exchange	Design capacity: 55,482 gal/yr; 210 m ³ /yr
Savannah River Site	SRL Ion Exchange Treatment Probe, Low Activity	Existing, operating	Ion exchange	Design capacity: 396,300 gal/yr; 1,500 m ³ /yr
West Valley Demonstration Project	Integrated Radwaste Treatment System	Existing, operating	Chemical precipitation, ion exchange	Design capacity: chem. precip. 2,305 m ³ /yr; ion exchange 2,123 m ³ /yr
West Valley Demonstration Project	Liquid pretreatment System	Existing ²	Carbon adsorption	Design capacity: 4,731 m ³ /yr

¹ Including those on the Oak Ridge Reservation.

² Could be used for mixed waste.

Source: Extracted from *Conceptual Site Treatment Plan for Mixed Wastes on the U.S. DOE Oak Ridge Reservation*, prepared for DOE Office of Environmental Restoration and Waste Management by Energy Waste Management Organization, Oct. 1993, DOE/OR-1093.

U.S. PUBLIC DRINKING WATER

The EPA estimates that 718,000 people using public water supplies are exposed to uranium at levels exceeding 20 ug/L (20 ppb), with combined upper and lower 95 per cent confidence bounds of 26,000 and 1,559,000. Most of the population predicted to have drinking water exposure above this limit are served by 1,446 small and medium ground water supplies. These population exposure estimates are probably overestimates of exposure levels as a result of using ground water data as the basis for the surface water occurrence distributions.

This section presents EPA's quantitative estimates of the number of community and non-transient, non-community ground water supplies and surface water supplies of various sizes expected to have uranium present in excess of certain levels of interest for evaluating regulatory alternatives.

URANIUM OCCURRENCE

Two versions of a drinking water occurrence and exposure assessment document addressing uranium have been prepared in support of EPA's analysis of regulatory options (SAIC, 1987; WMA, 1990). Both of these documents presented the uranium occurrence and exposure information primarily in terms of activity levels, expressed in pCi units, reflecting the concern for the carcinogenic effects associated with alpha particle emissions from the radioactive decay of the three uranium isotopes. However, exposure to uranium is also of concern because of its chemical toxicity, which is related to the total mass of uranium rather than to specific amounts of each isotope present. The EPA has considered both options: 1) setting the uranium MCL in units of ug/L on the basis of its chemical toxicity and 2) setting it in units of pCi/L based on its carcinogenicity.

The report mentioned previously (WMA, 1990) reviews isotope-specific data for 285 drinking water samples in the Nationwide Radon Survey (USEPA, 1985) as well as approximately 70 drinking water samples from the National Inorganics and Radionuclides Survey (NIRS). The NIRS was conducted by the EPA Office of Drinking Water's Technical Support Division between 1985 and 1986. The NIRS obtained representative national occurrence data for ground water supplies (but no surface water) on 36 inorganic substances and 4 radionuclides, including uranium. One set of data that provides some insight to uranium levels in surface waters is that provided by ORNL (1981). This report provides a summary of uranium in U.S. water compiled from approximately 90,000 samples obtained primarily through the National Uranium Resource Evaluation (NURE) program, with additional data from older water supply studies, such as the study of the 100 largest cities in the early 1960s reported by Durfor and Becker (1964).

These data indicate that surface water (not limited to those supplying drinking water) had an overall range of uranium values of 0.015 to 856 ug/L with a median range of 0.15 to 0.29 ug/L. For ground water (again, not limited to drinking water), the overall range reported was 0.015 to 960 ug/L, with a median range of 0.29 to 0.74 ug/L. These data suggest that uranium levels are typically lower in surface water than in ground water.

These reports suggested that the activity-to-mass ratio could be as much as 10 pCi/g or more. However, all of the high values occurred in those samples where the total amount of uranium mass was relatively low, that is, less than 5 ug/L, with the very highest values occurring where the total uranium present was less than 0.5 ug/L. For samples where uranium exceeded 5 ug/L, the ratio ranged only from about 0.7 to 2.1 pCi/ug.

Recognizing the uncertainty in estimating uranium activity levels from mass measurements in drinking water samples, two sets of occurrence estimates are presented here for uranium activity levels. The first set, called the "best estimate," was obtained by applying a conversion factor of 0.9 pCi/ug. The second set, referred to as the "conservative estimate," was obtained by applying a conversion factor of 1.3 pCi/ug.

Table 13 below is a summary of the National Inorganics and Radionuclides Survey (NIRS) results. Uranium data were available for 976 sites.

TABLE 13
SUMMARY OF URANIUM OCCURRENCE
(NATIONAL INORGANICS AND RADIONUCLIDES SURVEY)

		NUMBER OF SYSTEMS WITH CONCENTRATION (UG/L) OF:					
SYSTEM SIZE (POPULATION SERVED)	TOTAL SYSTEMS SAMPLED IN NIRS ¹	≥0.08	>10	>20	>40	>50	>80
Very Small							
25-100	330	241	15	11	5	3	1
101-500	332	236	11	7	2	1	0
Small							
501-1,000	113	73	1	0	0	0	0
1,001-3,300	119	90	4	1	0	0	0
Medium							
3,301-10,000	54	43	0	0	0	0	0
Large/Very Large							
10,001-25,000	22	17	0	0	0	0	0
25,001-50,000	3	2	0	0	0	0	0
50,001-75,000	2	1	0	0	0	0	0
75,001-100,000	0	0	0	0	0	0	0
100,001-500,000	1	1	0	0	0	0	0
500,001-1,000,000	0	0	0	0	0	0	0
>1,000,000	0	0	0	0	0	0	0
Total	976	704	31	19	7	4	1

¹ Includes only those sites from which uranium data are available.

Source: *Occurrence and Exposure Assessment for Uranium in Public Drinking Water*, prepared by Wade Miller Associates for the U.S. EPA, Office of Ground Water and Drinking Water, EPA project monitor: Denis Borum, June 1991.

Ground Water

The estimated cumulative number of ground water supplies having uranium exceeding various concentrations of interest are presented by system size in Table 14 for community ground water supplies and Table 15 for non-transient, non-community ground water supplies. The model predicts that approximately 957 community and 442 non-transient, non-community supplies will have uranium concentrations above 20 ug/L.

TABLE 14
ESTIMATED CUMULATIVE NATIONAL OCCURRENCE OF
URANIUM IN COMMUNITY GROUND WATER SUPPLIES BY TOTAL
URANIUM CONCENTRATION¹

SYSTEM SIZE (POPULATION SERVED)	NUMBER OF SYSTEMS IN THE U.S. ²	NUMBER OF SYSTEMS WITH CONCENTRATION (UG/L) OF:					
		≥0.08	>10	>20	>40	>50	>80
Very Small							
25-100	17079	11994	808	400	181	138	75
101-500	15354	10783	726	360	163	124	67
Small							
501-1,000	5038	3569	192	89	37	27	14
1,001-3,300	5185	3673	198	91	38	28	14
Medium							
3,301-10,000	2308	1767	45	16	5	3	1
Large/Very Large							
10,001-25,000	823	612	4	1	0	0	0
25,001-50,000	278	207	1	0	0	0	0
50,001-75,000	77	57	0	0	0	0	0
75,001-100,000	17	13	0	0	0	0	0
100,001-500,000	39	29	0	0	0	0	0
500,001-1,000,000	4	3	0	0	0	0	0
>1,000,000	0	0	0	0	0	0	0
Total	46202	32707	1974	957	424	320	171
Lower bound ³		31147	1280	465	96	34	0
Upper bound ³		34265	2672	1446	754	607	383

¹ Based on National Inorganics and Radionuclides Survey.

² Number of systems based on Federal Data Reporting System (FRDS).

³ Lower and upper bound based on 95 per cent confidence intervals.

Source: *Occurrence and Exposure Assessment for Uranium in Public Drinking Water*, prepared by Wade Miller Associates for the U.S. EPA, Office of Ground Water and Drinking Water, EPA project monitor: Denis Borum, June 1991.

TABLE 15
ESTIMATED CUMULATIVE NATIONAL OCCURRENCE OF
URANIUM IN NON-TRANSIENT, NON-COMMUNITY GROUND
WATER SUPPLIES: BY TOTAL URANIUM CONCENTRATION¹

		NUMBER OF SYSTEMS WITH CONCENTRATION (UG/L) OF:					
SYSTEM SIZE (POPULATION SERVED)	NUMBER OF SYSTEMS IN THE U.S. ²	≥0.08	>10	>20	>40	>50	>80
Very Small							
25-100	13899	9761	657	325	147	112	61
101-500	3964	2784	188	93	42	32	17
Small							
501-1,000	1151	815	44	20	8	6	3
1,001-3,300	205	145	8	4	2	1	1
Medium							
3,301-10,000	49	38	1	0	0	0	0
Large/Very Large							
10,001-25,000	4	3	0	0	0	0	0
25,001-50,000	11	8	0	0	0	0	0
50,001-75,000	6	4	0	0	0	0	0
75,001-100,000	2	1	0	0	0	0	0
100,001-500,000	7	5	0	0	0	0	0
500,001-1,000,000	0	0	0	0	0	0	0
>1,000,000	0	0	0	0	0	0	0
Total	19298	13564	898	442	199	151	82
Lower bound ³		12825	555	198	34	7	0
Upper bound ³		14304	1241	686	365	296	189

¹ Based on National Inorganics and Radionuclides Survey.

² Number of systems based on FRDS.

³ Lower and upper bounds based on 95 per cent confidence intervals.

Source: *Occurrence and Exposure Assessment for Uranium in Public Drinking Water*, prepared by Wade Miller Associates for the U.S. EPA, Office of Ground Water and Drinking Water, EPA project monitor: Denis Borum, June 1991.

Tables 16 and 17 provide the occurrence estimates by activity level. The "best estimate" indicates that 7,995 community ground water supplies have activity levels exceeding the 10^{-6} risk level of 1.69 pCi/L, with 50 supplies exceeding the 10^{-4} risk level of 169 pCi/L. The corresponding "conservative estimates" for these levels are 10,196 systems and 86 systems, respectively.

TABLE 16
ESTIMATED CUMULATIVE NATIONAL OCCURRENCE OF
URANIUM IN COMMUNITY GROUND WATER SUPPLIES BY
URANIUM ACTIVITY¹

System Size (Population Served)	Number of Systems with Activity Levels (pCi/L) of:					
	>1.69		>16.9		>169	
	Best Estimate ²	Conserva- tive ³	Best Estimate	Conserva- tive	Best Estimate	Conserva- tive
Very Small						
25-100	3104	3917	428	625	22	38
101-500	2791	3522	385	562	20	34
Small						
501-1,000	839	1080	96	145	4	7
1,001-3,300	863	1111	99	150	4	7
Medium						
3,301-10,000	314	433	17	31	0	0
Large/Very Large						
10,001-25,000	56	89	1	2	0	0
25,001-50,000	19	30	0	1	0	0
50,001-75,000	5	8	0	0	0	0
75,001-100,000	1	2	0	0	0	0
100,001-500,000	3	4	0	0	0	0
500,001-1,000,000	0	0	0	0	0	0
>1,000,000	0	0	0	0	0	0
Total	7995	10196	1026	1516	50	86

¹ Based on National Inorganics and Radionuclides Survey.

² "Best Estimate" based on a 0.9 pCi/ug conversion factor.

³ "Conservative" estimate based on 1.3 pCi/ug conversion factor.

Source: *Occurrence and Exposure Assessment for Uranium in Public Drinking Water*, prepared by Wade Miller Associates for the U.S. EPA, Office of Ground Water and Drinking Water, EPA project monitor: Denis Borum, June 1991.

TABLE 17
ESTIMATED CUMULATIVE NATIONAL OCCURRENCE OF
URANIUM IN NON-TRANSIENT, NON-COMMUNITY GROUND
WATER SUPPLIES: BY URANIUM ACTIVITY¹

System Size (Population Served)	Number of Systems with Activity Levels (pCi/L) of:					
	>1.69		>16.9		>169	
	Best Estimate ²	Conserva- tive ³	Best Estimate	Conserva- tive	Best Estimate	Conserva- tive
Very Small						
25-100	2526	3188	348	509	18	31
101-500	721	909	99	145	5	9
Small						
501-1,000	192	247	22	33	1	2
1,001-3,300	34	44	4	6	0	0
Medium						
3,301-10,000	7	9	0	1	0	0
Large/Very Large						
10,001-25,000	0	0	0	0	0	0
25,001-50,000	1	1	0	0	0	0
50,001-75,000	0	1	0	0	0	0
75,001-100,000	0	0	0	0	0	0
100,001-500,000	0	1	0	0	0	0
500,001-1,000,000	0	0	0	0	0	0
>1,000,000	0	0	0	0	0	0
Total	3481	4400	473	694	24	42

¹ Based on National Inorganics and Radionuclides Survey.

² "Best Estimate" based on a 0.9 pCi/ug conversion factor.

³ "Conservative" estimate based on 1.3 pCi/ug conversion factor.

Source: *Occurrence and Exposure Assessment for Uranium in Public Drinking Water*, prepared by Wade Miller Associates for the U.S. EPA, Office of Ground Water and Drinking Water, EPA project monitor: Denis Borum, June 1991.

Surface Water

The estimated cumulative number of surface water supplies having uranium levels exceeding the indicated concentrations are presented by system size for community supplies in Table 18 and for non-transient, non-community supplies in Table 19. The model predicts that approximately 78 community and 11 non-transient, non-community surface water supplies will have uranium levels above 20 ug/L.

TABLE 18
ESTIMATED CUMULATIVE NATIONAL OCCURRENCE OF
URANIUM IN COMMUNITY SURFACE WATER SUPPLIES:
BY TOTAL URANIUM CONCENTRATION¹

SYSTEM SIZE (POPULATION SERVED)	NUMBER OF SYSTEMS IN U.S. ²	NUMBER OF SYSTEMS WITH CONCENTRATION (UG/L) OF:					
		≥0.08	>10	>20	>40	>50	>80
25-100	833	585	39	20	9	7	4
101-500	779	547	37	18	8	6	3
Small							
501-1,000	754	534	29	13	6	4	2
1,001-3,300	1040	737	40	18	8	6	3
Medium							
3,301-10,000	1156	885	23	8	2	2	1
Large/Very Large							
10,001-25,000	569	423	2	1	0	0	0
25,001-50,000	328	244	1	0	0	0	0
50,001-75,000	157	117	1	0	0	0	0
75,001-100,000	108	80	0	0	0	0	0
100,001-500,000	175	130	1	0	0	0	0
500,001-1,000,000	43	32	0	0	0	0	0
>1,000,000	15	11	0	0	0	0	0
Total	5957	4325	173	78	33	25	13
Lower bound ³		3989	86	24	0	0	0
Upper bound ³		4662	261	133	66	53	32

¹ Based on National Inorganics and Radionuclides Survey.

² Number of systems based on Federal Data Reporting System (FRDS).

³ Lower and upper bound based on 95 per cent confidence intervals.

Source: *Occurrence and Exposure Assessment for Uranium in Public Drinking Water*, prepared by Wade Miller Associates for the U.S. EPA, Office of Ground Water and Drinking Water, EPA project monitor: Denis Borum, June 1991.

TABLE 19
ESTIMATED CUMULATIVE NATIONAL OCCURRENCE OF
URANIUM IN NON-TRANSIENT, NON-COMMUNITY SURFACE
WATER SUPPLIES: BY TOTAL URANIUM CONCENTRATION¹

SYSTEM SIZE (POPULATION SERVED)	NUMBER OF SYSTEMS IN U.S. ²	NUMBER OF SYSTEMS WITH CONCENTRATION (UG/L) OF:					
		≥0.08	>10	>20	>40	>50	>80
25-100	298	209	14	7	3	2	1
101-500	151	106	7	4	2	1	1
Small							
501-1,000	27	19	1	0	0	0	0
1,001-3,300	19	13	1	0	0	0	0
Medium							
3,301-10,000	7	5	0	0	0	0	0
Large/Very Large							
10,001-25,000	0	0	0	0	0	0	0
25,001-50,000	0	0	0	0	0	0	0
50,001-75,000	0	0	0	0	0	0	0
75,001-100,000	1	1	0	0	0	0	0
100,001-500,000	1	1	0	0	0	0	0
500,001-1,000,000	0	0	0	0	0	0	0
>1,000,000	0	0	0	0	0	0	0
Total	504	354	23	11	5	3	2
Lower bound ³		336	14	5	1	0	0
Upper bound ³		373	32	18	9	8	5

¹ Based on National Inorganics and Radionuclides Survey.

² Number of systems based on Federal Data Reporting System (FRDS).

³ Lower and upper bound based on 95 per cent confidence intervals.

Source: *Occurrence and Exposure Assessment for Uranium in Public Drinking Water*, prepared by Wade Miller Associates for the U.S. EPA, Office of Ground Water and Drinking Water, EPA project monitor: Denis Borum, June 1991.

Tables 20 and 21 provide the surface water system occurrence estimates in terms of activity levels. The "best estimate" assumptions indicate that 844 community surface water supplies have uranium activity levels exceeding the 10^{-6} risk level of 1.69 pCi/L, but only 4 systems exceed the 10^{-4} risk level of 169 pCi/L. The corresponding "conservative estimates" for these levels are 1,123 systems and 6 systems, respectively.

TABLE 20
ESTIMATED CUMULATIVE NATIONAL OCCURRENCE OF
URANIUM IN COMMUNITY SURFACE WATER SUPPLIES:
BY URANIUM ACTIVITY¹

System Size (Population Served)	Number of Systems with Activity Levels (pCi/L) of:					
	>1.69		>16.9		>169	
	Best Estimate ²	Conserva- tive ³	Best Estimate	Conserva- tive	Best Estimate	Conserva- tive
Very Small						
25-100	151	191	21	31	1	2
101-500	142	179	20	29	1	2
Small						
501-1,000	126	162	14	22	1	1
1,001-3,300	173	223	20	30	1	1
Medium						
3,301-10,000	157	217	9	15	0	0
Large/Very Large						
10,001-25,000	39	61	1	1	0	0
25,001-50,000	22	35	0	1	0	0
50,001-75,000	11	17	0	0	0	0
75,001-100,000	7	12	0	0	0	0
100,001-500,000	12	19	0	0	0	0
500,001-1,000,000	3	5	0	0	0	0
>1,000,000	1	2	0	0	0	0
Total	844	1123	85	129	4	6

¹ Based on National Inorganics and Radionuclides Survey.

² "Best Estimate" based on a 0.9 pCi/ug conversion factor.

³ "Conservative" estimate based on 1.3 pCi/ug conversion factor.

Source: *Occurrence and Exposure Assessment for Uranium in Public Drinking Water*, prepared by Wade Miller Associates for the U.S. EPA, Office of Ground Water and Drinking Water, EPA project monitor: Denis Borum, June 1991.

TABLE 21
ESTIMATED CUMULATIVE NATIONAL OCCURRENCE OF
URANIUM IN NON-TRANSIENT, NON-COMMUNITY SURFACE
WATER SUPPLIES: BY URANIUM ACTIVITY¹

System Size (Population Served)	Number of Systems with Activity Levels (pCi/L) of:					
	>1.69		>16.9		>169	
	Best Estimate ²	Conserva- tive ³	Best Estimate	Conserva- tive	Best Estimate	Conserva- tive
Very Small						
25-100	54	68	7	11	0	1
101-500	27	35	4	6	0	0
Small						
501-1,000	4	6	1	1	0	0
1,001-3,300	3	4	0	1	0	0
Medium						
3,301-10,000	1	1	0	0	0	0
Large/Very Large						
10,001-25,000	0	0	0	0	0	0
25,001-50,000	0	0	0	0	0	0
50,001-75,000	0	0	0	0	0	0
75,001-100,000	0	0	0	0	0	0
100,001-500,000	0	0	0	0	0	0
500,001-1,000,000	0	0	0	0	0	0
>1,000,000	0	0	0	0	0	0
Total	89	114	12	19	0	1

¹ Based on National Inorganics and Radionuclides Survey.

² "Best Estimate" based on a 0.9 pCi/ug conversion factor.

³ "Conservative" estimate based on 1.3 pCi/ug conversion factor.

Source: *Occurrence and Exposure Assessment for Uranium in Public Drinking Water*, prepared by Wade Miller Associates for the U.S. EPA, Office of Ground Water and Drinking Water, EPA project monitor: Denis Borum, June 1991.

DOE PUBLIC WATER SUPPLY PROGRAM

DOE has supplied bottled water to homeowners whose private wells have been impacted by the Fernald South Plume. This action is, however, considered only a temporary solution. The preferred alternative is to eliminate individual homeowner wells that withdraw water from the aquifer and to provide these residents with water from a public water supply.

DOE has committed to providing its fair share of the cost for installation of the water mains in the South Plume area. This funding is in conjunction with the Hamilton County Department of Public Works, the agency responsible for coordinating all water supply within Hamilton County.

The portion of this proposed action that is of concern to DOE involves the installation of approximately 23 km (14 miles) of pipeline within Hamilton and Butler counties. This installation will occur along East Miami River Road from Bolton Water Works to the intersection of state routes 126 and 128, then south along State Route 128 to approximately 2.7 km (1.7 miles) south of the New Haven Road intersection. Installation will also occur along Willey, New Haven, and Paddy's Run roads.

INTERNATIONAL MARKET

Because of time constraints, research into the international market for uranium-removal technologies was focused primarily on Germany, the country of the biosorbent project's CRADA partner (Ogden Environmental). Limited information was also available on Canada and Europe, which was extracted from SENES Consultants Ltd.'s (SCL, Ontario, Canada) report entitled *Discussion Paper on Waste Water Treatment Issues at Wismut Properties* (March 1992). The primary focus of the SCL document is Germany. Note that SCL requested that this information be treated as confidential and that it be used solely in respect to this specific DOE project.

CANADA

The prime regulatory authority for uranium projects in Canada is the Atomic Energy Control Board (AECB). The AECB incorporates the standards, objectives, or policies set by all other federal and provincial agencies into a mandatory operating license. Operating uranium mines are located in the Provinces of Saskatchewan and Ontario.

Environment Canada regulates discharges to ambient surface water under The Fisheries Act. Section 33 of The Fisheries Act prohibits the deposit of deleterious substances in water, or in a place that may result in deleterious substances entering water, frequented by fish, except in accordance with the conditions of a regulation authorizing the same and written directions of the Minister. Deleterious substances are defined by the Metal Mining Liquid Effluent Regulations made under the Act as arsenic copper, lead, nickel, zinc, total suspended matter, and radium-226. The regulated release of uranium to ambient surface water is as follows: Saskatchewan Environment: 2.5 mg/L monthly mean, 5 single grab or composite and British Columbia 2.0-5.0 mg/L as UO_2 . There are no active uranium mines in Quebec or British Columbia.

In the Province of Saskatchewan, the release to the environment of solid and liquid waste from a uranium mining or mill operation is currently subject to The Environmental Management and Protection Act. Regulations under this Act were issued in July 1991. Previously, ministerial orders were used to control these emissions. Control is based upon guidelines included in the Mineral Industry Pollution Prevention Regulations.

In the province of Ontario, the release of waste water from mining or milling operations (including uranium) is currently subject to the Ontario Water Resources Act. Recommended provincial limits for waste water quality are outlined in the Ministry of the Environment Effluent Guidelines, but apparently do not specify uranium limits. However, more stringent mine-mill effluent guidelines may be defined by the Ontario Ministry of the Environment for a specific mining property or for a specific mining area should such actions be warranted. Actual limits are established via a Certificate of Approval issued by the Ministry for each discharge. The Ontario government has agreed to establish and enforce requirements at least as stringent as the Federal baseline effluent requirements.

EUROPE

The Council of European Communities (CEC) has not established sectorial effluent limits for mining operations similar to those in place in North America (U.S. EPA: 2 mg/L 30-day average, 4 mg/L single-day effluent limit). The CEC has, instead, adopted a series of surface and ground water quality directives that represent minimum requirements that Member States are to adopt. The directives that have been developed are listed in Table 22.

TABLE 22
EUROPEAN COMMUNITY DIRECTIVES

TOPIC	DIRECTIVE	COMPLIANCE DATE
Quality of Surface Water	75/440/EEC	12/31/95
	79/869/EEC	
Quality of Bathing Water	76/160/EEC	12/31/93
Discharges of Dangerous Substances	76/464/EEC	12/31/92
	86/280/EEC	
	88/347/EEC	
Quality of Fish Farming Water	78/659/EEC	12/31/92
Protection of Ground Water Against Pollution	80/68/EEC	12/31/95
Quality of Water Intended for Human Consumption	80/778/EEC	12/31/91

Source: *Discussion Paper on Waste Water Treatment Issues at Wismut Properties*, Senes Consultants Ltd., Ontario, Canada, March 1992.

The latest date for compliance with these directives, as specified in Council Directive 90/656/EEC for the territory of the former German Democratic Republic, is also shown in this table.

To establish effluent limits consistent with these objectives, characteristics of both the receiving water and effluent are required on a site-specific basis. The CEC undertook studies for the purpose of developing standard effluent limits across Europe by 1992. Until those standards were adopted, limits established by individual countries were in effect.

Germany

KEI requested answers to the questions listed below from the following people: Dr. Wolf-J Schmidt-Küster, IEAL Energie Consult GmbH; Dr. Wolfgang Goldammer, Brenk Systemplanung; Dr. Manfred Hagen, Wismut GmbH; James W. Frolich, Environmental & Energy Services Co., Inc. The contacts were supplied to KEI by Dr. Brendlyn Faison, the primary researcher on the biosorbent project.

1. Who in Germany needs technologies to remove uranium from water: which organizations, what specific sites, and whom to contact?
2. What technologies are currently used for uranium removal?
3. Are there any uranium-removal technology deficiencies that need to be addressed by researchers?

4. What is the size of the market (e.g., is it possible to get an estimate in some quantifiable measure, such as gallons or liters of ground water, surface water, and process streams)?
5. What is the makeup of the water that needs to be remediated: specific contaminant forms (uranyl nitrate versus uranyl carbonate), concentrations of all contaminants that are present?
6. What final uranium concentration is needed (i.e., what are the government regulations or industry standards that dictate the extent of cleanup required)?

The following information was provided by Dr. Wolfgang Goldammer, Brenk Systemplanung, the only person who responded to the fax:

1. Because the German program is still in its beginning phase, not much information is available in the form of reports. One report has been prepared by SENES Consultants, subcontractors for Brenk Systemplanung. The report (dated March 1992) discusses water treatment issues with respect to the Wismut sites and descriptions of current treatment facilities and a discussion of regulatory approaches. In the time since this report was written, the knowledge about the problem Germany faces with respect to water treatment has increased considerably.

WISMUT needs water treatment facilities for two purposes: 1) treatment of water during the reclamation process (in particular treatment of free water in tailings-impoundments Seelingstadt and Crössen and treatment of existing water at *in situ* leach mine in Königstein) and 2) long-term treatment of residual seepages after reclamation work is completed (at all mining and milling sites). Details are given in the report mentioned above. In addition, there are several abandoned mining or milling facilities that are no longer in the responsibility of Wismut. Their reclamation lies in the responsibility of the current owners (mostly communities).

Although most of these sites are small, it is possible that at a few of those sites water treatment facilities are required as well. The Wismut sites and the abandoned sites are more or less the only candidates for a removal of uranium from waste water in Germany. Although there are other nuclear facilities, there are only very few where uranium is a major issue.

2. The current technologies are described in the SENES report. They are, in most (or presumably all) cases, not suitable for the required long-term water treatment. Therefore, there is a need at all Wismut sites to establish new water treatment facilities. German regulations require an optimization to be carried out in order to identify the optimum water treatment option with respect to all factors of influence such as contaminant discharge, impacts from deposition of treatment residues, safety, costs, etc. This optimization has not been carried out yet; there is still a lot of time until long-term discharge criteria have to be defined. The use of the term BAT here indicates "best available technology" from a technological point of view, not from a legal perspective, since the German legal framework on radiation protection does not prescribe the use of BATs (subject to change, of course).
3. The currently used technologies are in general very simple and certainly do not represent BAT. Thus, there are considerable deficiencies to be addressed by researchers. Main considerations for this research are: 1) extraction efficiency, 2) quantity and quality of waste products (especially with respect to the question of the safe deposition of these wastes and, possibly, the option to extract uranium from them for sale), 3) ease of operation (some of these facilities will have to be operated for decades, possibly longer, so that this becomes a very important issue), and 4) costs.

The research that has been done or contracted by Wismut, so far, has lead to some concepts for water treatment. But this research has mainly focused on the immediate water treatment requirements (water treatment during reclamation--see above). The water treatment after reclamation is completed has only been approached in very limited fashion.

Short- and long-term requirements are considerably different (e.g., with respect to contaminant concentrations and the deposition of water treatment wastes). Contaminant concentrations will be considerably higher in waters to be treated in the short term. However, concentrations will decline as treatment progresses. Disposal today is much easier than it will be in the future because all waste management facilities are still open. Therefore, there is a lot of room for research concerning the long-term water treatment problem. This research should focus on developing easy-to-use, cost-effective technologies that can treat large quantities of water having relatively small (but not environmentally acceptable) contamination loads.

4. The "size of the market" can only be estimated currently because reclamation concepts are not finalized at all sites. The estimate for the Ronneburg mining area is that 200-300 cubic meters per hour of ground water have to be collected and treated (at least for a few decades). Some additional seepage may arise from waste heaps. In the Aue mining area, the quantity of water to be treated could be even higher; it is unclear, though, how long this treatment is required. For the other major facilities (mills in Seelingstadt and Crössen and *in situ* leach mine in Königstein) no sound estimates exist. But it can be suspected that the seepage quantity there will also be significant and that contaminant loadings will be substantial enough to require a long-term treatment as well.
5. Some information about water qualities to be expected are given in the SENES report. As far as the Ronneburg mining area is concerned, we have by now better estimates:

PARAMETER	SHORT-TERM	LONG-TERM
pH (in Gessenbach*)	3.5	4.8
Sulfate (g/l)	5.1	3.3
Calcium (g/l)	0.38	0.48
Iron (mg/l)	1.7	0.1
Uranium (mg/l)	6.3	5.5
Radium (Bq/l)	0.7	0.65
Lead-210 (Bq/l)	3.2	0.25

* Gessenbach is a small creek into which the ground water will be discharged.

6. The targets for the water treatment are not decided upon yet. The reason is that Germany has adopted a risk-based optimization approach for the whole reclamation program. This means that criteria will eventually be defined on the basis of actual impacts (i.e., doses from the discharge of radioactive waters or risks from non-radioactive contaminants) compared to the legally acceptable risks (doses). Another major factor within the optimization is technical feasibility (here of course BAT comes into play), impacts from the necessary deposition of treatment wastes and, of course, costs. Since this optimization has not been carried out yet there is no clear answer to question number 6. But in practical terms, it is likely that treatment requirements will be similar to those in other countries and that BAT will be a driving factor because this is always easiest to sell.

In addition to the above information, Dr. Goldammer asked SENES Consultants Ltd. (SCL, Ontario, Canada) to send their report entitled *Discussion Paper on Waste Water Treatment Issues at Wismut Properties*, March 1992. Note that SCL requested that this information be treated as confidential and that it be used solely in respect to this specific DOE project. The following text was extracted from that report. The Canadian expert team of SENES/Golder/CANMET, in cooperation with Brenk Systemplanung, was asked to advise the German Federal Ministry of the Environment with respect to Wismut's waste water treatment plans. The following sections, *Scope of Problem* and *BATs*, were obtained from that document.

SCOPE OF PROBLEM

A critical requirement for the development of a publicly and environmentally acceptable strategy for the decommissioning and rehabilitation of Wismut's uranium mining and milling sites is the design and implementation of appropriate water management and water treatment systems. Collection and treatment of large volumes of waters contaminated with dissolved salts, radionuclides and/or heavy metals are common requirements at the Crossen, Seelingstädt, Königstein/Gittersee, Ronneburg/Drosen, and Aue sites. Emphasis is placed on Crossen and Seelingstädt, the sites for which the most data are available, and to a lesser extent, on Königstein and Ronneburg. These sites are believed to have the most challenging waste water treatment requirements and to have a priority with respect to public health and environmental impact.

Management and treatment of these contaminated waters will be needed for long or indefinite periods of time. Integral to such systems are water treatment technologies that accommodate future and more stringent water discharge criteria and the environmentally sound disposal of water treatment products.

Waste water treatment requirements center on three main concerns: neutralization of acid water removal of radionuclides and metals, and removal of dissolved salts, with ammonia being a secondary concern at Seelingstädt and Königstein. At Crossen, Seelingstädt, and Königstein sites, Wismut is using, or planning to use, similar treatment technologies to remove radionuclides and metals as those used at uranium mines in other countries. Current performance of the system at Königstein is apparently reduced possibly due to the large volumes of water processed.

BEST AVAILABLE TECHNOLOGY

The two radionuclides of concern are uranium and radium. Uranium removal is typically achieved by lime precipitation, similar to that for metal removal, at pH 8 to 10 followed by settling or mechanical filtration. Ion exchange, co-precipitation with barium sulfate, and lime neutralization have been applied at uranium mines as well.

The BAT concept provides a tradeoff between the costs and benefits associated with increasingly stringent removal requirements. BAT as it is implemented in the uranium-mining sector represents state-of-the-industry waste water treatment, economic factors considered. Effluent limits based on BAT are readily achievable with existing technology that has proven to be effective in a given application. While other technologies exist that can provide increasingly higher degrees of treatment, these technologies are typically available at substantially higher costs that are not justifiable given the net benefits of improved performance.

CHAPTER 5: URANIUM-REMOVAL TECHNOLOGIES

The EPA does not require water suppliers to use a particular technology to remove uranium from drinking water. It is the responsibility of the individual water systems to select one or more procedures that are optimal for their particular water supply situation. Whichever individual or combination of technologies is ultimately selected by a water supplier must be based upon a case-by-case technical evaluation of the system's entire treatment process and an assessment of the economics involved. The major factors that must be considered include: quality and type of water source, degree of uranium contamination, economies of scale and the cost of water, treatment requirements, and efficient waste disposal.

The EPA conducted a search to identify currently operating conventional water treatment facilities with a minimum of 0.015 mg/L (10 pCi/L) uranium in raw feed waters. Of the systems identified, 34 use surface water and 21 use ground waters as sources. These municipal systems are located in Colorado, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. The search was made by inspecting existing state and federal records and may not be complete.

Testing indicates that for uranium concentrations of raw waters in the range 0.0001 to 0.016 mg/L, unmodified municipal treatment practices do not adequately remove uranium from raw waters except in a few instances. A reasonably high degree of removal may be achieved by carefully controlled, modified conventional treatment methods such as coagulation/filtration and lime softening. Other technologies such as ion exchange, including point-of-use, are capable of improving the degree of removal in the event significant concentrations of uranium are present in a drinking water supply. Variations in the physical and chemical characteristics of source water, initial uranium concentration, and other site-specific conditions will affect removal efficiencies of the methods identified.

Some technologies may be more complex and expensive than others but, because of site-specific conditions and system size, are more applicable and effective for removing uranium from drinking water. Prior to implementing a technology, site-specific engineering studies of the methods should be made. In some cases a simple survey may suffice, whereas in others, extensive chemical analysis, design and performance data will be required. The study may include laboratory tests and/or pilot-plant operations to cover seasonal variations, preliminary designs and estimated capital and operating costs, and disposal costs for full-scale treatment. The evaluation of other options, such as bottled water, point-of-use, regionalization and alternate water sources may be included.

BEST AVAILABLE TECHNOLOGIES (BAT)

Section 1412(b)(6) of the Drinking Water Act states that each national primary drinking water regulation, which establishes a maximum contaminant level (MCL), shall list the technology, treatment techniques, and other means which the Administrator finds to be feasible for purposes of meeting the MCL. In order to fulfill the requirements of section 1412(b)(6), the EPA has identified best available technologies (BAT) for each radionuclide covered in this proposal.

Technologies are judged to be BAT based upon the following factors: high removal efficiency, general geographic applicability, cost, reasonable service life, compatibility with other water treatment processes, and the ability to bring all of the water in a system into compliance.

At one time, the Agency proposed that, of the technologies capable of removing uranium from source water, coagulation/filtration, ion exchange, lime softening, and reverse osmosis fulfill the requirements of the Safe Drinking Water Act (SDWA) as BAT for uranium removal. (NOTE: A new proposal eliminates ion exchange and only lists coagulation/filtration, ion exchange, lime softening, and reverse osmosis.) These technologies have demonstrated effective uranium removal, are currently available, have been installed in public water supplies, and are compatible with other water treatment processes in different regions. The EPA anticipates the following distribution of use of these technologies by the public water supplies: lime softening (40%), coagulation/filtration (30%), and reverse osmosis (30%).

Table 23 summarizes the BATs identified by EPA for the removal of the subject drinking water contaminants and their respective removal capabilities. Table 24 shows theoretical technology limits of BATs. The achievable effluent concentrations are based upon maximum removal of influent levels from the NIRS survey data and maximum demonstrated BAT removal efficiencies. Public water systems (PWSs) applying these BATs will not need to design treatment systems to achieve these estimated low effluent concentrations.

TABLE 23
BAT CONTAMINANT REMOVAL EFFICIENCIES (PER CENT)¹

CONTAMINANT	ION EXCHANGE	LIME SOFT- ENING	AERATION	REVERSE OSMOSIS	COAGULATION/ FILTRATION
Uranium	65-99	85-99		98-99.4	80-95
Radium (226 and 228)	80-97	75-95		87-98	
Radon			Up to 99.9		
Beta Emitters					
Cs-137	95-99			90-99	
I-131				90-99	
Sr-89	95-99			90-99	
²	90-99 ³			96-99	

¹ Information regarding removal efficiencies, test conditions, and other factors are contained in the EPA Technology and Cost documents (T&C) and supplements to each T&C, i.e., for uranium, radium, radon, and man-made radionuclides.

² Mixed commercially produced radionuclides.

³ Mixed bed or two bed (anionic/cationic) exchange resins. Removal does not include I-131.

Source: *Federal Register*, Vol. 56, No. 138, Thursday, July 18, 1991.

TABLE 24
TECHNOLOGY LIMITS FOR RADIONUCLIDE REMOVAL

CONTAMINANT/ TECHNOLOGY (BAT)	GREATEST PER CENT REMOVAL	MAXIMUM INFLUENT (pCi/L) ¹	ACHIEVABLE EFFLUENT (pCi/l)
Ion exchange			
Uranium	99	88	0.9
Radium 226	97	15	0.45
Radium 228	97	12	0.36
Beta emitters (two beds)	99	--	--
Lime softening			
Uranium	99	88	0.9
Radium 226	95	15	0.75
Radium 228	95	12	0.60
Aeration			
Radon	99.9	26,000	26
Reverse osmosis			
Uranium	99	88	0.9
Radium 226	98	15	0.3
Radium 228	98	12	0.24
Beta emitter	99	--	--
Coagulation/ Filtration			
Uranium	95	88	4.4

¹ Maximum levels in ground water sources of drinking water as reported in NRS.

Source: Adapted from *Federal Register*, Vol. 56, No. 138, Thursday, July 18, 1991.

MODIFIED COAGULATION/FILTRATION

Unmodified coagulation/filtration treatment technology has been widely used by the water treatment industry to make water suitable for potable use. The removal of uranium from water by coagulation/filtration can be up to 75 per cent effective. As a new installation for removal of uranium only, the method may not be cost effective. However, for those systems where reduction of turbidity and uranium from the source water are required, consideration should be given to this method of treatment.

Little change can be made in existing coagulation/filtration systems to improve uranium removal other than adjustments of chemical dosages. Coagulants, such as ferric sulfate and aluminum sulfate (alum), when used to obtain turbidity removal in conventional water treatment facilities, may effectively remove uranium. Coagulation/filtration involves the continuous addition and mixing of a coagulant with the raw water for formation of a flocculant precipitate. Polymers are often added as coagulant aids in site-specific situations. The resultant floc develops in size and weight, making it easier to separate suspended materials from water hydraulically or by sedimentation.

Laboratory and pilot studies have shown that pH and coagulant dosage significantly impact uranium removal efficiency in water treatment. From these studies, it was concluded that

the pH dependency of uranium removal is related to the stability and charge characteristics of the uranyl species and the metal hydroxide precipitates at the adjusted pH values. It was further concluded that conventional coagulation treatment could remove uranium from moderately hard and soft waters if optimum pH control and coagulant dosages are possible. Application of aluminum sulfate above 10 mg/L is not recommended as the solubility of the precipitate increases.

Iron- and aluminum-based coagulants are generally more effective in aiding the removal process at pH values near 6 and 10, with efficiencies of 85 to 95 per cent. Removal by coagulation appears to be low at pH 8 due to stability and charge characteristics of uranyl species in solution. In one study, removal efficiencies of greater than 80 per cent were reported (Sorg, 1988) in tests using 20 mg/l doses of ferric sulfate, ferrous sulfate, or aluminum sulfate coagulants. Influent uranium levels were about 83 ug/l in that study. Coagulation/filtration has been demonstrated to achieve removal efficiencies as high as 95 per cent when using aluminum sulfate dosed at 10 mg/l or more, at pH 10 (Sorg, 1988). Use of coagulant aids, such as polymers has resulted in improved removal of uranium in operating water treatment facility at Arvada, CO.

Coagulation/filtration involves a greater degree of complexity than is required for removing conventional contaminants such as turbidity. These differences result in increased operating time and level of expertise needed to operate coagulation/filtration systems. Specific differences include: a) specific pH control for coagulation of uranium; b) higher doses of chemical coagulants for precipitation of radionuclides than for conventional turbidity removal, which can complicate treatment operations with respect to chemical supply, and waste by-product (sludge); and c) larger sedimentation basins and possible two-stage processes (one for turbidity softening and one for radionuclides precipitation).

LIME SOFTENING

Lime softening is a commonly used process to remove hardness from drinking water. Addition of lime removes hardness by the formation of insoluble calcium carbonate and magnesium hydroxide. It has been shown that at elevated pH levels, lime softening is very effective in the removal of uranium from drinking water. Lime softening is capable of uranium-removal efficiencies of 85 to 99 per cent. At optimum pH levels of 10.6 to 11.5 in the presence of magnesium carbonate, removal efficiencies of up to 99 per cent can be achieved. Best results can be achieved by increasing the dosage of lime to approximately 250 mg/L and maintaining the pH above 11. Lower dosages of Ca(OH)_2 , 50 to 100 mg/L, have achieved 85 per cent uranium removal. This treatment should be given serious consideration if removal of hardness from source water is also a desired objective.

Addition of lime for softening of hard waters, especially at the higher pH range, is effective for removal of uranium. However, it may not be cost effective for the removal of uranium alone. Uranium removal efficiencies of greater than 85 per cent have been achieved. At many water treatment systems, when reduction in the hardness of a water source is necessary, lime softening has been widely used. Depending upon the type and amount of hardness in the water, lime softening, excess lime treatment, and split treatment are common to municipal water treatment systems. The equipment required for the lime softening plant consists mainly of devices for rapid mix of the lime with the water, slow mix tank for flocculation, sedimentation basin where insoluble precipitates are allowed to settle, and filters for final solids removal. In some plants other equipment is added for generating and feeding carbon dioxide and recarbonation of softened water prior to filtration.

Lime softening involves a greater degree of complexity than is required for removing conventional contaminants such as turbidity. These differences result in increased operating time and level of expertise needed to operate coagulation/filtration systems. Specific differences include: a) higher doses of lime for precipitation of radionuclides than for conventional lime softening, which can complicate treatment operations with respect to chemical supply, and waste by-product (sludge); and c) larger sedimentation basins and possible two-stage processes (one for turbidity softening and one for radionuclides precipitation).

ION EXCHANGE

The ion exchange process has been used for many years in the commercial recovery of uranium from aqueous solutions (*Proposal for Removing Uranium from Drinking Water Supplies: Demonstration of Selected Ion Exchange and Chemical Clarification*, New Mexico State University, 1982). Strong base anionic exchange resins have been shown to be effective retainers for uranyl carbonate complexes in natural waters. Anion exchange systems for the removal of uranium and other soluble ions have demonstrated uranium removal efficiencies of between 65 and 99 per cent.

Anion exchange resins have very large adsorption capacity for uranium, in some cases exceeding 20,000 bed volumes of treated water. Due to the large capacity for uranium, wastes may become so concentrated to preclude safe disposal. Some in the EPA (Marc Parrotta, EPA Office of Ground Water and Drinking Water, Drinking Water Standards Div., 202-260-3035) are discussing dropping ion exchange as a uranium BAT. According to Tom Sorg (EPA Office of R&D, Drinking Water Research Div., 513-569-7370), the states' rationale for this is that they do not want uranium-removal systems to generate solutions and sorbent materials containing "concentrated" uranium. He referred to 10 CFR 40, which indicates that any material that exceeds 0.05 wt.% uranium content must be licensed through the Nuclear Regulatory Commission.

In order to avoid licensing, a 30-60 day regeneration cycle is necessary--even though the resin can go for a year or more without the need to regenerate. Another EPA source indicated that it may be necessary to regenerate even more often (possibly weekly). This policy results in a tremendous amount of uranium-contaminated liquid waste to deal with. However, Tom Sorg indicates that the use of ion exchange will most likely continue because of the lack of better treatment methods.

REVERSE OSMOSIS

Reverse osmosis (RO) membranes are capable of removing uranium and many other contaminants, including heavy metals and other radionuclides, in source water. At high efficiencies, RO has been used primarily for removing total dissolved solids (TDS) from water in the treatment of brackish and sea waters for desalinization purposes. At reduced pressures RO is adaptable to fresh water sources. Using semi-permeable cellulose acetate membranes, at 250 psi pressure, RO has successfully achieved 98 to 99.4 per cent removal efficiencies. The treated water is passed to storage and to distribution for potable use, and the rejected concentrate is discharged as a concentrated liquid waste stream. However, RO performance is adversely affected by the presence of turbidity, iron, manganese, silica, or scale producing constituents in source water. If pretreatment is not already in place to remove these constituents, the cost to install the pretreatment facility would be an important factor.

Several types of membranes are commercially available with different salt rejection properties, materials of construction, and configuration. Design of a pretreatment system is dependent upon the quality and quantity of the feed water source. Pretreatment may include one or more of the following: pH adjustment, filtration, or additives for scale prevention. Existing treatment plants may already provide much of the pre treatment required, for example, coagulation/filtration for highly turbid surface waters or iron removal from well waters.

RO is adaptable to all size systems, especially small systems. It is particularly suited for point-of-use systems since the quality of the feed water should be clean thus obviating the need for any further pretreatment. Installation of a reverse osmosis facility for removal of uranium only is not generally cost effective, especially if pretreatment of the water source is required. Normally when reverse osmosis is to be used for uranium removal, reduction in total dissolved solids will also be an objective and a concurrent benefit. The selection of reverse osmosis for uranium removal may also be beneficial through the possibility of simultaneous removal of other inorganics that may be present.

Because reverse osmosis systems generally produce high-quality water, blending of treated water with raw water to produce a mixed finished water of acceptable quality may be a factor in selecting a reverse osmosis system.

POINT-OF-USE/POINT-OF-ENTRY TREATMENTS

Point-of-use/point-of-entry devices offer a small utility (less than 3,300 persons) the option of treating only the water required for drinking and cooking (or to treat all of the water for indoor use) in a residential setting as an alternative to centralized- treatment facilities. POU/POE treatments for uranium removal can be either ion exchange or reverse osmosis devices that are provided and maintained by the water utility.

In 1982, a dozen units, each containing one-quarter cubic feet anion exchange resin, were placed in homes in Arizona, Colorado, and New Mexico that were using uranium-contaminated waters as drinking water sources. (The widely used ion exchange household softeners are very similar to anion exchange units, except for the resin used.) The initial concentrations of uranium varied from 0.022 to 0.104 mg/L (15 to 71 pCi/L). Efficiencies, before column breakthroughs, were 99.5 to 99.9 per cent for up to 18,000 gallons of treated water. Breakthroughs were experienced at 22,000, 31,000, 45,000, and 118,000 gallons. When breakthrough occurs, the cartridge is regenerated or replaced.

With reverse osmosis, most of the uranium waste is continuously flushed with very little accumulation on the membrane. Any radiation that may be present due to captured uranium is not expected to be a concern. The membranes will need to be periodically replaced due to membrane fouling, which is dependent upon the quality of the tap water used as feed water. It may also require a booster pump to increase the operating pressure. Although the RO system requires additional energy and water to maintain effective operation, it is economically and technically feasible for small point-of-use application.

DOE EVALUATIONS OF CURRENTLY AVAILABLE TECHNOLOGY

EX SITU METHODS

KEI extracted from the *Crosswalk* database the following evaluations of *ex situ* environmental restoration activities for the problem of ground water contaminated with radionuclides (Table 25) and metals (Table 26).

TABLE 25
EVALUATION OF EX SITU METHODS FOR REMEDIATING GROUND WATER
CONTAMINATED WITH RADIONUCLIDES (EAST 7)

Technology Evaluation Criteria	% of Respondents (36 total)
Why is current <i>ex situ</i> technology inadequate?	
Not demonstrated, particularly for site-specific conditions/contaminants	42
Uncertain if current technology meets performance goals	31
Current technology generates mixed waste or excess secondary waste	31
Existing technology is too expensive	28
Location of contamination imposes physical constraints for implementation	19
Not acceptable to legislators/public	17
Existing technology has unacceptable risk to workers/public	11
Does not provide adequate level of certainty/data quality	11
Does not adequately control spread of contamination	11
Cannot adequately monitor/verify performance	8
Existing technology is too slow	8
Technology does not exist	8
Time/labor intensive	6
Other	3
How must the <i>ex situ</i> technology be further developed?	
Increase removal/recovery/treatment rates	33
Automated systems	19
Achieve lower treatment levels	19
Field operation capability	17
Need treatability studies	17
Reduce secondary waste generation	11
Develop easier operation	8
Real-time results	8
Develop alternative chemicals for use in treatment process	6
Other	6
Improve detection limits	3
Increase resolution	3
Remote operation	3
Reduce leachability, permeability	3

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

TABLE 26
EVALUTION OF *EX SITU* TECHNOLOGY FOR REMEDIATING GROUND WATER
CONTAMINATED WITH METALS
(EAST 10)

Technology Evaluation Criteria	% of Respon- dents (36 total)
Why is current <i>ex situ</i> technology inadequate?	
Uncertain if current technology meets performance goals	36
Not demonstrated, particularly for site-specific conditions/contaminants	33
Current technology generates mixed waste or excess secondary waste	27
Existing technology is too expensive	27
Location of contamination imposes physical constraints for implementation	18
Does not provide adequate level of certainty/data quality	15
Does not adequately control spread of contamination	15
Not acceptable to legislators/public	9
Cannot adequately monitor/verify performance	9
Existing technology is too slow	6
Time/labor intensive	6
Technology does not exist	3
Existing technology has unacceptable risk to workers/public	3
Other	0
How must the <i>ex situ</i> technology be further developed?	
Increase removal/recovery/treatment rates	39
Achieve lower treatment levels	24
Automated systems	18
Need treatability studies	15
Reduce secondary waste generation	15
Field operation capability	12
Develop easier operation	12
Real-time results	9
Develop alternative chemicals for use in treatment process	9
Improve detection limits	3
Increase resolution	3
Remote operation	3
Reduce leachability, permeability	3
Other	0

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear
Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

SEPARATION/VOLUME REDUCTION AND DISPOSAL

Tables 27 and 28 present an overview of this information for *ex situ* treatment and the related topics of separation/volume reduction and disposal of uranium, plutonium, and metals.

TABLE 27
EVALUATION OF *EX SITU*, SEPARATION/VOLUME REDUCTION, AND
DISPOSAL TECHNOLOGIES FOR GROUND WATER CONTAMINATED WITH
PLUTONIUM, URANIUM, OR METALS
(SOUTHWEST 2-2)

Technology Evaluation Criteria	<u>Per Cent of Respondents</u>		
	<i>Ex situ</i> treat- ment (33 total)	Separation/ volume reduc- tion (4 total)	Disposal (7 total)
Why is current <i>ex situ</i> technology inadequate?			
Uncertain if current technology meets performance goals	36	25	0
Not demonstrated, particularly for site-specific conditions/contaminants	33	25	29
Current technology generates mixed waste or excess secondary waste	27	50	14
Existing technology is too expensive	27	25	29
Location of contamination imposes physical constraints for implementation	18	0	0
Not acceptable to legislators/public	9	0	0
Existing technology has unacceptable risk to workers/public	3	0	14
Does not provide adequate level of certainty/data quality	15	0	0
Does not adequately control spread of contamination	15	25	14
Cannot adequately monitor/verify performance	9	0	0
Existing technology is too slow	6	0	0
Time/labor intensive	6	0	14
Technology does not exist	3	0	14
Other	0	0	0
How must the technology be further developed?			
Increase removal/recovery/treatment rates	39	0	14
Achieve lower treatment levels	24	0	14
Automated systems	18	0	0
Need treatability studies	15	25	0
Reduce secondary waste generation	15	0	0
Field operation capability	12	0	14
Develop easier operation	12	0	14
Real-time results	9	0	14

Technology Evaluation Criteria**Per Cent of Respondents**

	<i>Ex situ</i> treatment (33 total)	Separation/ volume reduction (4 total)	Disposal (7 total)
Develop alternative chemicals for use in treatment process	9	0	14
Improve detection limits	3	0	0
Increase resolution	3	0	0
Remote operation	3	0	0
Reduce leachability, permeability	3	25	0
Other	0	0	0

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

TABLE 28

EVALUATION OF *EX SITU*, SEPARATION/VOLUME REDUCTION, AND DISPOSAL TECHNOLOGIES FOR GROUND WATER (NORTHWEST 3-B)

Technology Evaluation Criteria**Per Cent of Respondents**

	<i>Ex situ</i> treatment (33 total)	Separation/ volume reduction (4 total)	Disposal (7 total)
Why is current <i>ex situ</i> technology inadequate?			
Uncertain if current technology meets performance goals	31	17	0
Not demonstrated, particularly for site-specific conditions/contaminants	35	33	25
Current technology generates mixed waste or excess secondary waste	26	33	8
Existing technology is too expensive	24	17	17
Location of contamination imposes physical constraints for implementation	19	17	8
Not acceptable to legislators/public	15	0	8
Existing technology has unacceptable risk to workers/public	7	0	8
Does not provide adequate level of certainty/data quality	11	17	0
Does not adequately control spread of contamination	15	33	17

Technology Evaluation Criteria	<u>Per Cent of Respondents</u>		
	<i>Ex situ</i> treatment (33 total)	Separation/ volume reduction (4 total)	Disposal (7 total)
Cannot adequately monitor/verify performance	7	0	0
Existing technology is too slow	13	0	0
Time/labor intensive	11	0	25
Technology does not exist	6	0	8
Other	2	0	8
How must the technology be further developed?			
Increase removal/recovery/treatment rates	35	17	17
Achieve lower treatment levels	26	17	8
Automated systems	19	17	0
Need treatability studies	13	33	0
Reduce secondary waste generation	15	0	0
Field operation capability	17	17	17
Develop easier operation	9	17	17
Real-time results	9	17	17
Develop alternative chemicals for use in treatment process	7	0	8
Improve detection limits	2	0	0
Increase resolution	2	0	0
Remote operation	6	17	0
Reduce leachability, permeability	2	17	0
Other	7	0	0

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

NEW TECHNOLOGIES BEING DEVELOPED BY DOE

The technologies presented in this section were gathered through the following keyword searches of the *Crosswalk* database: "uranium and surface water," "surface water and rad and metals," "uranium and ground water," "ground water and rad and metals," "uranium and soil," and "soil and rad and metals," "biotechnology," "ion exchange," "membrane," "precipitation," "reverse osmosis," and "uranium and disposal." A search on the word "Germany" was also performed but it was not one of the keywords included in the database.

The "hits" are listed below by keyword. Table 29 groups them by Field Office and Table 30 lists all of the keywords that apply to each of the technologies. Again, the numbering system used in this section is consistent with that used in the *Crosswalk* database. For example, TCH002 refers to a technology which is monitored by the Chicago Field Office. The numbers in parentheses indicate which other searches include that particular problem unit or technology. For example, TID018B can be found under "precipitation" (Search 9B) and "ion exchange" (Search 8B).

1. Uranium AND surface water

TCH002 (1B,2A,4)
TOR034 (3A)
TRL033 (1B,2A,2B,5A,5B,7)

1B. Surface water AND rad AND metals

TAL052, 064 (2B)
TCH002 (1A,2A,4), 021
TNV002
TRL033 (1A,2A,2B,5A,5B,7), 051
TSR010 (2B,3B)

2A. Uranium AND ground water

TAL009, 012 (4)
TCH002 (1A,1B,4)
TRL033 (1A,1B,2B,5A,5B,7)

2B. Ground water AND rad AND metals

TAL009 (2A,4), 046, 047, 064 (1B)
TRL027, 033 (1A,1B,2A,5A,5B,7), 051
TSR010 (4)

3A. Uranium AND biotechnology

TID011 (4)
TOR034 (1A)

3B. Biotechnology

TID018F
TSR010 (2B)

4. Uranium AND soil

TAL009 (2A,2B), 010, 011, 012 (2A), 065 (6)
TCH002 (1A,1B,2A)
TID001C, 002, 011 (3A)
TNV001 (6), 004
TOR009, 027, 028, 029, 036 (6), 042
TRL012
TSR007, 013 (6)

4B. Soil AND rad AND metals

Too many to list.

5A. Uranium AND reverse osmosis

TRL033 (1A,1B,2A,2B,5B,7)

5B. Reverse osmosis

TRL033 (1A,1B,2A,2B,5A,7)

6. Uranium AND disposal

TAL065 (4)
TNV001 (4)
TOR036 (4)
TSR013 (4)

7. Membrane

TCH013
TOR030
TRL016, 033 (1A,1B,2A,2B,5A,5B), 034, 038
TSF011
TSR009

8A. Uranium AND ion exchange (No hits)

8B. Ion Exchange

TID018B
TRL038 (7)

9A. Uranium AND precipitation (No hits)

9B. Precipitation

TID018B (8B), 018E

TABLE 29
TECHNICAL TASK PLAN SUMMARY

FIELD OFFICE	TECHNICAL TASK PLAN ID
Albuquerque	TAL009, 010, 011, 012, 046, 047, 052, 064, 065
Chicago	TCH002, 013, 021
Idaho	TID001C, 002, 011, 018B, 018E, 018F
Nevada Test Site	TNV001, 002, 004
Oak Ridge Operations	TOR009, 027, 028, 029, 030, 034, 036, 042
Richland	TRL012, 016, 027, 033, 034, 038, 051
San Francisco	TSF011
Savannah River	TSR007, 009, 010, 013

Source: KEI

TABLE 30
TECHNOLOGY KEYWORD SUMMARY

TNA ID	CROSSWALK KEYWORDS
TAL008	Biotechnology, ground water, in situ, modeling, organics, soil
TAL009	LLW, americium, electromigration, ground water, in situ, metals, non-intrusive, plutonium, rad, remote, soil, treatment, uranium
TAL010	LLW, metals, rad, separation, soil, support-sampling, uranium, volume reduction
TAL011	LLW, ex situ, extraction, metals, rad, soil, treatment, uranium
TAL012	LLW, basic research, geochemistry, ground water, inorganics, mixed waste, rad, soil, speciation, uranium
TAL046	HLW, LLW, chromates, electrokinetics, ground water, in situ, metals, mixed waste, ponds, rad, sludges, soil, treatment
TAL047	LLW, burial grounds, characterization, geophysics, ground water, metals, mixed waste, object location, plume definition, rad, soil
TAL052	Burial grounds, characterization, field operation, ground water, metals, mixed waste, mobile lab, organics, rad, real-time, soil, surface water, x-ray fluorescence
TAL062	Biotechnology, drums, ex situ, metals, mixed waste, oils, organics, organics destruction, rad, separation, tanks, treatment, volume reduction
TAL064	D&D, LLW, TRU, ground water, metals, mixed waste, physical setting n/a, plutonium, rad, separation, surface water, volume reduction, waste water
TAL065	Disposal, ex situ, metals, retrieval, soil, treatment, uranium
TCH002	HLW, ICP, LLW, TRU, actinides, automated, characterization, field operation, ground water, mass spectrometry, metals, physical setting n/a, plutonium, rad, sludges, soil, surface water, uranium
TCH021	LLW, burial grounds, ex situ, ground water, immobilization, metals, mixed waste, organics, rad, sediments, separation, sludges, soil, soil washing, stabilization, surface water, treatment, vitrification, volume reduction, wasteform
TID001C	HLW, LLW, TRU, all physical settings, characterization, field operation, geophysics, in situ, neutron probe, plutonium, rad, real-time, soil, uranium

TNA ID	CROSSWALK KEYWORDS
TID002	HLW, LLW, TRU, burial grounds, centrifugal jig, drums, ex situ, flotation, hydrocyclone, metals, ponds, rad, sediments, separation, separation-physical, soil, tanks, treatment, uranium, volume reduction
TID010	TCE, biotechnology, ex situ, field operation, ground water, in situ, modeling, organics, soil, treatment
TID011	HLW, LLW, biotechnology, ex situ, immobilization, in situ, metals, rad, soil, stabilization, technology evaluation, treatment, uranium
TID017	LLW, TRU, biotechnology, ex situ, field operation, mixed waste, nitrate destruction, nitrates, physical setting n/a, rad, separation, sludges, treatment, volume reduction, waste salts
TID018B	TRU, ex situ, ion exchange, mixed waste, nitrates, physical setting n/a, precipitation, rad, treatability study, treatment, waste salts
TID018E	TRU, electrodialysis, ex situ, mixed waste, nitrates, physical setting n/a, precipitation, rad, treatability study, treatment, waste salts
TID018F	TRU, above ground, below ground, biotechnology, drums, in situ, mixed waste, nitrate destruction, nitrates, ponds, rad, surface water, tanks, treatability study, treatment, waste salts, waste water
TCH013	Distillation, ex situ, extraction, field operation, gases, ground water, membrane, organics, physical setting n/a, surface water, treatment
TID030	Biotechnology, ex situ, gases, organics, organics destruction, soil, treatment
TNV001	TRU, characterization, chemical analysis, disposal, ex situ, plutonium, rad, retrieval, soil, treatment, uranium
TNV002	HLW, LLW, burial grounds, characterization, field operation, metals, monitoring, non-intrusive, organics, ponds, rad, remote, sediments, sensing-remote, soil, subsurface mapping, surface water
TNV004	TRU, ex situ, flotation, magnetic separation, plutonium, rad, soil, soil washing, treatment, uranium
TOR005	Biotechnology, burial grounds, ground water, in situ, organics, organics destruction, remote, soil, treatment
TOR007	TCE, biotechnology, burial grounds, ex situ, field operation, ground water, organics, organics destruction, remote, treatment
TOR009	PCB, above ground, burial grounds, drums, ex situ, mixed waste, organics destruction, rad, sludges, soil, tanks, treatment, uranium
TOR010	TCE, biotechnology, burial grounds, ground water, in situ, monitoring, organics, organics destruction, ponds, soil, treatment
TOR024	TCE, biotechnology, burial grounds, ground water, in situ, organics, organics destruction, soil, treatment
TOR027	Burial grounds, ex situ, extraction, soil, treatment, uranium, wasteform
TOR028	HLW, LLW, burial grounds, characterization, field operation, monitoring, non-intrusive, paper study, rad, real-time, separation, soil, support-management, systems analysis, technology evaluation, uranium, volume reduction, wasteform
TOR029	Ex situ, metals, soil, support-sampling, transportation, treatment, uranium, wasteform
TOR030	Burial grounds, chromic acid, field operation, in situ, membrane, metals, organics, separation, soil, treatment, volume reduction
TOR031	PCB, biotechnology, burial grounds, field operation, in situ, organics destruction, soil, treatment
TOR034	Biotechnology, ex situ, metals, surface water, treatment, uranium, wasteform

TNA ID CROSSWALK KEYWORDS

TOR036	HLW, LLW, TRU, burial grounds, characterization, disposal, ex situ, field operation, in situ, non-intrusive, rad, real-time, retrieval, separation, soil, support-management, treatability study, treatment, uranium, volume reduction, waste processing, wasteform
TOR042	Physical setting n/a, separation, soil, uranium, volume reduction, wasteform
TRL004	Biotechnology, ground water, in situ, nitrates, non-intrusive, organics, organics destruction, real-time, retrieval, soil, soil heating, treatment
TRL010	TCE, biotechnology, characterization, ground water, in situ, microorganism detection, monitoring, organics, organics destruction, soil, treatment
TRL02A	Biotechnology, ex situ, ground water, nitrate destruction, nitrates, organics, organics destruction, physical setting n/a, treatment
TRL012	LLW, ex situ, metals, ponds, rad, soil, support-sampling, treatment, uranium
TRL016	TCE, gases, membrane, organics, separation, volume reduction, wasteform
TRL027	HLW, TRU, above ground, below ground, drums, ground water, metals, mixed waste, rad, separation, sequestering agents, sludges, tanks, volume reduction
TRL033	Ex situ, ground water, membrane, metals, nitrates, physical setting n/a, radionuclides, reverse osmosis, separation, surface water, treatment, uranium, volume reduction, waste water
TRL034	Ex situ, gases, membrane, organics, physical setting n/a, separation, treatment, volume reduction
TRL038	Electrodialysis, ex situ, ion exchange, liquids, membrane, physical setting n/a, rad, radionuclides, separation, treatment, volume reduction, waste water
TRL051	HLW, ground water, immobilization, liquids, metals, rad, separation, sequestering agents, stabilization, surface water, volume reduction
TSF010	TCE, barriers-subsurface, biotechnology, burial grounds, ground water, in situ, organics, organics destruction, soil, treatment
TSF011	TCE, ex situ, gases, ground water, membrane, organics, sludges, surface water, treatment, wasteform
TSR001	TCE, biotechnology, ex situ, flow fermentation, ground water, in situ, organics, organics destruction, soil, support-management, surface water, treatment, waste water
TSR007	LLW, ex situ, field operation, rad, real-time, soil, soil washing, treatment, uranium
TSR008	TCE, biotechnology, catalytic oxidation, ex situ, field operation, flow fermentation, gases, ground water, in situ, microorganism detection, organics, soil, treatment
TSR009	TCE, biotechnology, catalytic oxidation, combustion, ex situ, field operation, gases, ground water, membrane, organics, organics destruction, plasma, retrieval, separation, soil, treatment, volume reduction, wasteform
TSR010	HLW, LLW, above ground, below ground, biotechnology, drums, ex situ, ground water, in situ, metals, mixed waste, rad, soil, surface water, tanks, treatment, waste water
TSR013	TRU, above ground, burial grounds, characterization, concrete, disposal, drums, ex situ, field operation, immobilization, metals, mixed waste, monitoring, organics, plutonium, ponds, rad, real-time, remote, sensors, sludges, soil, stabilization, tanks, treatment, uranium, vitrification, wasteform

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

Table 31 is an overview of DOE-developed technologies. This listing includes the Technology Needs Assessment ID number, the project title, when the technology is expected to be transferred to ER, and other comments of interest that were gleaned from the assessment sheets. Refer to Appendix 7 for contacts for each of these technologies.

TABLE 31
DOE-DEVELOPED TECHNOLOGY OVERVIEW

TNA ID	TECHNOLOGY IDENTIFICATION	WHEN AVAIL.	COMMENTS
TAL009	Electrochemical Decontamination by Electromigration & Capture	2 yrs.	Technology is only <i>in situ</i> technique being developed for removal of actinides from soils and ground waters. Over 90% removal from soils and ground waters is expected.
TAL011	Selective Extraction/ Leaching ¹	FY94	Technology being developed is chemical extraction using strong chelators for selective removals. Currently available technology is flushing with water, acidic solutions, basic solutions, and non-selective chelating agents; excavation and reburial; and vitrification.
TAL046	Electrokinetic Remediation	FY95	Currently available technology is excavation of contaminated soils and soil washing.
TAL054	Evaluation of the Hydraulic Cage Concept in Containment Systems of Hazardous Waste Materials-Germany ²	2-3 years	GSF (Graunschweig, Germany) is preparing a series of studies using this technology for disposal of toxic wastes in underground repositories. Technology being evaluated under EM-50's International Technology Exchange Program for possible import to U.S.
TAL064	Sequestering Agents for Removal of Transuranics from Radioactive Waste	FY95	Currently available technology is non-selective precipitation or ion-exchange processes, or liquid-liquid extraction. Note that while RFP will not manufacture weapons components as in 1988 in the likely future, this technology can potentially be used during D&D activities at RFP and other sites.
TAL065	Australia/Kuwait-- Cleanup of Heavy Metals ¹		Project to assess the following: 1) whether the government of Kuwait and the U.S. DOD have any interest in DU cleanup in Kuwait, 2) whether there was a potential for collaborations with the Australians, and 3) the potential for applications of existing technologies in Australia or Kuwait.
TCH013	Ground Water Decontamination of VOCs ³	FY94	Technology is a combination of membrane-assisted solvent extraction and membrane-assisted distillation stripping.

TNA ID	TECHNOLOGY IDENTIFICATION	WHEN AVAIL.	COMMENTS
TCH021	Minimum Additive Waste Stabilization (MAWS) Program	Now	Project is to demonstrate that <i>ex situ</i> vitrification of low-level radioactive waste is a competitive alternative to other treatment methods. Water treatment and soil washing segments are included to exhibit how a fully integrated treatment process can achieve even greater volume and cost reductions. Combined processes (soil washing and waste water treatment) separate contaminants and reduce volumes of waste.
TID002	Soil Treatment Equipment ¹	FY93	
TID011	Bioprocessing Technologies for Uranium-Contaminated Solid	Field demo in FY92	This integrated microbially enhanced leaching/extraction process is being evaluated for removing uranium and heavy metals. Control of microbial activity may result in the ability to prevent contaminant migration. Currently available technologies include chemical leaching, physical separation, solid ion exchange method, reverse osmosis, and heavy metal precipitation.
TID018E	Pad A Treatability Study	2-3 yrs	This technology is a combination of precipitation and electrodialysis, which is a unique way to destroy nitrates. Currently available technology is cementation of nitrate salts into salt crete. It is expected that electrodialysis can achieve 100% nitrate destruction. Precipitation can achieve 10x removal of TRU in the nanocurie/g range with the proper filters, agents, and incoming stream. Precipitation is not proven on low-level TRU removal. Electrodialysis has not been proven in radiochemical applications.
TID018F	Pad A Treatability Study	Now to 2 years depending on use	This technology, biodenitrification, uses living organisms to denitrify solutions and possibly precipitate heavy metals. New saline resistant organisms are being tested. Currently available technology is cementation of nitrate salts into salt crete. This new technology has lower cost and energy consumption. Nitrate reduction from 800 ppm to <44 ppm has been proven.
TNV001	Plutonium Contaminated Soil Cleanup Demonstrated ¹	FY94	Goal is to provide an optimized remediation system for cleanup of large land area surface particulate contamination by heavy metals such as uranium and plutonium

TNA ID	TECHNOLOGY IDENTIFICATION	WHEN AVAIL.	COMMENTS
TNV004	Physical Methods for Soil Decontamination ¹	10/93	This project is to establish a soil treatability test facility at the NTS for demonstrating and testing physical separation technologies for removing heavy metal contaminants. Technologies to be tested include Mineral Jigs, Magnetic Separation, Air-Sparged Hydrocyclone and other flotation methods. Volume will be reduced to 1/10 to 1/500 of original volume.
TOR009	Base-Catalyzed Destruction of PCBs in Mixed Wastes ¹	1-2 yrs	Method for chemical destruction of PCBs without incineration of mixed waste soils at K-25 plant that contains PCBs, uranium, and technetium.
TOR027	Selective Extraction/Leaching of U from Soil ¹	FY93	This task evaluates the potential to selectively extract uranium from uranium-contaminated soils without physiochemical destruction of the soil. Uranium at FMPC soils as high as 70,000 ppm (<35 pCi/g cleanup levels). Uranium at Y-12 in excess of 1,000 ppm.
TOR028	Uranium Soils ID Performance Assessment ¹	1/94	Project to assess the performance of treatment/remediation technologies utilized during the uranium soils integrated demonstration with respect to risk reduction, cost effectiveness, ease of implementation, and public acceptance.
TOR030	Development of Inorganic Membranes for Mixed Waste ID ³	FY94	This task is to evaluate and apply inorganic membrane technology to <i>in situ</i> remediation of various contaminant species in mixed waste landfills. The membrane units could be used repeatedly and should have a long lifetime. Membrane processes are known to be energy efficient. The limits will be determined by the maximum separation factors that can be achieved with the membranes. In the case of inorganic reverse osmosis membranes, the waste stream can be concentrated to a level corresponding to the osmotic pressure at the highest operating pressures for the unit, which could be up to 1000 psi or higher. The secondary waste stream will be pure water.
TOR034	Removal of Uranium by Biosorption—Germany	FY94	This task aims to develop biosorption technology for the removal of uranium and other metals from uranium mill tailings waste water. Currently available technologies include alkaline precipitation, extraction with tributyl phosphate, adsorption onto activated carbon, and ion exchange. Technology will reduce dissolved uranium concentrations from ppm to ppb levels.

TNA ID	TECHNOLOGY IDENTIFICATION	WHEN AVAIL.	COMMENTS
TOR036	Uranium Soils Integrated Demonstration Management ¹	Some in FY93	The purpose of the integrated demonstration is to demonstrate and evaluate a system of technologies for the removal of uranium from soils. Current baseline technologies require perpetual monitoring. Baseline technologies are immobilization through slurry walls and capping, solidification/ stabilization, excavation/decontamination, <i>in situ</i> decontamination, and excavation/burial.
TOR042	Secondary Waste Treatment/Disposal for Uranium Soils ID ¹	10/92	The purpose of this TTP is to characterize secondary waste streams generated from the uranium/soil separation technologies being evaluated under the uranium soils ID, to determine the treatment and disposal requirements for the potential waste streams, and to initiate treatability tests for waste treatment technologies.
TRL016	TCE & PCE Membrane Separation Tests ³	8/93	This technology is a gas separation membrane for removing vapors from air. A commercially available technology is granular activated carbon. Membrane technology removes 95 per cent of volatile organics from 0.5 to 5 volume per cent in air flowing up to 100 SCFM.
TRL033	Decontamination of GW from Arid Site Demo Using Supported Liquid Membranes ³	FY95	This technology is reverse osmosis/coupled transport with support liquid membranes. Currently available technologies are reverse osmosis, ion exchange, and evaporation. Final concentrations that can be achieved for an RO/CT system: uranium <10 ppb, technetium <900 pCi/L, chromium <30 ppb, and nitrate less than 45 ppm.
TRL034	VOC Off-Gas Membrane Separation ³	FY93	Technology used for membrane separation of VOCs from gas streams. Competes with adsorption by granular activated carbon. 95% removal of VOCs from 35 SCFM vapor stream.

TNA ID	TECHNOLOGY IDENTIFICATION	WHEN AVAIL.	COMMENTS
TRL038	Continuous Cesium Recovery ³	3-5 years	Continuous recovery by a membrane process using ion exchange, facilitated membrane transport, liquid membranes, and/or electrodialysis. Currently available technologies are batch recovery by zeolite and organic ion exchange resins. Batch recovery by zeolite results in brine waste stream. Waste generated as a result of eluting and recharging organic resins. Baseline technology applicable only to alkaline streams; new technology applicable to acidic streams as well as alkaline. New technology has no down time for regeneration or disposal. New technology will not suffer from radiation-induced crosslinking of the polymer adsorbent and will not increase the volume of waste (e.g., gallons in = gallons out). The efficacy of a non-radiolytic material will provide higher DFs than current ion exchange material. DFs on the order of 500+ should be achievable with electrodynamic ion exchange membranes.
TRL051	Solid Sorbents for Selective Separation of Radioactive Nuclides	End of 1995	Technology: solid-based high-capacity sequestering agents. Baseline technologies are solvent extraction and ion exchange methods. Expected performance capabilities are high capacities for cesium, strontium, and possibly actinides, easy incorporation into vitreous waste forms, and low secondary waste generation. The materials are expected to be robust in a radiation environment.
TSR007	Soil Contaminant Extraction/Leaching ¹	Field 1994	Technology simultaneously washes out uranium from uranium-contaminated soils (2000 ppm or 1500 pCi/g) and nickel (1000 ppm). Baseline technology is soil washing. The chemistry for solubilization and leaching of uranium and other metallic contaminants (Ni, Pb, Hg) is currently inadequate. The time required for leaching is too long (hours) for a practical process. A rapid soil washing process requires minutes of treatment versus hours.

TNA ID	TECHNOLOGY IDENTIFICATION	WHEN AVAIL.	COMMENTS
TSR010	Bioremoval of Heavy Metals from Aqueous Solutions	Not listed	Currently available technologies: chemical or physical processing such as hydroxide precipitation and ion exchange resins.
TSF011	Method of Remove Chloroform & TCE from Ground Water & Waste Water ³	9/94	Remove TCE and CHCl ₃ from aqueous and gas waste streams using diffusion membrane technology; degrade the removed product through diffusion into a concentrated reagent. Existing removal technologies: air stripping, carbon adsorption, biological treatment.

¹ Soil/solid treatment technology.

² Included because relates to Germany.

³ Included because Statement of Work specifically requests information on membranes.

Source: Extracted from *DOE Technology Needs Crosswalk Report*. 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

TECHNOLOGY OVERVIEW

Technologies for removing uranium from aqueous streams can be divided into two major categories: sorbent based and non-sorbent based. They can be further divided into biological and non-biological. Besides the DOE biosorbent, the only other biological-based sorbents discovered by KEI are Algasorb and Bio-Fix, which was developed by the Bureau of Mines and licensed to Harrison Western Environmental Services. The Bio-Fix licensee was extremely unhelpful and no information was found on Algasorb. One biological-based, non-sorbent-based (i.e., bioflocculant) technology was identified.

Sorbent-based methods include adsorbents (i.e., alumina and biosorbent), absorbents (i.e., sponges or foams), and chemisorbents (ion exchange resins and zeolites). Although no source indicated that zeolite could be used to remove uranium, it is commonly used to remove radioactive contaminants such as cesium, so KEI included it in this discussion. No reference indicated that carbon could be used to remove uranium, although personal communications indicated that it is sometimes used. This technology is discussed in Appendix 3.

SORBENT BASED

Adsorbent

The adsorptive affinity of a compound is characterized by the ease with which the dissolved compound can be removed. Without modifications, the adsorbents, activated alumina, silica gel, and zeolites are highly selective to water adsorption. Activated carbon is extremely hydrophobic compared to zeolites, silica gel, and activated alumina. Consequently, it adsorbs organic compounds preferentially. Activated carbon is the most common adsorbent for organics separation and finds a major application in solvent recovery. Carbon may be altered in order to remove compounds such as sulfur-bearing or odorous materials, taste-causing compounds, and mercury. Modifications, such as impregnation with iron chloride, allow carbon to be custom tailored.

Alumina

Alumina adsorption towers have been used to remove metals such as uranium, mercury, silver, lead, and cadmium. According to Alcoa, the adsorption processes compete favorably with resin ion exchange, electrolysis, and solid disposal techniques for these impurity separations. Work at Alcoa has shown that virtually any metal ion can be adsorbed to some degree with efficient regeneration, including alkalis, alkaline earths, transition metals, and noble metals. Adsorption capacities on the order of a few weight per cent are obtained for many ions. This corresponds to favorable time on stream per cycle relative to ion exchange resins, particularly for dilute streams below 500 ppm of total metals. Limited experimental studies have shown that activated alumina is capable of achieving good removal of uranium from drinking water. However, caution is expressed regarding any water treatment that has a very high capability to concentrate radionuclides.

Alumina, a by-product of aluminum production, is an adsorbent that is used primarily as an analytical reagent and as a desiccant. It is primarily an aluminum oxide that has been exposed to high temperature. An amphoteric substance, it will adsorb cations above its isoelectric point of pH 9.5 and anions below that pH. At the lower pH, the operation of activated alumina is similar to that of an anion exchanger. The material is extremely

porous, ground into granular form and screened into various mesh sizes. Its crystalline structure consists of local sites of negative charge within a cationic lattice. Positively charged sites are also available, which accommodate anion adsorption. It is through this process, a combination of ion exchange and adsorption, that this granular media is thought to remove uranium from water.

Information for regenerating alumina for uranium removal is very limited. Although this material may offer an economical removal method, especially for a very small system, disposal of the exhausted alumina or a regeneration waste stream may increase costs significantly, especially for a small community.

A column bed of activated alumina has been evaluated by the EPA Municipal Engineering Research Laboratory for removal capability for Alva, FL, water, which has a uranium concentration of 0.273 mg/L (185 pCi/L). The column was preceded by a 25-micron filter ahead of the alumina bed to help prevent clogging. The alumina treated 5,000 BV before the effluent reached raw water uranium concentration. A uranium-removal efficiency of 99 per cent was obtained at 2,000 bed volumes (14,700 gallons of treated water per cubic foot of alumina) and decreased to 50 per cent removal efficiency after 4,100 bed volumes.

Biosorbent

Until recently biosorbents being developed at ORNL were produced from a solution of solvent/immobilization matrix/microorganism feed solution, which was comprised of 90-94.5 wt.% water, 5 wt.% polyacrylamide, and 0.5-5 wt.% microorganisms. This feed was pumped to a single vibrating nozzle that produced droplets, which were collected in a fixative bath. This bath consisted of a volumetric flask filled with a 10 ml of mineral oil floating on 90 ml of water. The droplets solidified and collected at the bottom of the flask. Scaleup of this process to a continuous operation might consist of simply hooking additional nozzles to the system and substituting a fluid-filled column and collection system for the volumetric flask.

Recently, however, the ORNL researchers have adopted a more efficient way to make the sorbent using a polyurethane foam-in-place technique. A biosorbent foam having a density of 0.057 g/cm³ is created by the new process, which requires very simple equipment (i.e., a mixing tank that can handle viscous fluids).

According to the ORNL researchers, biosorbents offers the advantage of selectivity for uranium as opposed to Group I and II elements (i.e., calcium, magnesium, potassium, and sodium), which are common constituents of untreated water. These elements do not quickly saturate the biosorbent as they do ion-exchange resins. A precipitation step is often incorporated prior to ion exchange treatment in order to solve this problem. The biosorbent, however, is quickly saturated by transition elements, particularly iron, and may require a pre treatment as well. However, in regions of the country, transition elements are somewhat less common in natural water than the Group I and II elements.

Note that the issue of NRC licensing may make the selectivity less important for public water treatment facilities if the time between regenerations or recharging with new sorbent is short in order to avoid licensing as a source material. At these plants, material cost is not necessarily a major factor with ion-exchange systems that are sometimes allowed to run for years without replacement. However, if this practice is discontinued, material cost becomes more important when evaluating the economics of single-use sorbents, which are disposed of prior to reaching 0.05 wt.% uranium content.

Absorbent--Forager Sponge

The *Forager*TM *Sponge* from Dynapore, Inc. (2709 Willard Rd., Richmond, VA 23294, Norman B. Rainer, Pres.) is listed by the EPA as an innovative technology for ground water treatment. The manufacturer claims that this product offers the potential for an *in situ* treatment of dissolved hazardous substances. The sponge, which is in the pilot scale, is currently used in various water treatment applications other than *in situ* remediation of ground water and small-scale experimental trials of *in situ* remediation have been conducted. However, effectiveness has not been clearly established because of site limitations. The company claims the absorbent sponge has actually been used to treat heavy metals, non-metallic toxic elements, inorganic cyanides, and inorganic corrosives and that it can potentially be used to remove radioactive metals. The company holds U.S. patents 5,002,984; 5,064,540; and 5,096,946 on this technology.

Product Description

The absorbent is a porous open-celled sponge having a size of about a one-centimeter cube and containing an aliphatic organic polymer that has a high amine content. The polymer has a selective affinity for certain dissolved species in aqueous solutions. A large number of cubes are confined within a tubular fish-net enclosure to form an in-ground absorption unit. The unit may be lowered vertically into circular shafts drilled into the ground, or may be stacked horizontally one on top of each other in a trench in the ground to be treated. In either mode of installation, ground water flows by natural gravity transversely through the absorption unit. The installation is capable of functioning for a long period of time completely unattended until it becomes saturated with the hazardous substances. The saturated units are then lifted out of the ground and replaced with fresh units. Table 32 below summarizes sponge performance in bench- and full-scale testing.

TABLE 32
SUMMARY OF FORAGER SPONGE PERFORMANCE

CONTAMINANT	WASTE	SCALE	UNTREATED CONCENTRATION RANGE (MG/L)	TREATED CONCENTRATION RANGE (MG/L)
Lead and nickel	Acid mine drainage - Argo Tunnel, CO	Bench	0.320 to 0.330	0.100 to 0.100
Cadmium and zinc	Acid mine drainage water - Penn Mine, CO	Bench	0.240 to 57.51	0.100 to 8.57
Copper and selenium	Acid mine drainage water - London Tunnel, CO	Bench	1.28 to 0.170	0.100 to 0.100
Mercury	Water sample pro- vided by EPA, test monitored by EPA	Bench	0.058 to 0.058	0.001 to 0.001
Copper and silver	Heap leach detox effluent - Carson Hill Gold Mine, Angel Camp Canada	Full	0.330 to 4.25	0.100 to 0.910

Source: U.S. EPA

Bench-scale Testing

The water sample to be tested enters into the top of a four-inch inside-diameter plexiglass column that has a 40-inch bed of sponge. The flow rate through the bed is initially 0.1 bed volume/minute. Higher flow rates are subsequently tested. The top layer of sponge in the bed is visually observed for color change attributable to absorbed species. To determine the efficiency of operation of the bed, the influent and effluent water is tested for species of interest by atomic absorption methods or inductively coupled argon plasma technique. To determine the maximum absorption capacity of the sponge for a particular species, the top layers are analyzed after passage of a large volume of water through the bed and when influent and effluent readings are equal. Dynapore, Inc. has conducted 16 bench-scale studies, not including tests on surrogate wastes.

Pilot System

The pilot treatment system employs absorption units having a diameter of one foot and length of ten feet. Equipment is necessary to either drill 13-inch-diameter vertical holes or to dig 13-inch-wide trenches. A crane or other comparable lifting equipment is needed to remove the saturated absorption units. Analytical facilities are needed to monitor the sponge and/or upgradient and downgradient water. The capacity range for batch processes is 10 to 100 gallons per hour. Dynapore, Inc. has constructed two pilot-scale systems and has conducted nine pilot-scale studies on wastes from different sources or sites.

Large-scale System

In a large-scale ground water remediation operation, service trucks having a hoisting device and a cargo capacity to accomodate numerous tubular fishnet containers filled with the sponge are needed. Containers of metal-saturated sponge must be lifted from shafts and trenches in the ground undergoing treatment, and placed in the truck. Containers of fresh sponge are then be taken from the truck and placed in the same shafts and trenches. The large-scale capacity range is 100 to 10,000 gallons per hour. Dynapore, Inc. has one full-scale system in the planning stage.

Technology Limitations

A limitation of this technology is that it is not applicable to systems having high levels of oily substances. It is not practical where the content of the hazardous substance is so high that very frequent replacement of the absorption unit is necessary. In addition, it cannot sustain compressive forces that would compact the sponges.

Regeneration or Disposal

Upon removal from sub-soil installations, the saturated units must be either regenerated or disposed. Regeneration requires a column treatment in much of the same manner used in the regeneration of ion-exchange resins. This treatment produces an effluent containing the hazardous ingredients, or derivatives thereof, and constitutes a new disposal problem. Eventually, the sponge must be disposed of. This can be done by compaction to an extremely small volume or by incineration. Either of these methods involves consideration of environmental consequences. Depending on the absorbed species, four treatment options are possible:

- The sponge can be stripped with an agent that elutes the absorbed species, permitting reuse of the sponge.
- The sponge can be incinerated, with proper attention to the combustion gases. When volatile species such as Pb, Cd, Zn, Hg, As, and Se are present, an efficient gas scrubber will be essential.
- The sponge can be treated with a fixative, causing the metal to be immobilized sufficiently to qualify as a non-hazardous waste via TCLP test. The fixed sponge can then be disposed of in a non-hazardous landfill.
- The sponge can be blended with a phenolic resin precursor and the mixture heated under compactive pressure to form board or block products that constitute non-hazardous waste via TCLP test.

Chemisorbent—Ion Exchange

There are two principal types of ion exchangers: cationic and anionic. In general, there are five major types of ion exchange resins. By function group they are: 1) strongly acidic cationic, 2) weakly acidic cationic, 3) strongly base anionic, 4) weakly base anionic, and 5) a spectrum of ion-specific structures. These resins contain active groups having an ionic charge that permit the exchange of their cations or anions with those ions in the liquid phase that have a greater affinity for the matrix. Active groups are usually sulfonic, carboxylic, phenol, or substituted amino.

Cation resins generally contain bound sulfonic acid groups. Active sulfonic groups can be converted to the sodium salts. In this form, the resin exchanges its sodium ions with the calcium ions present in hard water. Less commonly, these groups are carboxylic, phosphonic, or phosphinic. Anionic resins involve quaternary ammonium groups (strongly basic) or other amino groups (weakly basic).

Ion-exchange materials have been used for well over a decade in radioactive waste management programs. Applications include removal of cesium from high-level waste water and decontamination of low- and intermediate-level waste water. It has been estimated that the former Soviet Union has used over 1.5 million metric tons of zeolites to decontaminate water and soils at the Chernobyl Nuclear Reactor. Since radium is a divalent cation similar in chemistry to calcium and magnesium, it will be removed along with them in cation exchange processes. A properly operated cation exchange plant is capable of removing over 90 per cent of the radium present. Anion exchange processes have been shown to be similarly effective in reducing uranium contamination.

Because of the various problems associated with nuclear radiation and the necessity of continuous use of nuclear reactor water, ion-exchange resins of higher purity than those normally used in water conditioning applications have been found more desirable for the treatment of water circulating in reactors.

Synthetic Polymer Resins

Although ion exchange occurs extensively in soils, synthetic resins are typically used, which are commonly available in the form of 10-100 mesh beads. Conventional ion-exchange polymers generally lack specificity for particular ions and usually saturate quickly with abundant innocuous species such as calcium, sodium, potassium, chloride, and sulfate. Nevertheless, the largest market for these resins is water conditioning. Cation exchange is commonly used to remove hardness (specifically, calcium and magnesium), and anion exchange to remove nitrate from waters.

The most commonly used resins consist of an organic polymeric backbone (usually a copolymer of styrene and divinyl benzene) with either acidic or basic exchange sites on its porous surface. Although the bulk of ion exchangers are made from styrene divinylbenzene, some are made from acrylic divinylbenzene. They can also be inorganic silicate polymers of micro crystalline type--zeolites or green sands. However, most ion exchangers in large-scale use are based on synthetic resins, usually polystyrene copolymerized with divinylbenzene to provide crosslinking. These resins are permeable only at molecular levels unless larger pores are deliberately formed.

Gel Resins

Gel resins are usually made of styrene divinylbenzene. These resins are not porous and, therefore, the ions to be exchanged must diffuse through the gel structure to the exchange sites. The intermolecular distances, which limit the size of the ion than can migrate through the gel, are often referred to as the apparent porosity. The apparent porosity is usually no greater than 40 angstrom units, even in low crosslinked gel-type resins.

Macroreticular Resins

Macroreticular resins can be compared with a small ball of tough, rigid sponge having large discrete pores. These pores have an average diameter of 1,300 angstroms. These resins offer a number of advantages over the conventional gel-type resins. The large pores allow high molecular weight ions to be more completely removed from solution and more completely eluted from the resin on regeneration. Also, the open structure of the macroreticular resins permits the use of tough copolymers, which would be too dense to effectively act as ion-exchange resins if they were used in a gel-type system. On the whole, macro reticular resins have a somewhat lower adsorption capacity than the gel-type resins. However, this is often offset by the longer operating life or the fact they can handle applications not possible with the gel-type resins.

Redox Resins

Electron-transfer or redox resins are used for oxidation and reduction reactions. Some of these resins incorporate hydroquinone groups into the polymer structure. These groups undergo reversible oxidation to quinone. Poly(mercaptostyrenes) have also been used for this purpose. Resins of these two types are able to raise (when oxidized) or lower (when reduced) the valence of susceptible metal ions. This is achieved without otherwise affecting the solution that is treated. These materials also appear to be suitable for oxygen removal from water supplies.

Chelating Resins

Chelating ion-exchange resins have been synthesized that display unusually high selectivity for certain cations. A polystyrene matrix containing imino-diacetate groups, which are particularly selective for copper, nickel, cobalt, and iron, is commercially available. An example of such a product is Dowex A-1 from Dow Chemical.

Zeolite

Zeolites, which are also referred to as molecular sieves, occur naturally and are also made synthetically. Over 40 structures are known, many of these occurring naturally. However, most of the commercially significant zeolites are synthetic. Until 1935, the only products available for ion exchange were natural or synthetic zeolites. Today, both natural and synthetic zeolites are used extensively for water softening and have been utilized for over a decade in radioactive waste management programs for removing cesium from high-level waste water and decontaminating low- and intermediate-level waste water.

Natural

The naturally-occurring zeolites are analcite, chabazite, heulandite, natrolite, stilbite, faujasite, and thomsonite. Chabazite is essentially a natural hydrated calcium aluminum silicate, usually containing some sodium and potassium. The material, which is used for water treatment, occurs naturally in New Jersey, Colorado, Oregon, and Europe. Sodium chabazite, which is also known as herschelite, occurs in minable quantities only at one deposit in the world, located at Bowie, AZ. Sodium chabazite mined from this deposit is being sold as mine run crude, unactivated granules and powder, activated extrudates and beads consisting of chabazite, and also as a blend of chabazite and other synthetic zeolites. Clinoptilolite is a natural, inorganic zeolite used as a selective ion-exchange medium for the removal of ammonia from plant waste water. Analcite (analcime) occurs in Europe, U.S., and Nova Scotia.

Synthetic

Synthetic zeolites are made by two different methods from mixtures containing an organic amine or quaternary ammonium salt. A gel process uses sodium silicate and alumina while a clay process uses kaolin, fuller's earth, or bentonite as the matrix. These methods are quite complex and involve the substitution of various rare-earth oxides. According to Bureau of Mines sources, clays are only used to a small extent with most synthetic zeolites being made from high-purity silica and alumina. However, technological advances in zeolite manufacturing coupled with less stringent utilization specifications (such as those in gas pollutant absorbers and phosphate substitutes in detergents) favor greater use of clays as raw materials for the future.

Molecular Sieves

The term "molecular sieve" denotes both natural and synthetic materials that exhibit shape selectivity, regardless of composition or degree of crystallinity. Molecular sieves have porous structures that adsorb some molecules while allowing others to pass. Only those molecules that are small enough to pass through the pores of the crystals can enter the cavities and be adsorbed on the interior surfaces. This screening action makes it possible to separate smaller molecules from the larger ones. Zeolite molecular sieves are also known for their ion-exchange capacity.

Originally, the water-adsorbing properties of molecular sieves made them unsuitable for water-based applications. Their adsorptive sites were quickly saturated with water molecules, so that few if any sites remained to adsorb other molecules. Because of this, molecular sieves were not effective even in humid air. However, in 1988, Union Carbide developed a new family of synthetic molecular sieves that have a strong affinity for organic

"odor molecules" and are not inactivated by moisture. Molecular sieves are composed of several different materials, including natural and synthetic zeolites (aluminosilicates), aluminophosphates, and carbon. The most well-known and widely used molecular sieves are the natural and synthetic aluminosilicate zeolites.

NON-SORBENT BASED

Biological—Biofloculant

According to an article in *Nature* (Vol. 365, Oct. 28, 1993), a biofloculant has been developed that can remove uranium and other radionuclides and has attracted the attention of the International Atomic Energy Agency (IAEA, K. Mahadev Rao). A biofloculant is a biological-based material that, when added to a dispersion of solids in a liquid bring the fine particles together to form flocs.

The product described in this article is derived from the seeds of *Strychnos potatorum*, a tree found growing in forests in the state of Andhra Pradesh. It is also said to be capable of removing cadmium, mercury, gold, silver, cobalt, copper, nickel, and other toxic heavy metals. The ease which the substance binds with a variety of metals is dependent on the pH of the reaction medium. The binding efficiency has been found to be high; one mole of biofloculant can apparently absorb between 20 and 25 moles of metal. The ability to bind metals appears to result from the presence of certain proteins. The ability of the biofloculant to bind with actinides means that it may be useful in nuclear waste disposal, particularly because the selective removal of actinides makes the remaining waste easier to handle. The product has a very high affinity for uranium.

Non-biological

Electro-osmosis/Electrokinetics

A major problem at thousands of cleanup sites is the tendency for the contaminated ground water to become trapped deep down in layers of impermeable clays or silts. According to Philip Brodsky, Monsanto's director of corporate research, the company's researchers recently began experimenting with electro-osmosis, a technique that has been used for 50 years to dry out water-soaked dams and other soils, in response to a U.S. EPA plea. Electro-osmosis may be included in EPA's *Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites* as electrokinetics. This reference indicates it is an innovative technology for soils contaminated with organic or inorganic waste. It also indicates that the soil matrix must be relatively permeable and saturated.

With electro-osmosis, a low-voltage electric current is applied to electrodes driven down to contaminated clays. Positively charged contaminated water is attracted to the negative electrode, moving toward it through the tightly packed clay at a rate of about an inch a day. About \$3 worth of electricity cleaned contaminate from a cubic yard of clay in the laboratory, sharply lower than the \$200 to \$1,000 that it costs to dig up and treat that amount of clay above the ground.

Monsanto is currently talking to federal agencies and companies such as Du Pont and General Electric about combining its electro-osmosis technology with technologies from these organizations. For instance, hydrofracturing used by oil companies to improve oil well flow could initially force cracks into the layers of clay. Electro-osmosis would then pull the

contaminants into "treatment zones," bore holes filled with sand or carbon granules, where microbes developed by genetic engineers could biodegrade the chemical.

Extraction

Solvent extraction is a process for separating liquids by mixing the stream with a solvent that is immiscible with part of the waste but will extract certain components of the waste stream. The extracted components are then removed from the immiscible solvent for reuse or disposal. This phase separation physical-treatment technology is used for aqueous streams contaminated with single- or multi-component dissolved organic wastes and sludge contaminated with oils, toxic organics, and heavy metals. The extracting solvent must be immiscible in the liquid and differ in density so gravity separation is possible. It is suitable for sludges containing <20 weight per cent oil/organics and <20 weight per cent solids. It has been suggested that, after concentrating the uranium in ground water by reverse osmosis, extraction could be used to separate the uranium from the other salts. This is necessary because there is generally little separation of uranium from other dissolved mineral matter.

Membranes

Reverse osmosis and ultrafiltration are the only membrane technologies listed in EPA's *Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites*. However, electrodialysis is another that might be useful for remediation of uranium-contaminated water.

Electrodialysis

Electrodialysis is an extension of dialysis, which is discussed in Appendix 3. This process is used to separate the components of an ionic solution by applying an electric current to the solution, which causes ions to move through the dialysis membrane. It is very effective for extracting acids and dissolved metal salts from water. As a water treatment process, it has had extensive use for desalination of brackish waters. Several manufacturing companies are engaged in the development and marketing of electrodialysis units for treating municipal and industrial waters.

Two types of membranes are used: a cation membrane that passes only cations and an anion membrane that passes only anions. The two membranes, along with the fluid compartment between them, is called a cell. A working unit repeats this cell a number of times between one set of electrodes. In operation, the feed water flowing into one compartment loses both cations and anions, thus becoming the diluted product as it leaves the unit. The adjacent compartment receives the transferred anions and cations and becomes concentrated salt or waste stream. There are two basic designs for an electrodialysis plant: electrodialysis (ED) and electrodialysis reversal (EDR). EDR allows salts that foul the membrane surface to be removed. Pretreatment such as clarification may be necessary for certain influent water characteristics; the system cannot be used on turbid waters without extensive pretreatment.

It has been reported that this technique should be able to achieve an estimated *in situ* uranium rejection rate of 80 per cent in mining waters. A three-month continuous test on these waters was conducted in 1980 with a commercial EDR unit of 30,000 gallons/day capacity. The unit reduced uranium from a mean concentration of 9.15 to 1.8 mg/L. In

1985, an EPA study (*Technologies and Costs for the Removal of Uranium from Potable Water Supplies*) indicated that no experience data were found for removing uranium from drinking water. It is expected that the method would be as effective as the reverse osmosis method. A search of the *Crosswalk* database indicates two projects (TID018E and TRL038) within DOE that are evaluating this treatment process, one for cesium removal and the other for nitrates.

An estimate of the power required for electrodialysis is 0.2 to 0.4 Kwh/1000 gallons of product water per each 100 mg/L of dissolved solids removed. Alternating current power for pumping and other purposes range from 2 to 3 Kwh/1000 gallons of product water.

Reverse Osmosis

Reverse osmosis is a phase separation physical-treatment technology that separates components in a liquid stream by applying external pressure to one side of a membrane so that solvent will flow in the opposite direction. It is used for aqueous waste streams containing <400 ppm heavy metals, high molecular weight organics, and dissolved gases. The use of this technology for uranium removal is discussed in more detail under "Best Available Technologies."

Precipitation

Precipitation is a process for removing contaminants from an aqueous organic or inorganic waste stream containing dissolved metals. In this treatment, a chemical that produces a precipitate is added to the waste, generating a sludge that requires further treatment. This technique requires optimization of the reaction pH for the specific mix of metals present and cross-reactivity may occur for mixed-metals content waste. Precipitation is unsuitable for sludges, tars, and slurries. Coagulation/filtration and lime softening are precipitation methods that are discussed under "Best Available Technologies" for uranium removal.

CHAPTER 6: COST/BENEFIT ANALYSIS

The purpose of this economic analysis is to evaluate the merit of continued funding for the biosorbent technology being developed at ORNL. Note that this technology was developed specifically for acidic pH conditions of 2-3 (uranyl ion form) as opposed to typical ground water pH levels, 6-8 (uranyl carbonate form). Because of this, KEI believes that, in order to make a fair comparison with Best Available Technologies (BATs), the researchers must first modify the current biosorbent material so that it is effective in higher pH applications.

This new material should then be compared with an anionic ion exchange resin, such as Dowex 21K, which is commonly used to treat uranium-contaminated water. Such a comparison is needed as a benchmark to gauge the success of the development efforts. Table 33 provides benchmarks that KEI determined using some recent data generated by the researchers. However, KEI believes that a more controlled test should be conducted to generate more reliable data that can be used to calculate a more accurate benchmark.

Because of the focus on low pH conditions, the ion exchange resins tested to date have been cationic resins that are known to be ineffective for removing anionic uranium complexes from ground water. In order to demonstrate the current biosorbent's performance with a representative water sample, however, the researchers conducted tests using Y-12 waste water on the biosorbent and selected cationic ion exchange resins. The water sample tested (pH 8.9) contained 5.6 ppm U, 0.5 ppm Fe, and a complex mixture of Ni, Na, Cl, SO₄, etc. Table 35 presents the results of those tests. Although the removal efficiency was only around 5 per cent, the biosorbent performed at least as well as the other cationic materials. Dowex 21K, which performs well at high pH, was tested at low pH to show its effect on performance. As expected, this resin performed poorly in the low pH test conditions.

Note that these test results were not obtained from packed-bed testing. They were simply laboratory measurements using the Y-12 water. For this analysis, KEI assumed the cells to be the only active ingredient in the foam biosorbent. This assumption implies that the foam serves strictly as an immobilization matrix. Again, much better results should be observed once the researchers develop a carbonate-selective version of the biosorbent. [Note: The researchers indicate the polyurethane matrix can potentially be modified so that it removes metals and radionuclides as well as the cells. This can be accomplished by changing free functional groups or active sites, which are grafted in the base matrix.]

BIOSORBENT VERSUS ION EXCHANGE

Ion exchange is the BAT that compares most directly with the biosorbent technology. As a result, this discussion will be limited to a comparison with that treatment method. Comparisons of ion exchange with the other BATs are presented later in this chapter.

According to the ORNL researchers, biosorbents offer the advantage of selectivity for uranyl cation at pH 2-3 as opposed to Group I and II elements (i.e., calcium, magnesium, potassium, sodium, iron, and other transition elements), which are common constituents of untreated water. According to the researchers, these elements (except for iron and the other transition elements) do not quickly saturate the biosorbent in acidic conditions as they do ion-exchange resins. Industry commonly uses a precipitation step prior to ion exchange treatment in order to solve this problem. Because the biosorbent is quickly saturated by transition elements, particularly iron, a precipitation step might also be required. The cost of pretreatments and labor were ignored in this analysis. Labor costs for biosorbent foam preparation were ignored because KEI assumed a fixed cost for fabrication. According to

the researchers. the entire lab process takes up to 7 days or 132 hours including setup time and biomass preparation. Actual operator time is estimated to be 5 hours.

Based on a biomass cost of \$50/kg (supplied by the researchers) KEI estimates the biosorbent cost to be \$52/ft³. Of this, materials make up 42/ft³ of the cost and foam-fabrication cost through a custom-foam fabricator is assumed to be \$10/ft³. Industry sources indicate that this is a high-end cost for fabrication. Note also that the biosorbent-materials cost used in this analysis is based on a bench-scale process that uses high-purity chemicals. Actual materials costs for a production-scale process should be lower. However, this analysis did not take into account many of the other factors listed in Table 33 that affect the biosorbent product cost. An analysis taking all of these factors into account was not possible due to time constraints. According to the biosorbent researchers, however, the final sales price should actually be less than for ion-exchange resin. The resin production process involves higher temperatures and pressures than the biomass and biosorbent processes. In the analysis presented in Table 33, KEI assumes three different biosorbent prices in order to show the effect of sorbent price on water treatment costs.

While sorbent price plays a significant role in water treatment economics, other factors must be considered. Kinetics and the resulting efficiency must also be taken into account in order to get the true economic picture. Kinetics and efficiency play an important role in costs associated with plant operation as well as spent-sorbent storage and disposal costs.

Dow Chemical's ion exchange literature indicates that small monodisperse particles having a narrow size distribution improve the rate of uranium uptake as a result of faster kinetics. It also results in a lower pressure drop. Dow indicates that it is important for no fines to fill in the small spaces between particles in the packed resin bed. These fines obstruct the flow through the column. Faster kinetics also result in longer time until breakthrough and higher throughput velocities, allowing smaller plant configurations to obtain equivalent production volumes. In many cases, three-column systems can be scaled back to two-column configurations, which can mean lower capital expenses in new installations and reduced resin inventory requirements for existing plants.

TABLE 33
ECONOMIC ANALYSIS RESULTS AND COST FACTORS

	BIOSORBENT (Anion Removal, Y-12 Water)	BIOSORBENT (Cation Removal, Uranyl Nitrate)	BENCHMARKS (Anionic/Cationic Ion Exchangers ¹)
Gal. water treated/ft ³ sorbent before regeneration or disposal (estimated)	37; 362 ²	58; 575	17,756/1,860
Treated water cost, \$/gal			0.0093/0.21
39 wt.% biosorbent (\$52/ft ³ , 100, 200)	1.42, 2.73, 5.46	0.895, 1.72, 3.44	
80 wt.% biosorbent (\$52/ft ³ , 100, 200)	0.14, 0.28, 0.55	0.090, 0.17, 0.35	
Treated water cost plus \$100/ft ³ for immediate disposal of spent sorbent, \$/gal.			0.0149/0.26
39 wt.% biosorbent	4.15, 5.46, 8.19	2.62, 3.44, 5.16	
80 wt.% biosorbent	0.42, 0.55, 0.83	0.26, 0.35, 0.52	
Treated water cost plus storage (\$35/ft ³) at K-25 and disposal (\$100/ft ³) of spent sorbent after 10 years of storage, \$/gal.			0.035/0.45
39 wt.% biosorbent	13.7, 15.0, 17.8	8.64, 9.46, 11.2	
80 wt.% biosorbent	1.39, 1.52, 1.80	0.87, 0.96, 1.13	

¹ Dowex 21K (\$166/ft³) with Y-12 water/Duolite C-467 (\$384/ft³) with uranyl nitrate solution.

² 39 wt.%; 80 wt.%

Continued...

	ION EXCHANGE	BIOSORBENT
COMPONENTS OF PRODUCT COST		
Manufacturing costs	NA	
Direct production costs		
Raw materials, \$/180 g foam (\$/ft ³)		4.4-4.6 (40-42)
Biomass suspen., \$/100 ml		3.86-4.06
Cells, \$/70 g		3.5
Polysulfone, \$/10 g		0.1-0.3
Dimethyl formamide, \$/100 ml		0.26
Hypol 2002 prepolymer, 100 g		0.54
Foam fabrication, \$/ft ³		10
Possible precipitation pretreatments	Ca, Mg, K, Na, Fe, & other transition metals	Fe & other transition metals
Operating supervision		
Power and utilities		
Maintenance and repairs		
Operating supplies		
Laboratory charges		
Royalties (if not on lump-sum basis)		
Fixed charges		
Depreciation		
Property taxes		
Insurance		
Rent		
Plant overhead		
Medical		
Safety and protection		
General plant overhead		
Payroll overhead		
Packaging		
Restaurant		
Recreation		
Salvage		
Control laboratories		
Plant superintendence		
Storage facilities		
General expenses		
Administrative expenses		
Executive salaries		
Clerical wages		
Engineering and legal costs		
Office maintenance		
Communications		
Distribution and marketing expenses		
Sales offices		
Salesmen expenses		
Shipping		

Advertising
 Technical sales service
 Research and development
 Financing (interest)

CAPITAL COSTS

Biosorbent foam production capital costs (does not include equipment needed to produce biomass), \$		
Foam manufacturing equipment (7.5-30 lbs/min)		46,200
Polyethylene molds		200
Granulation equipment (100; 400 lb/min)		12,500; 20,000
Water treatment capital costs (Culligan), \$		
Water softener-type equipment (1-stage, 120" non-stainless)		25-30,000
2-stage cation/anion demineralizer, 25 gpm (11 ft ³ 8% crosslinked DVB cation, 12 ft ³ Type 1 anion resin)	32,000	
2-stage cation/anion demineralizer, 2 gpm (10 ⁶ gal/yr capacity, 2 ft ³ cation, 2 ft ³ anion resin)	6,000	

Source: KEI

BIOMASS PREPARATION

The total biomass-suspension material cost for a 39 wt.% foam is estimated to be \$3.86-4.06/100 ml. The following steps are involved in biomass preparation:

- Prepare lyophilized biomass: Biomass preparation, cultivation, harvesting, and lyophilization (estimated price: \$50/kg, \$0.05/g).
- Prepare 1% solution of nonionic surfactant [2 ml (unavailable but assumed approx. zero) per 200 ml water (\$1.06x10⁻⁵).
- Dissolve copolymerization substance in dimethyl formamide [10 g (\$0.1-0.3)/100 ml (\$0.26), requires 2-3 hours].
- Add biomass to dimethyl formamide mixture [70 g lyophilized cells (\$3.5)/100 ml].

More detailed cost information is presented in Table 34, most of which was provided by Michael Hu, the ORNL engineer working on biosorbent development. He recently changed the production method from a bead-making process to a much simpler foaming process.

Note that there is a commercially available patented foam, Forager Sponge from Dynapore, that can potentially remove uranium in the cationic form. However, its use for uranium removal has not been demonstrated. The Forager Sponge, a polyethylene imine that is insolubilized by polycarboxylic acid in a thermal curing step, sells for \$95/ft³. In 1993, Dynapore estimated the cost of treating water with this technology to be less than \$0.001 to \$0.02 per gallon. The company estimates that one cubic foot of Forager Sponge can absorb 50-200 grams of cation. If the material is not regenerated, the cost is estimated to be in the range of \$100-300 per pound of metal removed. KEI estimates that 80 wt.% biosorbent costs

\$2,826 per pound of uranium removed assuming the biosorbent costs \$52/ft³. Based on ORNL test results (using adjusted uranium loading), the cost for Dowex 21K, which costs \$166/lb, is \$185 per pound of uranium removed.

TABLE 34
39 WT.% BIOSORBENT MATERIAL COST ASSUMPTIONS

MATERIAL	PRODUCER	PURCHASE QUANTITY	PRICE RANGE	QUANTITY USED/ ASSUMED COST
Biomass	ORNL		\$50/kg	70 g/\$3.5
Hypol prepolymers	W.R. Grace	65+ drums	\$2.45/lb.	1.0 g/\$0.0054
Polysulfone resin	Aldrich	200-500 kg 1000 kg Several thousand kg/yr	\$30.00/kg \$24.00/kg <\$10.00/kg	10 g/\$0.01- 0.03
Dimethylformamide	Sigma (Aldrich price)	202 L/drum	\$2.60/L	1 ml/\$0.0026
Water		2,500 gal. 75,000 gal.	\$0.0041/gal; \$0.0002/gal, \$5.2x10 ⁻⁸ /ml	2 ml/~\$0
Surfactant (optional)				small/~\$0
Total materials cost				180 g/ \$4.4-4.6

Foam density: 0.05714 g/cm³, 3.6 lb/ft³

Source: Michael Hu, ORNL

FOAM PREPARATION

The following procedure describes how the biosorbent foam is made.

- Add biomass suspension prepared above to hypol 2002 prepolymer [100 ml (\$3.86-4.06)/100 g hypol (\$0.54)].
- Add 200 ml surfactant solution described under "biomass preparation" to this mixture.
- Stir until mixture begins to foam (approx. 2 minutes).
- Cure with no stirring (approx. 15 minutes).
- Chop foam block into small (1-5 mm) particles with a blender.
- Dry overnight in vacuum oven at 85 °C, -25 in. Hg (test-control step only).
- Store at 4 °C until use (test-control step only--autoclaving at 121°C actually increased adsorbence).

Note that it is possible to use a foam fabricator to produce custom specialty foams instead of setting up a production line. However, if one desires to set up such a line, the following equipment is needed:

- Foam-making equipment or "pour machine" (\$46,200)
- Polyethylene mold (\$200)
- Granulation equipment (\$12,500; 20,000)

FOAM CAPITAL EQUIPMENT

KEI obtained the price for the pour machine from the Dow Chemical's subsidiary Admiral Equipment Co. This price includes a basic 7.5-30 lb/min pour machine having a 20-gallon resin tank and a 5-gallon solvent system. This basic machine lists for \$30,700. Optional equipment, which includes hot/cold water supply, constant level, automatic solvent flush and air purge, tank agitators, additional pour timer, lists for \$15,500. Polyethylene molds are recommended to avoid sticking.

Prices for granulation equipment were obtained from Rapid Granulation Co. The smallest unit, 100 lb/hr, sells for \$12,500. The next larger size, 400 lb/hr, sells for \$20,000. These prices include electrical work and a blower.

WATER TREATMENT CAPITAL EQUIPMENT

Assuming the researchers do not decide to use a fluidized-bed system, biosorbent water-treatment capital costs should be comparable to those for the ion-exchange process. The difference should simply be that the biosorbent foam is used in a water softening unit in place of the ion exchange resin.

Culligan recommends using a two-stage ion-exchange demineralizer for removing uranium from ground water. Such a system (\$32,000) having a 25 gpm capacity contains 11 ft³ of 8% crosslinked styrene divinylbenzene cation resin and 12 ft³ of Type 1 anion resin. A smaller system (\$6,000) having a 2 gpm capacity contains two ft³ cation and two ft³ anion resins. [Note: Mr. Foreman indicated that he knows of several 100-inch diameter (100 ft³) salvage stainless steel ion-exchange vessels. According to him, TVA originally paid \$50,000 each, but they can be purchased for significantly less.]

WATER TREATMENT COST ESTIMATES

This section presents the assumptions KEI made in order to estimate the water treatment costs associated with biosorbent foam. Differences in actual treatment costs between the biosorbents and ion exchange resins will result from parameters such as removal efficiencies, flow rates, cost to regenerate or replace the sorbent media in the column, and storage and disposal of the spent sorbent. However, the only information available from the researchers that allowed a comparison between biosorbent performance and ion exchange resin was cell-performance characteristics for the cationic materials as opposed to column testing using actual biosorbent foam.

Table 35 shows test results using Y-12 wastewater (pH 8.9), which contains 5.6 ppm U, 0.5 ppm Fe, and a complex mixture of Ni, Na, Cl, SO₄, etc. Although these results show removal of only around five per cent, the biosorbent must be in the anionic form in order to

be effective for ground water treatment. This table also shows the results using a uranyl nitrate solution (pH 2.5). The removal efficiency for this solution is around 95 per cent.

Again, note that the removal capacity of the biosorbent can theoretically be improved by increasing the quantity of cells that it contains. The current biosorbent has a 39 wt.% cell loading, but Table 35 also presents sorbent and water treatment cost estimates for 80 wt% biosorbent. **Note:** A major assumption in KEI's estimate for the 80 wt.% materials is that the incremental cost to add additional cells is essentially zero.

KEI estimates that 80 wt.% biosorbent with a loading of 2.13 mg U/g cells (0.0293 lb.U/ft³ biosorbent) costs \$1,775/lb. **cationic** uranium removed assuming the biosorbent costs \$52/ft³ and \$6,826/lb. cation if it costs \$200/ft³. Duolite C-467 costs \$4,021/lb. cation removed assuming \$384/ft³. Based on ORNL test results (using adjusted uranium loading), the cost for Dowex 21K (\$166/ft³) is \$184 per pound of **anionic** uranium removed.

TABLE 35
SORBENT TEST RESULTS AND ECONOMIC OVERVIEW

	Uranium Loading, (mg U/g dry cells)	Uranium Loading (mg U/g dry sorbent)**	Sorbent Cost, \$/ft ³	Water Treatment Cost, \$/gal*
Biological sorbents				
<i>Pseudomonas aeruginosa</i> ¹			52, 100, 200	
Y-12 waste water	0.276			
Uranyl nitrate (UN)		1.34 (0.0767)		
		2.13		
39% cell loading (current product) ²				
Water treatment only: Y-12/UN				1.42, 2.73, 5.46/ 0.90, 1.72, 3.44
Disposal without storage: Y-12/UN				4.15, 5.46, 8.19/ 2.62, 3.44, 5.16
Disposal with storage: Y-12/UN				13.7, 15.0, 17.8/ 8.64, 9.46, 11.2
80% cell loading (theoretical product) ²				
Water treatment only: Y-12/UN				0.14, 0.28, 0.55/ 0.09, 0.17, 0.35
Disposal without storage: Y-12/UN				0.42, 0.55, 0.83/ 0.26, 0.35, 0.52
Disposal with storage: Y-12/UN				1.39, 1.52, 1.80/ 0.87, 0.96, 1.13
<i>Pseudomonas atlantica</i>			---	---
Trial 1	0.291	1.19	---	---
Trial 2	0.220	0.99	---	---
Non-biological sorbents				
Cationic ion exchange resins			70-100 ³	
Amberlite IRC-718 (Supelco, Na form)		0.0871 (0.119)	384-390 ⁴	---
Duolite C-246 (Supelco, Na form)			384-390 ⁵	
Y-12 waste water		0.438 (0.998)		---
Uranyl nitrate		2.22		0.206, 0.260, 0.448
Dowex AG 50W-X4 (200-400)				
Dow Chemical			1517-1517 ⁶	
Bio-Rad		0.417 (0.0707)	2937-4513 ⁷	---
Chelex 100 (Bio-Rad, Fe form)		0.0905	5707-7539	---

* The three costs given for biosorbent were derived from the three different assumed sorbent costs. However, the three costs given for Duolite are based on one resin price, \$384/ft, but are for water treatment only; water treatment plus disposal; and treatment, storage, and disposal.

Continued...

	Uranium Loading, (mg U/g dry cells)	Uranium Loading (mg U/g dry sorbent)	Assumed Sorbent Cost, \$/ft ³	Water Treatment Cost, \$/gal
Anionic ion exchange resins ⁸	---			
Dowex 21K, 16/20: Y-12 Water, UN sol.		---	173-182	
Water treatment only				0.0093, 3.96
Plus disposal				0.0149, 6.34
Plus disp. & sto.				0.0345, 14.6
Dowex 21K, 16/30		21 (1.2) ⁹	166-175	
Dowex 21K, XLT		1.18	220-229	
Activated carbon (Type "KE")		0.0112	---	---

^{**}The numbers in parentheses are results from testing done 2/24/94 (non-immobilized cells) to provide a comparison with Dowex 21K. Y-12 water: 6.74 mg U/ml, pH 9.4. This solution was stored at room temperature for >90 days. A slow increase in pH and the formation of a precipitate have been noted. The complete chemical analysis performed 12/93 is probably no longer valid. Uranium concentration and pH were determined *de novo* for the 2/94 testing. At pH 9.4, U is probably present exclusively as anionic complexes with hydroxide or carbonate.

¹ Trial 1: 0.341 mg U/g dry sorbent, 4.10 mg U/g dry cells. Trial 2: 0.210 mg U/g dry sorbent, 2.75 mg U/g dry cells (performed 12/93).

² Costs are for: 1) water treatment only, 2) treatment with immediate disposal, and 3) treatment with disposal after 10 years of storage at K-25. Assumptions: Disposal, \$100/ft³; Storage, \$35/ft³.

³ According to Dow's Brian Powers, most cationic water treatment resins are around \$70-100/ft³.

⁴ Delivered price ranges from \$390 (1-39 ft³) to 384/ft³ (700 ft³ and up).

⁵ Rohm and Haas did not list a C-246. The delivered price for C-26 (Na form) ranges from \$144 (1-39 ft³) to 138/ft³ (700 ft³ and up). No density was available but should be approximately the same as the other styrene divinylbenzene resins.

⁶ Price plus shipping from Michigan. 5 ft³ minimum. No discount for large quantities.

⁷ \$1990 for 10 kg, \$64,750 for 500 kg. Density = 49.9 lb/ft³. Note that testing was done on analytical grade, 200-400 mesh resin. Note that AG is the most expensive grade and 200-400 is an extremely fine (and expensive) material. For large scale columns, Bio-Rad recommends 20-50 or 50-100 mesh resins. The 200-400 mesh resins do not work well in packed-bed columns.

⁸ According to Brian Powers and other uranium mining industry sources, Dowex 21K anionic resin is the material commonly used to remove uranium from ground water. The minimum price is for truckload quantities (700 ft³). The maximum price is for 5-400 ft³.

⁹ Because testing on Dowex 21K was not performed 12/93, it was necessary to correlate the results from 2/94 testing with the earlier results. The following relationship was used to determine the 21K uranium loading that was used in KEI's economic analysis: $0.0767/1.34 = 1.2/x$. Therefore, $x = 21$ mg/g dry sorbent.

Source: KEI

Biosorbent

The factors that greatly affect biosorbent treatment costs are: 1) grams uranium adsorbed per gram biomass cells, 2) grams biomass cells per gram of foam, and 3) biomass materials costs. Each of these factors can be controlled to some degree.

- 1) Biosorbent research suggests that the grams of uranium adsorbed per gram biomass cells is a function of the kind of cells used (i.e., *pseudomonas aeruginosa*, *pseudomonas atlantica*). This capacity can sometimes be increased by pretreatments.
- 2) The current biosorbent foam is 39 wt.% biomass cells. According to W.R. Grace, the foam prepolymer manufacturer, it can be theoretically load to 80 wt.%. The researchers, however, have not attempted to produce such a foam. Nevertheless, KEI made an estimate of how a higher loading would affect treatment costs. As is apparent from these calculations, this variable affects treatment costs dramatically.

3) Biomass materials cost makes up almost 90% of the total biosorbent materials cost used in these calculations. Anything that can be done to decrease the \$50/kg cost for the biomass (provided to KEI by the researchers) will improve the economics. Note that the biomass and biosorbent costs used to determine the \$52/ft³ estimate are based on bench-scale production quantities. It is important to remember that the ion exchange costs are based on actual sales prices from a distributor.

The calculations for the biosorbent with two different cell loading are given below for three different assumed prices: \$52, 100, and 200/ft³. **The numbers not in parentheses are for Y-12 water while those in parentheses are for a uranyl nitrate solution.** For this calculation, KEI assumed both solutions have 6.1 ppm uranium.

39 wt.% foam (Density: 0.05714 g/cm³):

70 / 180 = 0.39 g cells/g foam
 0.39 x 0.05714 = 0.0223 g cells/cm³ foam
 0.0223 x 28,317 cm³/ft³ = 631 g cells/ft³ foam
 631 x 1.34 (2.13) mg U/g cell = 846 (1,344) mg U/ft³ foam
 846 (1,344) / (6.1) mg/l = 139 (220) l/ft³ foam
 139 (220) / 3.785 gal/l = 36.6 (58.1) gal/ft³ foam

\$52/ft³:

52 / 36.6 (58.1) gal/ft³ foam = \$1.42 (0.895)/gal
 1,000,000 / 36.6 (58.1) gal/ft³ foam = 27,322 (17,212) ft³
 27,322 (17,212) x \$100/ft³ = \$2.73 (1.72) mil
 1.42 (0.895) x 1,000,000 gal. water = \$1.42 (0.895) mil.
 27,322 (17,212) x \$35/ft³ x 10 yrs = \$9.56 (6.02) mil
 2.73 (1.72) + 1.42 (0.895) + 9.56 (6.02) = \$13.7 (8.64) mil
 13.7 (8.64) mil / 1,000,000 gal water = \$13.7 (8.64)/gal

\$100/ft³:

100 / 36.6 (58.1) gal/ft³ foam = \$2.73 (1.72)/gal
 1,000,000 / 36.6 (58.1) gal/ft³ foam = 27,322 (17,212) ft³
 27,322 (17,212) x \$100/ft³ = \$2.73 (1.72) mil
 2.73 (1.72) x 1,000,000 gal. water = \$2.73 (1.72) mil.
 27,322 (17,212) x \$35/ft³ x 10 yrs = \$9.56 (6.02) mil
 2.73 (1.72) + 2.73 (1.72) + 9.56 (6.02) = \$15.0 (9.46) mil
 15.0 (9.46) mil / 1,000,000 gal water = \$15.0 (9.46)/gal

\$200/ft³:

200 / 36.6 (58.1) gal/ft³ foam = \$5.46 (3.44)/gal
 1,000,000 / 36.6 (58.1) gal/ft³ foam = 27,322 (17,212) ft³
 27,322 (17,212) x \$100/ft³ = \$2.73 (1.72) mil
 5.46 (3.44) x 1,000,000 gal. water = \$5.46 (3.44) mil.
 27,322 (17,212) x \$35/ft³ x 10 yrs = \$9.56 (6.02) mil
 2.73 (1.72) + 5.46 (3.44) + 9.56 (6.02) = \$17.8 (11.2) mil
 17.8 (11.2) mil / 1,000,000 gal water = \$17.8 (11.2)/gal

80 wt.% foam (Density: 0.275 g/cm³):

4.4 / 5.5 = 0.80 g cells/g foam
 0.80 x 0.275 = 0.22 g cells/cm³ foam
 0.22 x 28,317 = 6,230 g cells/ft³ foam
 6,230 x 1.34 (2.13) = 8,348 (13,270) mg U/ft³ foam
 8,348 (13,270) / (6.1) mg/l = 1,369 (2,175) l/ft³ foam
 1,369 (2,175) / 3.785 gal/l = 362 (575) gal/ft³ foam

52 / 362 (575) gal/ft³ foam = \$0.144 (0.090) /gal
 1,000,000 / 362 (575) gal/ft³ foam = 2,762 (1,739) ft³
 2,762 (1,739) x \$100/ft³ = \$0.276 (0.174) mil
 0.144 (0.090) x 1,000,000 gal. water = \$0.144 (0.090) mil.
 2,762 (1,739) x \$35/ft³ x 10 yrs = \$0.967 (0.609) mil
 0.276 (0.174) + 0.144 (0.090) + 0.967 (0.609) = \$1.39 (0.87)
 1.39 (0.93) mil / 1,000,000 gal water = \$1.39 (0.87)/gal
 2.13 mg U/g cells = 0.0293 lb U/ft³ foam = \$1,775/ft³

100 / 362 (575) gal/ft³ foam = \$0.276 (0.174) /gal
 1,000,000 / 362 (575) gal/ft³ foam = 2,762 (1,739) ft³
 2,762 (1,739) x \$100/ft³ = \$0.276 (0.174) mil
 0.276 (0.174) x 1,000,000 gal. water = \$0.276 (0.174) mil.
 2,762 (1,739) x \$35/ft³ x 10 yrs = \$0.967 (0.609) mil
 0.276 (0.174) + 0.276 (0.174) + 0.967 (0.609) = \$1.52 (0.96)
 1.52 (0.87) mil / 1,000,000 gal water = \$1.52 (0.96)/gal

200 / 362 (575) gal/ft³ foam = \$0.552 (0.348) /gal
 1,000,000 / 362 (575) gal/ft³ foam = 2,762 (1,739) ft³
 2,762 (1,739) x \$100/ft³ = \$0.276 (0.174) mil
 0.552 (0.348) x 1,000,000 gal. water = \$0.552 (0.348) mil.
 2,762 (1,739) x \$35/ft³ x 10 yrs = \$0.967 (0.609) mil
 0.276 (0.174) + 0.552 (0.348) + 0.967 (0.609) = \$1.80 (1.13)
 1.80 (1.13) mil / 1,000,000 gal water = \$1.80 (1.13)/gal
 2.13 mg U/g cells = 0.0293 lb U/ft³ foam = \$6,826/ft³

39 wt.% Cell Loading

The following assumptions were made in the calculations that are summarized above: foam density = 0.05714 g/cm³; Y-12 water and uranyl nitrate solution: 5.6 ppm U and 0.5 ppm Fe; biosorbent cost = \$52, 100, and 200/ft³, disposal cost, \$100/ft³; K-25 storage cost (assumes disposal within 10 years), \$35/ft³.

The current biosorbent foam, which has a cell loading of 39 wt.%, has 0.0223 g cells/cm³ or 631 g cells/ft³. Based on the test results presented in Table 35, KEI assumed the cells will adsorb 1.34 mg/g cells. Therefore, each cubic foot of 39 wt.% foam will adsorb 846 mg uranium. For water having a 5.6 ppm uranium concentration and 0.5 ppm Fe (6.1 mg/l or 23 mg/gal), this biosorbent will treat 36.6 gal/ft³. It will treat 58.1 gal of the UN solution.

With Storage

For \$52/ft³ biosorbent, KEI estimates that treatment cost (including cost of disposal after 10 years storage at K-25) for one million gallons of Y-12 water is \$13.7 million (\$13.7/gallon) compared to \$8.64/gallon for UN. If the biosorbent cost is \$100/ft³ biosorbent, treatment cost for one million gallons of Y-12 water rises to \$15.0 million (\$15.0/gallon). If the cost of the biosorbent is \$200/ft³, which is closer to ion exchange pricing, the cost for Y-12 water rises to \$17.8 million (\$17.8/gallon).

Each of the Y-12 water estimates includes \$2.73 million for disposal cost of 27,322 ft³ of resin. If the spent resin is stored at K-25 prior to disposal, storage costs of \$35/ft³ are also incurred. Assuming the spent resin is stored for 10 years prior to disposal adds an additional cost of \$9.56 million per million gallons of water (\$9.56/gal) treated. For the purpose of this analysis, KEI assumed that disposal costs would stay constant during this 10-year period--an unlikely occurrence. Therefore, the disposal cost will most likely be even higher in 10 years.

Without Storage

The following are estimates of treatment cost assuming immediate disposal of spent sorbent. For \$52/ft³ biosorbent, KEI estimates that treatment cost for one million gallons of Y-12 water is \$4.15 million (\$4.15/gallon) compared to \$2.62 million for UN. If the biosorbent cost is \$100/ft³ biosorbent, treatment cost for one million gallons of Y-12 water rises to \$5.46 million (\$5.46/gallon). If the cost of the biosorbent is \$200/ft³, which is closer to ion exchange pricing, the cost rises to \$8.19 million (\$8.19/gallon).

80 wt.% Cell Loading

These assumptions were made for the 89 wt.% calculations: foam density = 0.275 g/cm³; Y-12 water and uranyl nitrate (UN) solution: 5.6 ppm U and 0.5 ppm Fe; biosorbent cost, \$52/ft³, disposal cost, \$100/ft³; K-25 storage cost (assumes disposal within 10 years), \$35/ft³.

An 80 wt.% cell loading is achieved with 4.4 g cells per 5.5 g foam (0.275 g/cm³). This is 0.22 g cells/cm³ or 6,230 g cells/ft³. If KEI assumes the cells adsorb 1.34 mg U/g cells, each cubic foot of 80 wt.% foam will adsorb 8,348 mg uranium. For water having a 5.6 ppm uranium concentration and 0.5 ppm Fe (6.1 mg/l or 23 mg/gal), the biosorbent will treat 362 gal/ft³. This compares with 575 gallons of UN solution.

With Storage

For \$52/ft³ biosorbent, KEI estimates that treatment cost (including cost of disposal after 10 years storage at K-25) for one million gallons of Y-12 water is \$1.39 million (\$1.39/gallon) compared to \$0.87 million for UN. If the biosorbent cost is \$100/ft³ biosorbent, treatment cost for one million gallons of Y-12 water rises to \$1.52 million (\$1.52/gallon). If the cost of the biosorbent is \$200/ft³, which is closer to ion exchange pricing, the cost rises to \$1.80 million (\$1.80/gallon).

Each of the Y-12 water estimates includes \$276,000 (\$0.276/gallon) for disposal cost of 2,762 ft³ of resin. If the spent resin is stored at K-25 prior to disposal, storage costs of \$35/ft³ are also incurred. Assuming the spent resin is stored for 10 years prior to disposal adds an

additional cost of \$967,000 per million gallons of water (\$0.97/gal) treated. For the purpose of this analysis, KEI assumed that disposal costs would stay constant during this 10-year period--an unlikely occurrence. Therefore, the disposal cost will most likely be even higher in 10 years.

Without Storage

The following are estimates of treatment cost assuming immediate disposal of spent sorbent. For \$52/ft³ biosorbent, KEI estimates that treatment cost for one million gallons of Y-12 water is \$420,000 (\$0.42/gallon) compared to \$264,000 for UN. If the biosorbent cost is \$100/ft³ biosorbent, treatment cost for one million gallons of water rises to \$550,000 (\$0.55/gallon). If the cost of the biosorbent is \$200/ft³, which is closer to ion exchange pricing, the cost rises to \$830,000 (\$0.83/gallon).

Ion Exchange

Because of the research focus on low pH conditions, the ion exchange resins tested until recently have been cationic resins that are known to be ineffective for removing uranium from ground water. In order to make a comparison with resin that is commonly used by the mining industry to remove uranium from water, KEI requested that the researchers determine the quantity of uranium that a gram of Dowex 21K (43 lb/ft³) will adsorb using the same Y-12 waste water that was previously used. The results from that test are also presented in Table 35. Note that KEI had to adjust the resin results in order to compare it with data from the testing that was done in December. Based on this adjustment, the loading for this resin is 21 mgU/g resin. A footnote in Table 35 describes how KEI determined this figure.

The following calculations show how the cost per gallon was determined for Y-12 waste water and for the uranyl nitrate solution described previously. **Y-12 waste water calculations for Dowex 21K are not in parentheses, while those in parenthesis represent Dowex 21K and Duolite, respectively, with the UN solution.** For these calculations, KEI assumed a concentration of 6.1 ppm for both the Y-12 water and the UN solution. Note that Dowex 21K removed less than two per cent of the uranium from the uranyl nitrate solution, while Duolite and biosorbent both removed around 94%.

21 (0.05; 2.2) mg U/g resin x 43 lb/ft³ resin x 454 g/lb = 409,962 (976; 42,948) mg U/ft³ resin
 409,962 (976; 42,948)/6.1 mg/l = 67,207 (160; 7,041) l/ft³ resin
 67,207 (160; 7,041)/3.785 gal/l = 17,756 (42; 1,860) gal/ft³ resin
 \$166/ft³ Dowex 21K resin; \$384/ft³ Duolite
 2.22 mg U/g resin = 0.0955 lb U/ft³ : assuming \$384/ft³ : \$4,021/lb U
 21 mg U/g resin = 0.903 lb U/ft³ ; assuming \$166/ft³ : \$184/lb U
 166 (384)/17,756 (42; 1,860) gal/ft³ resin = \$0.0093/gal or 0.93 cents/gallon (\$9.14/gal; 0.206)
 0.0093 (9.14; 0.206) x 1,000,000 gal water = \$9,300 (\$9.14 mil; 0.206 mil)
 1,000,000 / 17,756 (42; 1,860) gal/ft³ resin = 56 ft³ (23,810; 538)
 56 (23,810; 538) x \$100/ft³ = \$5,600 (2.38 mil; 53,800)
 5,600 (2.38 mil; 53,800) / 1,000,000 = \$0.0056/gallon or 0.56 cents/gallon (\$2.38/gal; 0.054)
 56 (23,810; 538) x \$35/ft³ x 10 yrs = \$19,600 (\$8.3 mil; \$188,300)
 19,600 (8.34 mil; 0.188 mil) / 1,000,000 = \$0.0196/gallon or 1.96 cents/gallon (\$8.3/gal; 0.188)
 9,300 (9.14 mil; 0.206 mil) + 5,600 (2.38 mil; 0.0538 mil) + 19,600 (8.3 mil; 0.188 mil) = \$34,500 (\$20 mil; 0.448 mil)
 \$34,500 (20 mil; 0.448 mil) / 1,000,000 gal water = \$0.035/gal or 3.5 cents/gallon (\$20/gal; 0.448)

[Note that the EPA's estimate of cost per gallon of treated water (95-100% removal efficiency) for ion exchange ranges from 0.148-0.556 cents/gallon (\$0.00148-0.00556/gallon) for water having a 10 pCi/L influent and a 1 pCi/L effluent and 0.161-0.584 cents/gallon (\$0.00161-0.00584/gallon) for water having a 50 pCi/L influent and a 2.5 pCi/L effluent. Refer to Table 51 and Figure 1 for more detailed information on ion exchange economics.]

EFFECTS OF URANIUM-REMOVAL LIMITS ON COSTS

The EPA analyzed a number of cost factors for uranium-removal technologies. The Agency evaluated the cost of reducing the uranium concentration in drinking water to two different levels: 1) technically feasible levels and 2) the Lifetime Individual Risk Level. Table 36 compares proposed and lowest feasible MCL options.

TABLE 36
COMPARISON OF PROPOSED AND LOWEST FEASIBLE MCL
OPTIONS FOR URANIUM

COST/BENEFIT	PROPOSED	ALTERNATE
MCL options (ug/L)	20	5
Lifetime risk	1×10^{-5}	3×10^{-5}
Cases avoided/yr	0.1*	0.6
Fraction of total cases avoided per year	0.17	0.33
Number of systems affected	1500	7200
Total \$M/yr	55	225
\$/rem(K)	380,000	700,000
\$/uCi	2	4
Increased \$M/case	57	----

* Approximately 900,000 people also reduced to exposure level with increased probability of kidney toxicity.

Source: *Federal Register*, Vol. 56, No. 138, Thursday, July 18, 1991. (EPA, 1991).

According to the *Federal Register*, uranium and radium-226 and -228, naturally occurring contaminants, are less prevalent than radon but are present in a significant number of water systems. The total person-remS ede and associated population risk attributable to these contaminants collectively are much lower than for radon alone, although in some communities individual risks from these contaminants exceed the target risk range. The Agency identified several technologies that are highly efficient in removing uranium and radium-226 and -228 from water. Based on this evaluation, uranium could be theoretically treated to a level lower than 5 pCi/L. Radium-226 and -228 could each be theoretically treated to a level lower than 2 pCi/L. The Agency also established practical quantitation level (PQLs) for these three radionuclides at 5 pCi/L for each. EPA's analysis indicated that it is technologically feasible to achieve control levels of 5 pCi/L for uranium and radium-226 and -228.

TECHNICALLY FEASIBLE LEVEL

The cost of reducing radioactivity and remS ede of delivered dose by removing uranium (and radium) to the technically feasible level is much greater than the cost of reducing radioactivity and remS ede by removing radon. First, the cost of the treatments for uranium and radium on a household basis, would be approximately \$20 to \$60 per year for large systems and \$700 to \$800 per year for the smallest systems. These costs are far greater

than for treatment of radon, which would be approximately \$4 per house per year for large systems and up to \$170 per house per year for the smallest systems.

The total number of both uCi and rems ede that would be removed by controlling radon at 300 pCi/L is much greater than the number that would be removed by controlling radium and uranium at the technically feasible levels. At the 300 pCi/L proposed standard for radon, nearly 8300 uCi annually, representing approximately 200,000 person-rems ede per year would be removed from drinking water. The total annual costs for removing this radiation by treating radon is about \$180 million. In contrast, at the technically feasible levels, 150 uCi, representing 86,000 rems ede of uranium and radium would be removed annually, at a cost of nearly \$400 million. The cost of removing radiation by controlling uranium and radium is approximately 200 fold greater per uCi removed and 5 fold per rem removed greater than that for radon treatment.

The Agency concludes that the cost of reducing radioactivity and rems ede of delivered dose by removing these three contaminants to the technically feasible level is disproportionate to the cost of reducing radioactivity and rems ede by removing radon. The Agency does not believe it would be reasonable to select maximum contaminant levels (MCLs) that would impose such disproportionate costs.

LIFETIME INDIVIDUAL RISK LEVEL

Since it is not cost effective to set the MCLs for uranium and radium at the technically feasible levels, EPA examined alternatives at the 10^{-4} lifetime individual risk level, which are approximately 20 ug/L (20 ppb) for uranium, 20 pCi/L for radium-226, and 20 pCi/L for radium-228. These levels are less costly but still assure that persons served by public water systems will not be exposed to a greater than approximately 10^{-4} risk. In addition, the uranium value is protective against kidney toxicity, which may occur at levels far below the 10^{-4} lifetime risk level for uranium. For drinking water contaminants, EPA has set a reference risk range for carcinogens (after regulation) at 10^{-4} to 10^{-6} excess individual risk from lifetime exposure and therefore considers an approximately 10^{-4} risk protective of human health. Based on these considerations, EPA proposes to set the MCL for uranium at 20 ug/L, radium-226 at 20 pCi/L, and radium-228 at 20 pCi/L.

BEST AVAILABLE TECHNOLOGY COSTS OVERVIEW

Annualized treatment and waste disposal costs for the radionuclide-treatment (uranium, radon, radium, beta, and alpha) regulations under consideration are approximately \$307 million, assuming that process residuals are disposed of as sanitary wastes. Over 60 per cent of this annual cost is attributed to the radon standard of 300 pCi/L, which is estimated to affect nearly 26,000 systems. Monitoring costs, averaged over an 18-year time frame, are estimated to be \$6.5 million per year. Costs to state programs are estimated by the EPA and the Association of State Drinking Water Administrators to range from \$15 to 28\$ million during an initial phase of promulgation and \$10 to \$19 million per year to support ongoing compliance and enforcement actions by the states in the out years.

Thus, total annual costs for regulating radionuclides at the proposed MCLs average over \$325 million annually for approximately 27,627 affected systems. Of this total, uranium treatment is expected to comprise approximately \$55 million for 1,446 systems. The benefits of removing these radionuclides from drinking water are: 84 fewer cancer cases per year and reducing exposure to uranium for 900,000 individuals. The majority of these 84 cases, approximately 80, would result from controlling the levels of radon in drinking water. Existing concentrations of the radionuclides contribute to approximately 226 baseline cancers annually.

COST FACTORS AND ASSUMPTIONS

Much of the cost/benefit information contained in the following sections was obtained from proposed EPA rule changes discussed in the *Federal Register* (Vol. 56, No. 138, Thursday, July 18, 1991) and from the following four documents:

- *Technologies and Costs for the Removal of Uranium from Potable Water Supplies* prepared by V.J. Ciccone & Associates, Inc. for the U.S. EPA Office of Drinking Water, Criteria and Standards Div., Oct. 1985 (1982 cost estimates).
- *Technologies and Costs for the Removal of Uranium from Potable Water Supplies* prepared by Malcolm Pirnie, Inc. for the U.S. EPA Office of Drinking Water, Criteria and Standards Div. (EPA project officer: Stephen W. Clark), Dec.30, 1986 (1986 cost estimates).
- *Regulatory Impact Analysis of Proposed National Primary Drinking Water Regulations for Radionuclides*, prepared by Wade Miller Associates, Inc. for the U.S. EPA Office of Drinking Water, EPA project manager: Steve Folsom, July 1991 (1991 cost estimates).
- *The Cost of Compliance With the Proposed Federal Drinking Water Standards for Radionuclides*; prepared by RCG/Hagler, Bailly, Inc. for the American Water Works Association, Water Industry Technical Action Panel; Oct. 10, 1991.

Note that KEI was unable to perform a full-scale economic analysis to update the 1991 cost estimates to 1994 dollars due to the limited time allowed for completion of this project. Table 37 summarizes EPA's estimates of the national costs and benefits of proposed maximum concentration levels (MCLs) for uranium in drinking water.

TABLE 37
NATIONAL COSTS¹/BENEFITS SUMMARY OF PROPOSED
MCLS FOR URANIUM IN DRINKING WATER

Proposed MCL	20 ug/L
Cancer cases avoided/yr.	0.2
Systems affected	1,446
System size <10 K	1,445
System size >10 K	1
Treatment cost	
Total capital	\$347M
System size <10 K	\$339 M
System size >10 K	\$7.7M
Total annual cost	\$55yr
System size <10 K	\$53 M/yr
System size >10 K	\$1.4M
Annual O&M	\$32M
System size <10 K	\$31 M
System size >10 K	\$0.9M
Gross alpha monitoring	\$0.003M/yr
State implementation	
Initial	NA
Annual	NA
Annual household cost by system size	
Very small (25-500)	\$580
Small (501-3,300)	\$180
Medium (3,301-10,000)	\$80
Large (over 10,000)	\$40

¹ The original source for this information did not specify 1986 dollars, although this is most likely the case.

Source: *Federal Register*, Vol. 56, No. 138, Thursday, July 18, 1991.

General Assumptions

This report presents EPA's 1982 and 1986 cost estimates for uranium-removal BATs. EPA cost estimates assume the existence of no residential point-of-use (POU) water treatment such as water softening for aesthetic reasons, which might incidentally reduce some pollutant levels. The prevalence of such home treatments is extremely difficult to estimate and incorporate into a national-level analysis.

Note that costs may vary significantly from those presented in this report, depending on local circumstances. Costs of treatment will be less if contaminant concentration levels encountered in the raw water are lower than those used for the calculations. However, costs of treatment will be higher if additional treatment or storage requirements need to be satisfied. The costs in these tables do not include those attributable to the treatment and disposal of wastes generated by water treatment plants. These costs do include, however, sanitary sewer charges for disposal. Note that costs for disposal of waste by-products are addressed separately in a report prepared by Malcolm Pirnie, Inc. for the U.S. EPA entitled, *Technologies and Costs for the Treatment and Disposal of Waste By-products from Water Treatments for the Removal of Inorganic and Radioactive Contaminants*.

For all the uranium removal or control technologies, design and unit costs should be viewed as preliminary to be used only for planning purposes by a community with a specific uranium removal problem. More and detailed designs and cost estimates should be developed based upon pilot-plant testing and site-specific considerations. Note that EPA did not propose coagulation/filtration or lime softening as BAT for small systems (i.e., ≥ 500 connections) because they are not technologically feasible for such systems. These treatments are considered too complex in terms of operating time and levels of technical and managerial expertise usually available at small systems. In addition, costs of installing and operating reverse osmosis and ion exchange are high for small systems relative to costs for large systems. As a result, the EPA has conducted an additional study on treatment methods for very small water systems. The results of that study, in which 1982 cost estimates were updated to 1986 dollars, are also included in this report. Table 38 itemizes some of the assumptions that were made by the EPA in developing 1982 and 1986 BAT treatment costs for uranium removal.

TABLE 38
GENERAL ASSUMPTIONS MADE IN DEVELOPING TREATMENT
COSTS FOR URANIUM REMOVAL¹

	MID-1982 ²	LATE-1986 ³
Electric power	\$0.07 Kwh	0.086 Kwh
Labor		
Small systems (<150,000 gpd)	\$4.55/hr	\$5.90/hr
Large systems (>150,000 gpd)	\$11.00/hr	\$14.30/hr
Diesel fuel	\$1.00/gall	\$0.8/gal
Natural gas	\$0.004/scf	\$0.0027/scf
CCI index	356	405
PPI index	280	301
Sitework	15% of construction costs	Same
Contractor's overhead & profit	12% of construction costs (including sitework)	Same
Contingencies	15% of construction costs	Same
Engineering & technical fee	15% of construction costs (including sitework & contractor's O&P)	Same
Interest rate	12%	10%
Number of years	20	20
CHEMICAL COSTS⁴		Small System/Large System⁵
Alum, dry (17% Al ₂ O ₃)	235	500/250
Liquid alum (50% alum)	255	300/125
Lime (quick lime)	31.23	100/75
Lime (slaked lime)	32.50	
Lime (hydrated)	---	150/100
Ferric chloride (anhydrous)	176	500/275

	MID-1982 ²	LATE-1986 ³
Ferrous sulfate (heptahydrate)	115	200/155
Ferric sulfate (partly hydrated)	118	277/250
Soda ash (light)	150	250/200
Sodium hydroxide	520	595/316
Chlorine (liquid)	145	500/300
Sodium hypochlorite	---	190/150
Sodium hypochlorite (14% Cl ₂)	0.82/lb.	---
Calcium hypochlorite (65% Cl ₂)	94.50/100 lb. drum	---
Polyelectrolyte	2.00/lb.	1,500/1,000
Liquid carbon dioxide	0.05/lb.	350/100
Sodium hexametaphosphate	0.32/lb.	1,180/1,100
Bi-metallic phosphate	1.80/lb.	---
Ammonia, aqua	210	230/200
Ammonia, anhydrous	---	410/350
Sulfuric acid (66° Baume)	80	140/100
Hydrochloric acid	70	171/166
Powdered activated carbon	0.35/lb.	950/800
Granular activated carbon	1.00/lb.	1,900/1,600
Activated alumina	30/ft ³	1,694/1,156
Salt	50	105/85
Potassium permanganate	3.62/lb.	2,800/2,500
Sodium bisulfite (anhydrous)	0.29/lb.	909/673
Sodium silicate	0.17/lb.	400/200
Cation resin	264/ft ³	---
Anion resin	71/ft ³	---
Diatomaceous earth	---	680/310
Magnesium	---	650/582
Sodium chlorite	---	3,200/2,800
Sodium hydroxide, 76%	---	590/316
Sodium bicarbonate	---	490/380
Calcium hypochlorite	---	2,700/1,540

¹ Site-specific circumstances may result in considerable variations from the costs encountered by typical systems. Not all costs presented here are required for uranium removal systems.

^{2, 3} See source at end of table.

⁴ \$/ton unless otherwise noted.

⁵ Note that the 1982 cost estimates did not reflect the differences in chemical costs for large systems versus small systems.

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by V.J. Ciccone & Associates, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., Oct. 1985²; *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by Malcolm Pirnie, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., EPA project officer: Stephen W. Clark, Dec. 30, 1986³.

1982 Estimates

Capital and Operating Costs

Capital and operating costs (1982) for the technologies were established for the EPA based on inputs, reviews, and discussions with staff members from EPA Office of Drinking Water, EPA Municipal Environmental Research Laboratory (MERL), engineering consultants, actual experiences, and equipment manufacturers. Table 39 lists by system size (in million gallons/day) the unit processes that were included in cost estimates.

TABLE 39
UNIT PROCESSES APPLIED TO SYSTEM SIZE CATEGORIES (1982)

UNIT PROCESS	SYSTEM SIZE (MILLION GALLONS/DAY)								
	0.01	0.04	0.14	0.44	0.90	1.55	8.82	76	722
Wells	X	X	X	X	X	X	X	--	--
Well pump, turbine	X	X	X	X	X	X	X	--	--
Well pump, submersible	X	X	X	X	X	X	X	--	--
Transmission pipeline	X	X	X	X	X	X	X	X	X
Pump station	X	X	X	X	X	X	X	X	X
Impounded reservoir	X-S	X-S	X-S	X-S	X-S	X-S	X-L	X-L	X-L
Intake tower	--	--	--	--	--	--	X-L	X-L	X-L
Raw water pumping	X	X	X	X	X	X	E	E	E
Packaged treatment plant	X	X	X	X	X	X	--	--	--
Sludge handling	X-S	X-S	X-S	X-S	X-S	X-S	X-L	X-L	X-L
Rapid mix and coagulation	--	--	--	--	X	X	E	E	E
Clarification	--	--	--	--	X	X	E	E	E
Gravity filtration	--	--	--	--	X	X	E	E	E

X: New facility; E: Existing facility; X-S: Small design; X-L: Large design

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by V.J. Ciccone & Associates, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., Oct. 1985.

The 1982 costs for new systems designed for capacities >1,000,000 gallons/day were determined from equations developed by MERL using the computer model written for EPA by Culp/Wesner/Culp, which was presented in EPA publications, *Estimating Water Treatment Costs, Vol. 1-3* (EPA-600/2-79-162a,b,c). For new systems designed for capacities <1,000,000, costs were developed through a coordinated effort involving EPA and several engineering firms actively working with treatment technologies for drinking water. Much of the cost information was obtained for the EPA from ongoing studies, data banks, visitation of actual installations and personal contact with equipment manufacturers, design engineers, and construction firms.

Capital costs are based on the design capacity of the plant and are presented as costs per year updated to 1982 dollars using the Engineering News Record (ENR) average of the annual Construction Cost Index (CCI) for 20 U.S. cities. Operating costs are based on the average annual water production capacity of the plant and the Producer Price Index (PPI) for 1982 dollars. Operating and maintenance (O&M) costs include sewer charges for waste water disposal based upon the plant capacity for the system. For the purpose of estimating costs per 1,000 gallons, the capital costs were amortized over 20 years at a 12 per cent interest rate. Costs for acquiring new land for construction sites or easements for a raw water transmission line are not included since these costs are extremely site specific; however, these costs when included would be a significant factor.

In this analysis, waste water disposal for all technologies was by discharge to a sanitary sewer, sludge and solids from settling basins are deposited in landfills and costs estimated as an annual O&M cost. In some locations, sanitary sewers may not be available or may not be acceptable, and other more expensive waste water disposal methods would be required. Waste water disposal could be an important factor in determining the feasibility of treatment for some systems. In addition to the BATs (modified coagulation/filtration, modified lime softening, ion exchange, and reverse osmosis), cost estimates were also provided in the EPA analysis for bottled water, regionalization, and alternate source. These topics are beyond the scope of this report, but statistics may be included in some of the tables for comparison purposes.

Efficiencies

Table 40 summarizes uranium-removal efficiencies that have been reported in the literature.

**TABLE 40
BEST AVAILABLE TECHNOLOGY EFFICIENCIES**

TREATMENT	URANIUM REMOVAL, %	COMMENTS
Coagulation/ filtration	89-95 (pH10) 50-60 (pH 6) 20-40 (pH 4,8)	Laboratory scale tests: coagulation of 0.085 mg/L U-237-spiked pond water using aluminum sulfate and ferric sulfate dosages of 10 to 25 mg/L in the pH range 4 to 10; carbonate and bicarbonate alkalinity 100 mg/L.
	72-100	Jar tests: coagulation of 0.06 mg/L naturally occurring uranium water with aluminum sulfate dosages of 10 to 200 mg/L; no pH or alkalinity values available.
	50-78	Conventional water treatment plant: coagulation of 0.016 mg/L uranium raw waters with 10 mg/L aluminum sulfate, polymer and lime at pH 7.5; alkalinity 20 to 30 mg/L; finished water pH 7.8.
	18-90	Conventional water treatment plant: coagulation of 0.001 mg/L to 0.036 mg/L uranium waters using 12 to 25 mg/L aluminum sulfate and 0.8 mg/L polymer at pH 7.5; alkalinity 20 to 30 mg/L; finished water pH 7.2.

TREATMENT	URANIUM REMOVAL, %	COMMENTS
Lime softening	85-99 (pH>10.6) 15 (pH 9.9)	Laboratory scale tests: lime softening of 0.083 mg/L U-237-spiked pond water with indigenous manganese content and pH 8.5, modified with NaOH and HCl, using dosages of 50 to 250 mg/L $\text{Ca}(\text{OH})_2$ and MgCO_3 powder up to 35 mg/L; carbonate and bicarbonate alkalinity 100 mg/L.
	11-100	Jar tests: coagulation of 0.06 ug/L naturally occurring uranium water with 100 to 400 mg/L lime; no pH or alkalinity values available.
Ion exchange	63-99	Laboratory strong base anionic resin exchange columns: used 0.3 mg/L uranium-contaminated natural waters without filtration through 9,000 to 30,000 gal/ft ³ of resin and a corresponding 800 to 4,000 bed volumes; prepassage filters extended one column's treatment capacity to 209,000 gal/ft ³ of resin, or 28,000 bed volumes, at 63 per cent removal.
	99	Twelve individual home point-of-use ion exchange installations: includent uranium (natural waters) ranging between 0.022 and 0.104 mg/L; efficiencies of removal remained high in units at 12,000 through 65,000 bed volumes.
	99	Laboratory scale anionic exchange resin columns: used with 0.06 mg/L uranium-contaminated waters; 48 bed volumes.
	35-97	Laboratory scale anionic exchange resin columns; uranium-mine waters; no loadings or capacities reported.
Reverse osmosis	99.5	Laboratory-scale test: used with cellulose acetate membrane on natural waters with uranium concentrations varying between 0.53 and 0.88 mg/L; no specifics for pH or pretreatment.
	98-99.4	Industrial waste stream: used cellulose acetate membrane on wastes with 100 to 8,000 mg/L uranyl sulfate; no specifics for pH or pretreatment.
	97	Mine waste: used cellulose acetate membrane on synthetic mine waste with 30 mg/L uranium concentration; no specifics for pH or pretreatment.
Electrodialysis	80.3	Mine waste: used commercial unit in three-month continuous test at 30,000 gallons per day; pretreatment with CO_2 ; influent pH adjustment to 5.8-6.0 with HCl.

TREATMENT	URANIUM REMOVAL, %	COMMENTS
Activated alumina	50-99	Municipal water: used laboratory activated alumina column on a Florida water with 0.273 mg/L uranium contaminated with natural water with prepassage filtration through 14,000 to 30,000 gal/ft ³ of alumina and corresponding 2,000 to 4,100 bed volumes.

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by V.J. Ciccone & Associates, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., Oct. 1985.

1986 Estimates

Capital and Operating Costs

The 1986 capital and operating costs were determined using the updated computer model written for the USEPA by Culp/Wesner/Culp entitled, *Water Cost: A Computer Program for Estimating Water and Waste Water Treatment Costs*. The capital costs presented were updated to late 1986 dollars using indices specific to the major cost components of the construction cost. The Bureau of Labor Statistics (BLS) and Engineering News Record (ENR) indices used for updating the capital costs are given in Table 41. Table 38 lists the Producers Price Index for Finished Goods, which was used to update the cost of maintenance materials, a component in the operations and maintenance cost.

TABLE 41
COST INDICES FOR LATE 1986

DESCRIPTION	INDEX REFERENCE	NUMERICAL VALUE
General purpose machinery	BLS 114	329.3
Concrete	BLS 132	343.9
Steel	BLS 1017	373.4
Skilled labor	ENR U.S. Average	385.3
Pipe & valves	BLS 1149	352.8
Electrical	BLS 117	259.2
Housing	ENR Building Cost	367.2
Housing	\$/ft ²	150.00

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by Malcolm Pirnie, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., EPA project officer: Stephen W. Clark, Dec. 30, 1986.

Other cost considerations such as chemical costs are also listed previously in Table 38. For the purpose of estimating 1986 costs per 1,000 gallons, the capital costs were amortized over 20 years at a 10 per cent interest rate. Costs for acquiring new land for construction sites or easements for a raw water transmission line are not included since these costs are site specific. However, these costs when included would be a significant factor.

Costs for finished water pumping and storage were also included in the source document but were not included here. All large system costs include costs for finished water storage but do not include costs for finished water pumping. Small systems costs do not include either finished water pumping or storage. Depending upon individual requirements, costs from Table 42 may be added or deducted from the costs developed for each process.

TABLE 42
UNIT PROCESSES APPLIED TO SYSTEM SIZE CATEGORIES (1986)

UNIT PROCESS	SYSTEM SIZE (MILLION GALLONS/DAY)											
	0.06	0.14	0.31	0.96	3.06	7.52	15.44	25.33	44.15	123.88	464.85	1504.63
Wells	X	X	X	X	X	X	X	--	--	--	--	--
Well pump, turbine	X	X	X	X	X	X	X	--	--	--	--	--
Well pump, submersible	X	X	X	X	X	X	X	--	--	--	--	--
Transmission pipeline	X	X	X	X	X	X	X	X	X	X	X	X
Pump station	X	X	X	X	X	X	X	X	X	X	X	X
Impounded reservoir	X-S	X-S	X-S	X-S	X-S	X-L	X-L	X-L	X-L	X-L	X-L	X-L
Intake tower	--	--	--	--	--	X-L	X-L	X-L	X-L	X-L	X-L	X-L
Raw water pumping	X	X	X	X	X	E	E	E	E	E	E	E
Packaged treatment plant	X	X	X	X	X	--	--	--	--	--	--	--
Rapid mix and coagulation	--	--	--	X	X	E	E	E	E	E	E	E
Clarification	--	--	--	X	X	E	E	E	E	E	E	E
Gravity filtration	--	--	--	X	X	E	E	E	E	E	E	E
X New facility E Existing facility X-S Small design X-L Large design												

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by Malcolm Pirnie, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., EPA project officer: Stephen W. Clark, Dec. 30, 1986.

Efficiencies

The uranium influent/effluent combinations that were used for developing 1986 cost estimates are shown in Table 43 along with the per cent removal associated with each combination. Unless otherwise noted, costs for influent/effluent combinations that require process efficiencies less than the maximum removal efficiency of the specific process are based upon the assumption that only a portion of the flow is treated and blended with untreated water to achieve the desired effluent concentrations.

TABLE 43
INFLUENT/EFFLUENT COMBINATIONS AND EFFICIENCIES

INFLUENT CONCENTRATION, pCi/L	EFFLUENT CONCENTRATION, pCi/L	REMOVAL, %
50	30	40
	10	80
	1	98
30	20	33
	10	66.7
	1	96.7
10	1	90

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by Malcolm Pirnie, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., EPA project officer: Stephen W. Clark, Dec.30, 1986.

Plant Size

Small water systems are defined as those with design flow requirements less than 1.0 million gallons per day. Several surveys of small systems were performed for the EPA to determine characteristics such as system-supply capacity, treatment-design capacity, average-day-flow requirements, and system-storage capacity. The survey results, coupled with data collected informally from other small water systems, lead to the definition of flow characteristics for four flow categories as defined below. Table 44 lists plant characteristics such as capacities and average plant ground water flows.

Assumptions by BAT

This section presents the assumptions that were used by the EPA in generating the cost estimates for each uranium-removal BAT and groups them into two classifications: utility-scale and point-of-use treatments.

Centralized Treatment Facilities

Modified Coagulation/Filtration

1982: For the purpose of developing 1982 cost estimates, the following assumptions were used:

- Uranium concentration in the feed water: 0.3 mg/L.
- New chemical feeding equipment for coagulants and pH control will be installed. Other existing treatment facilities are adequate and acceptable for the modification.
- Ferric sulfate dose is 10 mg/L; 7.5 mg/L of lime is added for raising the pH for ferric sulfate coagulation; or alum, 20 mg/L is used to coagulate at pH 6.0 and cationic polyelectrolyte added at 0.2 mg/L.
- Soda ash or acid chemical feeder added to adjust pH of product water to pH 8.0.

TABLE 44
CAPACITIES AND AVERAGE FLOWS FOR ALL GROUND WATER
TREATMENT SYSTEMS

SYSTEM SIZE CATEGORY	POPULATION RANGE	AVERAGE PLANT DAILY FLOW (MGD)	GROUND WATER SYSTEM SUPPLY CAPACITY (MGD)	TREATMENT DESIGN CAPACITY (MGD)	STORAGE CAPACITY (MGD)
1*	25-100	0.013	0.06	0.026	0.034
2*	101-500	0.045	0.14	0.068	0.072
3*	501-1,000	0.133	0.31	0.166	0.155
4*	1,001-3,300	0.40	0.96	0.500	0.460
5	3,301-10,000	1.30	3.06	NA	NA
6	10,001-25,000	3.25	7.52	NA	NA
7	25,001-50,000	6.75	15.44	NA	NA
8	50,001-75,000	11.50	25.33	NA	NA
9	75,001- 100,000	20.00	44.15	NA	NA
10	100,001- 500,000	55.50	123.88	NA	NA
11	500,001- 1,000,000	205.00	464.85	NA	NA
12	>1,000,000	650.00	1,504.63	NA	NA

* Considered to be "small systems."

Source: Adapted from *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by Malcolm Pirnie, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., EPA project officer: Stephen W. Clark, Dec. 30, 1986.

Unit processes used to estimate low- and high-range costs for the removal of uranium by modified coagulation/filtration are shown in Table 45. The low-range costs represent the substitution of ferric sulfate for the existing coagulant and coagulating feed water at pH 10. The high-range costs represent the use of alum and coagulation of feed water at pH 6.0 with addition of a polyelectrolyte. The cost estimates for various plant capacities are average costs for the low- and high-range systems.

1986: For the purposes of developing updated cost estimates, the following assumptions were used for the low-range costs:

- Ferric sulfate is substituted for the existing coagulant and is fed at 10 mg/L. A lime feed system is added to feed 7.5 mg/L of lime to raise the pH for ferric sulfate coagulation to pH 10.
- A soda ash feed system is added to feed 5 mg/L to adjust the pH of the product water to pH 8.

TABLE 45
PROCESSES USED TO DETERMINE 1982 COSTS OF MODIFIED
COAGULATION/FILTRATION FOR URANIUM REMOVAL

PROCESS	COST RANGE	
	LOW	HIGH
Ferric sulfate feeder	x	--
Lime feeder	x	--
Acid feeder	x	x
Soda ash feeder	--	x
Alum feeder	--	x
Polymer feeder	--	x

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by V.J. Ciccone & Associates, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., Oct. 1985.

The assumptions used for the high-cost range are as follows:

- An alum feed system is added to feed 20 mg/L of alum for coagulation at pH 6.0.
- Also added is a polymer feed system to feed 0.2 mg/L of cationic polyelectrolyte.
- A soda ash feed system is added to feed 5 mg/L to adjust the pH of the product water to pH 8.0.

The low-range costs represent the substitution of ferric sulfate for the existing coagulant and coagulating feed water at pH 10. The high-range costs represent the use of alum and coagulation of feed water at pH 6.0 with the addition of a polyelectrolyte. The unit processes used to estimate the low- and high-range costs are listed in Table 46.

TABLE 46
PROCESSES USED TO DETERMINE 1986 COSTS OF MODIFIED
COAGULATION/FILTRATION FOR URANIUM REMOVAL

PROCESS	COST RANGE	
	LOW	HIGH
Ferric sulfate feeder	x	--
Lime feeder	x	--
Soda ash feeder	x	x
Alum feeder	--	x
Polymer feeder	--	x

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by Malcolm Pirnie, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., EPA project officer: Stephen W. Clark, Dec. 30, 1986.

Modified Lime Softening

1982: For the purpose of developing 1982 cost estimates, the following assumptions were used:

- Uranium concentration in the feed water: 0.3 mg/L.
- The existing lime softening plant is adequate and can be modified to permit softening at a higher pH range.
- Lime dosage is increased by 100 mg/L for excess lime treatment and to raise the pH to 11.5.
- Where recarbonation facilities are not existing, new recarbonation basins (15-minute detention) and CO₂ feed systems are installed.

The low-range costs represent a lime softening plant modified to increase the lime dosage and operate at a higher pH. The high-range costs include increasing the lime dosage and adding facilities for recarbonation. The cost estimates for the various plant capacities are average costs of the low- and high-range systems.

1986: For the purpose of developing updated cost estimates, the following assumption were used for the low-range costs:

- Addition of a lime feed system to feed 100 mg/L of lime for excess lime treatment and to raise the pH to 11.5.

The assumptions used for the high-range costs include those for the low-range costs plus the following:

- Recarbonation facilities will be added that include recarbonation basins sized on the basis of a 50-minute detention time along with a carbon dioxide feed system that will feed 35 mg/L of carbon dioxide.

The low-range costs represent a lime softening plant modified to increase the lime dosage and operate at a higher pH. The high-range costs include increasing the lime dosage and adding facilities for recarbonation.

Ion Exchange

1982: For 1982 cost estimates, the following assumptions were made:

- Uranium concentration in the feed water: 0.3 mg/L.
- The water supply has the following anion contents: sulfate = 72 mg/L; total dissolved solids (TDS) = 400 mg/L.
- Strong base anion exchange resins are replaced after 21,000 bed volumes.
- All system capacities less than 10,000,000 gal./day have pressure ion exchange tanks with baked phenolic lining, pumping equipment for service flow and backwash.
- Systems of 10,000,000 gal./day or larger have gravity flow ion exchange beds.
- Electrical energy for building heating, cooling, ventilation, and lighting is 70 Kwh/ft² of building area per year. Pumping energy for backwash, regeneration and rinse is calculated based on a total dynamic head (TDH) of 25 feet. No feed water pumping is included.
- Maintenance materials are one per cent of construction costs.

- Labor for operation and maintenance other than replacement of resin is two hours/day.
- Waste water discharge is to a sanitary sewer and spent resin is hauled to a landfill.
- Blending is not included in the operating modes.

The low-range costs represent a fixed-bed ion exchange treatment system using a source water that requires no pretreatment. The high-range costs include filtration for pretreatment. Costs for both ranges include waste disposal to the sewer and do not include chlorination since chlorine is not essential to the removal of uranium. If spent resin cannot be hauled to the local landfill, the system costs will increase. Unit processes used in estimating the low- and high-range costs are listed in Table 47. The cost estimates for various plant capacities shown in Figure 1 are average costs of the high- and low-range systems.

TABLE 47
PROCESSES USED TO DETERMINE 1982 COSTS OF ION
EXCHANGE FOR URANIUM REMOVAL

PROCESS	COST RANGE	
	LOW	HIGH
Filtration system	--	x
Ion exchange, system*	x	x
Clearwell, below ground	--	x
Filter, backwash pumping	--	x
Filter, surface wash	--	x
Filter media, sand	--	x
Waste water to sewer	x	x

* Includes facilities for process pumping, system housing, instrumentation, and chemical storage.

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by V.J. Ciccone & Associates, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., Oct. 1985.

1986: For the purpose of developing updated 1986 cost estimates, the following design criteria were used for the low-range costs:

- Process is designed for 95 per cent removal of uranium. In the cases where influent/effluent combinations required removal efficiencies less than 95 per cent only a portion of the flow would be treated.
- The water supply has the following anion contents: sulfate = 72 mg/L; TDS = 400 mg/L.
- Strong base anion exchange resins are replaced after 21,000 bed volumes.
- All system capacities less than 10,000,000 gal./day have pressure ion exchange tanks with baked phenolic lining.
- All systems greater than 960,000 gal./day capacity have additional pumping equipment for backwash to reclassify the resin.
- Systems of 10,000,000 gal./day or larger have gravity flow ion exchange beds.
- Energy for building heating, cooling, ventilation, and lighting is 70 Kwh/ft² of building area per year. No feed water pumping is included.
- Maintenance materials are one per cent of construction costs.
- Labor for operation and maintenance is two hours/day.

The design criteria used for the high-cost range include all those for the low-cost range plus the following:

- Dual media filtration at 5 gpm/ft².
- Filter backwash facilities sized at 18 gpm/ft², and hydraulic surface wash.

The low-range costs represent an ion exchange system as an add-on to existing water clarification treatment processes. The high-range costs represents filtration followed by ion exchange. Unit processes used in estimating the low- and high-range costs are listed in Table 48.

TABLE 48
PROCESSES USED TO DETERMINE SYSTEM 1986 COSTS OF ION EXCHANGE FOR URANIUM REMOVAL

PROCESS	COST RANGE	
	LOW	HIGH
Filtration, gravity	--	x
Ion exchange, system	x	x
Clearwell, above ground	--	x
Filter, backwash pumping	--	x
Filter, surface wash	--	x
Filter media, dual	--	x

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by Malcolm Pirnie, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., EPA project officer: Stephen W. Clark, Dec. 30, 1986.

Reverse Osmosis

1982: For the purpose of developing cost estimates for reverse osmosis, the following assumptions were used:

- Uranium concentration in the feed water: 0.3 mg/L.
- Cellulose acetate spiral wound or polyamide hollow fiber membranes with 98 per cent salt rejection capable of treating raw water with TDS of 5,000 mg/L in a single pass at 400 psi with a water recovery rate of 75 per cent and water temperature of 25°C are used.
- Facility includes all treatment equipment, structural steel and metalwork, tanks, piping, valves, high pressure pump, reverse osmosis membranes and pressure vessels, membrane cleaning equipment, cartridge filters, chemical metering pumps for acid and sodium hexametaphosphate and degasifier.
- Reverse osmosis equipment with controls and instrumentation panel are skid mounted units or multiples of such units.
- Pretreatment, when added, includes multimedia filtration at 5.0 gpm/ft² with cationic polyelectrolyte continuously added to feed water at a rate of 2.0 mg/L.
- For systems greater than 1,000,000 gallons/day capacity, separate filter backwash pumping facilities are provided.
- Pumping equipment for raw water and product water are not included.

- Degasifier equipment for treatment of reverse osmosis effluent is located outside of the building. Other equipment is housed.
- Electrical energy for building heating, lighting, and ventilation is 70 Kwh/ft² of building area per year. Process energy for high pressure pump is calculated at 60 per cent pump efficiency and process energy for the degasifier is 10 per cent of the high pressure pump.
- Labor varies with size of the system with a minimum of one man-hour/day for the systems smaller than 1,000,000 gallons/day.
- Reverse osmosis membrane cleaning cycle is every six months. A three-year operating life is anticipated for membranes.
- Sodium hexamethaphosphate is fed continuously at a rate of 5 mg/L and sulfuric acid at a rate of 100 mg/L for inhibiting scale deposition on membrane surfaces.
- Cartridge filters, replaced every six weeks are operated at 1.5 gal/min/ft².
- Discharge of waste water to sewer.

The unit processes used to estimate low-range and high-range costs for the removal of uranium by reverse osmosis are shown in Table 49. Blending of water is not considered for this cost estimate. Many site-specific factors will affect these costs. However, in this analysis the quality of the water source is the site specific factor used for estimating the low- and high-range costs. The low-range costs represent a clean water source that requires no pre-clarification processes, and the high-range costs represent a turbid water source requiring filtration.

TABLE 49
PROCESSES USED TO DETERMINE 1982 COSTS OF REVERSE
OSMOSIS FOR URANIUM REMOVAL

PROCESS	COST RANGE	
	LOW	HIGH
Polymer feed system	--	x
Filtration system	--	x
Filter media, mixed	--	x
Reverse osmosis system*	x	x
Filter wash water tank	--	x
Filter, backwash	--	x
Filter, surface wash	--	x
Waste water to sewer	x	x

* Includes reverse osmosis equipment, cartridge filters, sodium hexametaphosphate feed, instrumentation, process pumping, degasifier, and sulfuric acid feed and system housing.

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by V.J. Ciccone & Associates, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., Oct. 1985.

1986: For the purpose of developing updated cost estimates for the low-cost range, the following assumptions were used:

- A clean water source requiring no pre-clarification.
- Process is designed for 95 per cent removal of uranium. In those cases where influent/effluent combinations require removal efficiencies less than 95 per cent, only a portion of the flow is treated.
- Cellulose acetate spiral wound or polyamide hollow fiber membranes with 93 per cent salt rejection capable of treating raw water with TDS of 5,000 mg/L for small systems and 10,000 mg/L for large systems in a single pass at 400 to 450 psi.
- The temperature of the feed water is assumed to be between 65°F and 95°F.
- For design capacities of 960,000 gal/day and less, packaged reverse osmosis systems were used. Systems larger than this are site constructed. A building is provided for chemical storage, administration, laboratory, and maintenance requirements.
- Facility includes all treatment equipment, structural steel and metalwork, tanks, piping, valves, high pressure pump, reverse osmosis membranes and pressure vessels, membrane cleaning equipment, cartridge filters, chemical metering pumps for acid and sodium hexametaphosphate and degasifier.
- Water recovery is dependent on feed flow in the following manner:

FEED FLOW (GPD)	WATER RECOVERY, %
2,500-10,000	40
10,000-50,000	50
50,000-100,000	65
100,000-1 MGPD	85
1-10 MGPD	80
10-200 MGPD	85

- Pumping equipment for raw water and product water are not included.
- Degasifier equipment for treatment of reverse osmosis effluent is located outside of the building. Other equipment is housed.
- Electrical efficiency for building heating, lighting, and ventilation is 70 Kwh/ft² of building area per year.
- Process efficiency for high pressure pump is dependent on flow as presented below:

FLOW (GPD)	EFFICIENCY, %
<10,000	40
10,000-100,000	50
>100,000	60

- The process energy for the degasifier is 10 per cent of the high pressure pump.
- Labor varies with size of the system with a minimum of one man-hour/day for the systems smaller than 960,000 gal./day and two man-hours/day for larger systems.
- Reverse osmosis membrane cleaning cycle is to occur monthly. A three-year operating life is anticipated for membranes.
- Sodium hexamethaphosphate is fed continuously at a rate of 15 mg/L and sulfuric acid at a rate of 100 mg/L for inhibiting scale deposition on membrane surfaces.

The assumptions used for the high-cost range include all those for the low-cost range with the addition of:

- Source water has high turbidity.
- Pretreatment is added, which includes dual media filtration at 5.0 gal/min/ft² with a cationic polyelectrolyte continuously added to the feed water at a rate of 2.0 mg/L.
- Filter backwash facilities sized at 18 gal/min/ft², and hydraulic surface wash.

The low-range costs represent a clean water source that requires no pretreatment, and the high-range costs represent a turbid water source requiring filtration. Unit processes used to determine costs for the low- and high-range costs are presented in Table 50.

TABLE 50
PROCESSES USED TO DETERMINE 1986 COSTS OF REVERSE
OSMOSIS FOR URANIUM REMOVAL

PROCESS	COST RANGE	
	LOW	HIGH
Polymer feed system	--	x
Filtration system	--	x
Filter media, dual	--	x
Reverse osmosis system	x	x
Clearwell, ground level	--	x
Backwash pumping system	--	x
Hydraulic surface wash	--	x

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by Malcolm Pirnie, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., EPA project officer: Stephen W. Clark, Dec. 30, 1986.

Point-of-Use Treatments

For this analysis of the point-of-use treatment, either **ion exchange or reverse osmosis**, is a service provided by the water utility and the costs are additive to the other system costs for the total water supplied each household. Because the cost of point-of-use treatment is directly related to the number of devices require, there is a constant cost per unit of flow for all size categories. In reality, bulk purchase of this equipment would probably result in some reduction in unit costs in the larger systems, but this margin was not considered in this analysis.

Because point-of-use devices do not exhibit any economies of scale and become non-competitive with other treatment options, cost estimates were not developed for larger-size systems. The total cost of point-of-use treatment was prorated among all subscribers, which when added to the cost of water provided by the utility resulted in a cost per 1,000 gallons that is charged to all consumers. In this analysis, all the water consumers in a community share the cost of point-of-use treatment

1982

For the purpose of developing 1982 point-of-use cost estimates, the following assumptions were made:

- The water utility or community has responsibility for the purchase of the point-of-use device, its installation, and regularly scheduled maintenance.
- A single type of device will be selected for all residences and all customers will receive equal and uniform maintenance consisting of one replacement per year of the treatment cartridge (either resin or membranes).
- Filters and screening units are not included as a pretreatment protection for the point-of-use device, but may be necessary where feed water quality requires filtration.
- No costs for monitoring water quality have been included.
- Point-of-use capacity is based on one unit per household for use in cooking and drinking only. Rate of use is estimated at not less than two gallons/day per household.
- The total number of units required by a system is determined on the basis that each household will be supplied with 300 gallons/day by the utility.

The low-range of costs is based upon the use of anion exchange as the least expensive treatment. The high-range is based on the use of the more expensive reverse osmosis treatment. The average cost was based on an equal number of anion exchange and reverse osmosis treatment devices being installed.

1986

For the purpose of developing point-of-use cost estimates, the following assumptions were used:

- The water utility or community has responsibility for the purchase of the point-of-use device, its installation, and regularly scheduled maintenance.
- A single type of device will be selected for all residences so as to ensure compliance with the MCL requirement, and all customers will receive equal and uniform maintenance,
- All purchase and O&M costs are based on a survey of over 200 POU manufacturers performed by Malcolm Pirnie. Capital costs include 15 per cent for engineering and subcontractors fees, and 15 per cent for miscellaneous contingencies.
- Filters and screening units are not included as a pretreatment protection for the point-of-use device, however, many of the devices included in the cost survey have self-contained filtration capabilities.
- Monitoring costs are based on sampling each home for uranium twice per year and includes one hour for labor and \$30 for each analysis.
- Point-of-use capacity is based on one unit per household for use in cooking and drinking only. Rate of use is estimated at not less than two gallons/day per household.
- The total number of units required by a system is determined on the basis that each household will be supplied with 300 gallons/day by the utility.

COSTS OF BATS

CENTRALIZED-TREATMENT FACILITIES

The costs to the consumer decrease significantly as the capacity of the system increases. According to the EPA analysis, of the two treatment alternatives that require construction of new facilities (i.e., ion exchange and reverse osmosis), ion exchange is the most cost effective. Of the treatment alternatives that require modifications to existing systems, modified coagulation/filtration is less costly than modified lime softening. Point-of-use/point-of-entry treatment is more economical than new reverse osmosis and ion exchange facilities for systems of 250,000 gallons/day and 70,000 gallons/day, respectively. For system sizes greater than 250,000 gallons/day, point-of-use treatment is the most expensive technology overall. The EPA does not currently consider POU/POE an acceptable permanent compliance option for systems serving more than 3,300 persons.

Figure 1 represents total 1982 costs (cents/1000 gallons) as a function of plant design capacity (millions of gallons per day) for those methods and options identified as currently available to community water systems for providing drinking water with acceptable uranium concentrations. Figure 2 shows the average 1986 total costs in cents per 1,000 gallons for treatment methods that can be used to meet the uranium MCL. Table 51 details the 1982, 1986, and 1991 total production costs. Note that few technologies having total costs less than \$1.00/1000 gallons of water are available for the small water system.

Summaries of the 1982, 1986, and 1991 capital and O&M costs are presented in Tables 52 and 53. Adding the operating costs to the amortized capital cost gives a comparison of the methods based upon the cost in cents per 1,000 gallons of water treated. These total costs were presented in Table 51. Refer to the section describing cost factors and assumptions for key information regarding how to interpret these costs. Differences in assumptions include the fact that, in 1982 capital cost was amortized at 12 per cent over 20 years, while in 1986 it was amortized at 10 per cent.

Figures 3 through 7 show the following 1982 costs for each technology individually: 1) capital costs (thousands of dollars/year) as a function of plant design capacity (millions of gallons/day), 2) total costs (cents/1,000 gallons) as a function of plant production capacity (millions of gallons/day), and 3) operating and maintenance costs (thousands of dollars/year) as a function of plant production capacity (millions of gallons/day). Similar graphs were not provided by the EPA for the 1986 and 1991 cost estimates and, in the interest of time, KEI did not develop them.

Modified Coagulation/filtration

Estimated 1991 costs for an existing coagulation/filtration facility to modify treatment for 60 per cent removal of uranium from ground water sources range from \$4.40/1,000 gallons of water for systems serving a population of 25-100 persons, to \$0.02/1,000 gallons of water for systems serving over 1,000,000 persons. Modified coagulation/filtration as a new process designed specifically to remove uranium may not be cost effective, particularly for small utilities. However, where the reduction of turbidity in the source water is also a concern, this method can be very effective. Refer to Figure 3 for an overview of capital, total, and operating and maintenance costs for modified coagulation/filtration uranium-removal treatment systems.

Modified Lime Softening

It may not be cost effective for a utility to build a new lime softening treatment facility specifically to remove uranium. The 1991 estimated cost to modify an existing lime softening treatment facility to remove uranium from ground water ranges from \$4.20/1,000 gallons of water serving 25-100 persons to \$0.03/1,000 gallons of water serving more than 1,000,000 persons. Refer to Figure 4 for an overview of capital, total, and operating and maintenance costs for modified lime softening uranium-removal treatment systems.

Ion Exchange

The estimated 1991 costs for removal of uranium from ground water by ion exchange range from \$4.10/1,000 gallons of water treated for systems serving 25-100 persons, to \$1.00/1,000 gallons of water treated for systems serving more than 1,000,000 persons. Disposal of concentrated waste brine must also be considered. Refer to Figure 5 for an overview of capital, total, and operating and maintenance costs for ion exchange uranium-removal treatment systems.

Reverse Osmosis

The reverse osmosis system is adaptable to all size systems with 1991 costs ranging from \$6.20/1,000 gallons for systems serving 25-100 persons to \$0.89/1,000 gallons for systems serving over 1,000,000 persons. If reducing total dissolved solids is also a goal of the treatment process, reverse osmosis is a very cost-effective solution for the removal of uranium from source waters. Disposal of waste brine, the reject flow representing 20 to 50 per cent of the feed water, and the quantity of available feed (source) water to accommodate this technology, require consideration by a water system in its initial evaluation of alternative technologies. Refer to Figure 6 for an overview of capital, total, and operating and maintenance costs for reverse osmosis uranium-removal treatment systems.

FIGURE 1 TOTAL COSTS OF THE TECHNOLOGIES (1982)
FOR TREATING OR PROVIDING DRINKING WATER
WHEN URANIUM IS PRESENT IN SOURCE WATER

- REVERSE OSMOSIS
- ION EXCHANGE
- LIME SOFTENING MODIFIED
- x-x- COAGULATION/FILTRATION MODIFIED
- o—o— POINT-OF-USE

OFFICE OF DRINKING WATER
 ENVIRONMENTAL PROTECTION AGENCY
**AVERAGE TOTAL COSTS OF
 THE TECHNOLOGIES FOR
 THE REMOVAL OF URANIUM
 (1986)**

TABLE 51
ESTIMATED TOTAL PRODUCTION COST FOR REMOVING
URANIUM FROM GROUND WATER (CENTS/1,000 GAL)

TECHNOLOGY	Effic./ Treated (%)	POPULATION SERVED					
		25-99	100-499	500- 999	1,000- 3,300	3,300- 10,000	>10 ⁶
Design flow, 1986 (MGD)		0.06	0.14	0.31	0.96	3.06	1504.6
Avg. daily flow, 1986 (MGD)		0.13	0.045	0.133	0.40	1.3	650
Design flow, 1991 (MGD)		0.024	0.087	0.27	0.65	1.8	430
Design flow, 1991 (MGM)		0.730	2.65	8.21	19.8	54.8	13072
Design flow, 1991 (MGY)		8.76	31.8	98.6	237	657	156864
Avg. daily flow, 1991 (MGD)		0.0056	0.024	0.086	0.23	0.7	270
Modified coagulation/ filtration							
1982	>75/100	37	28	21	¹	¹	2
1986							
Low		256.9	128.8	51.6	22.8	9.9	1.5
High		199.2	92.9	37.2	16.4	8.4	1.8
1991--Low		437.9	208.6	82.5	37.5	10.3	1.5
Lime softening, modif.							
1982	>85/100	--	--	--	²	²	8
1986							
Low		228.3	111.6	50.2	25.9	18.8	3.3
High		476.3	203.1	90.6	46.2	26.6	6.5
1991--Low		420.1	206.2	92.9	47.1	20.0	3.3
Ion exchange							
1982	>95/100	227	214	204	³	³	130
1986							
Low							
Influent 50 pCi/L							
Effluent 20 pCi/L	60/63	221.0	153.2	128.4	117.3	112.9	100.0
" 10	80/84	277.5	198.3	165.7	159.3	152.2	135.1
" 2.5	95/100	323.8	234.7	193.7	182.6	182.3	162.0
Influent 30 pCi/L							
Effluent 20 pCi/L	33/35	119.8	98.1	76.4	68.0	64.8	55.9
" 10	67/70	236.1	172.7	142.7	127.4	124.7	111.1
Influent 10 pCi/L							
Effluent 1 pCi/L	90/95	305.7	222.3	186.7	176.4	168.9	148.3

TECHNOLOGY	POPULATION SERVED						
	Effic./ Treated (%)	25-99	100-499	500- 999	1,000- 3,300	3,300- 10,000	>10 ⁶
Ion exchange (Cont.)							
1986							
High							
Influent 50 pCi/L							
Effluent 20 pCi/L	60/63	514.4	257.6	173.7	140.6	142.1	108.7
" 10	80/84	582.1	312.0	217.5	181.6	183.7	147.2
" 2.5	95/100	639.7	350.7	252.0	217.6	223.2	170.0
Influent 30 pCi/L							
Effluent 20 pCi/L	33/35	399.8	187.1	113.9	85.9	73.5	59.4
" 10	67/70	534.1	277.0	187.6	153.3	156.4	120.0
Influent 10 pCi/L							
Effluent 1 pCi/L	90/95	626.2	334.6	236.4	199.8	207.9	161.1
1991--Low							
Influent 50 pCi/L							
Effluent 20 pCi/L	60/63	405.8	269.3	196.9	171.4	114.5	99.6
" 10	80/84	503.6	340.2	249.0	230.5	154.3	134.5
" 2.5	95/100	584.7	398.9	287.8	264.4	184.7	161.3
Influent 30 pCi/L							
Effluent 20 pCi/L	33/35	216.4	174.0	121.2	101.3	65.8	55.5
" 10	67/70	430.5	300.6	217.2	185.8	126.4	110.5
Influent 10 pCi/L							
Effluent 1 pCi/L	90/95	556.3	379.2	278.2	254.3	171.2	147.7
Reverse osmosis							
1982	>98/100	367	318	280	4	4	90
1986							
Low							
Influent 50 pCi/L							
Effluent 20 pCi/L	70/63	337.7	260.9	206.8	165.7	147.9	101.6
" 10	80/84	421.2	336.8	256.7	210.2	181.1	132.7
" 2.5	95/100	536.2	404.4	296.0	251.0	229.9	162.8
Influent 30 pCi/L							
Effluent 20 pCi/L	33/35	189.9	155.7	126.0	103.6	83.8	57.1
" 10	67/70	364.1	285.3	225.3	180.0	161.7	112.4
Influent 10 pCi/L							
Effluent 1 pCi/L	90/95	502.3	375.4	282.9	234.6	208.6	152.2

TECHNOLOGY

POPULATION SERVED

	Effic./ Treated (%)	25-99	100-499	500- 999	1,000- 3,300	3,300- 10,000	>10 ⁶
Reverse osmosis (Cont.)							
<i>1986</i>							
High							
Influent 50 pCi/L							
Effluent 20 pCi/L	70/63	923.9	503.9	323.6	240.4	190.6	109.5
" 10	80/84	1044.8	625.4	383.6	292.1	249.6	148.6
" 2.5	95/100	1180.2	704.1	433.1	332.8	277.1	173.8
Influent 30 pCi/L							
Effluent 20 pCi/L	33/35	582.1	348.5	227.5	149.1	112.9	62.3
" 10	67/70	969.8	551.7	345.3	264.9	209.3	122.2
Influent 10 pCi/L							
Effluent 1 pCi/L	90/95	1134.5	669.6	417.2	319.1	272.9	164.6
<i>1991--Low</i>							
Influent 50 pCi/L							
Effluent 20 pCi/L	60/63	621.9	473.3	350.7	273.1	153.9	89.4
" 10	80/84	772.3	606.2	433.9	344.2	189.4	117.5
" 2.5	95/100	983.7	729.3	500.8	407.5	241.1	144.1
Influent 30 pCi/L							
Effluent 20 pCi/L	33/35	343.3	281.9	211.0	171.3	86.7	50.3
" 10	67/70	666.9	511.2	381.2	295.6	168.3	98.9
Influent 10 pCi/L							
Effluent 1 pCi/L	90/95	926.4	674.4	478.5	382.9	218.4	52.6
Bottled water		97	96	96	5	5	---
Point-of-use		261	260	260	6	6	---
Regionalization		919	361	204	7	7	---
Alternate source		1,355	541	309	8	8	29

NOTES:

	1	2	3	4	5	6	7	8
1,000-2,499	16	---	194	245	95	260	123	194
2,500-4,999	13	11	185	219	94	259	87	187
5,000-9,999	11	11	179	201	94	259	62	99
10,000- 99,000	7	10	164	161	---	---	---	75
100,000- 999,000	11	9	147	121	---	---	---	43

Source: Compiled by KEI from EPA-sponsored reports.

TABLE 52
ESTIMATED CAPITAL COST FOR REMOVING URANIUM
FROM GROUND WATER (\$K)

		POPULATION SERVED					
	Effic./ Treated (%)	25-99	100-499	500- 999	1,000- 3,300	3,300- 10,000	>10 ⁶
Design flow, 1986 (MGD)		0.06	0.14	0.31	0.96	3.06	1504.6
Avg. daily flow, 1986 (MGD)		0.13	0.045	0.133	0.40	1.3	650
Design flow, 1991 (MGD)		0.024	0.087	0.27	0.65	1.8	430
Design flow, 1991 (MGM)		0.730	2.65	8.21	19.8	54.8	13072
Design flow, 1991 (MGY)		8.76	31.8	98.6	237	657	156864
Avg. daily flow, 1991 (MGD)		0.0056	0.024	0.086	0.23	0.7	270
Modified coagulation/ filtration							
1982	>75/100	1.0	2.1	4.0	¹	¹	313
1986							
Low		29.7	42.2	60.2	100.6	173.0	1670.7
High		41.7	50.8	61.7	79.3	168.9	2044.3
1991--Low		27.3	54.9	96.3	130.8	102.1	484.5
Lime softening							
1982	>85/100	---	---	---	²	²	234
1986							
Low		47.1	70.0	101.7	171.8	513.5	1670.4
High		122.6	160.5	210.3	314.2	712.0	34274.6
1991--Low		43.3	91.0	162.7	223.3	303.0	484.4
Ion exchange							
1982	>95/100	2	5	16	³	³	30,253.0
1986							
Low							
Influent 50 pCi/L							
Effluent 20 pCi/L	60/63	45.0	78.0	122.0	240.0	560.0	106,000.0
" 10	80/84	52.5	90.0	140.0	295.0	700.0	132,000.0
" 2.5	95/100	59.3	101.7	152.7	340.6	805.1	158,882.6
Influent 30 pCi/L							
Effluent 20 pCi/L	33/35	22.0	52.0	86.0	164.0	360.0	65,000.0
" 10	67/70	46.0	84.0	130.0	255.0	610.0	115,000.0
Influent 10 pCi/L							
Effluent 1 pCi/L	90/95	58.8	98.0	150.0	320.0	780.0	143,000.0

		POPULATION SERVED						
		Effic./ Treated (%)	25-99	100-499	500- 999	1,000- 3,300	3,300- 10,000	>10 ⁶
Ion exchange (Cont.)								
1986								
High								
Influent 50 pCi/L	60/63	138.0	190.0	275.0	530.0	1380.0	194,000.0	
Effluent 20 pCi/L	80/84	150.0	215.0	320.0	640.0	1800.0	248,000.0	
" 10	95/100	162.2	235.8	357.1	711.4	2223.4	293,321.1	
" 2.5								
Influent 30 pCi/L	33/35	107.0	151.0	207.0	370.0	800.0	118,000.0	
Effluent 20 pCi/L	67/70	140.0	200.0	290.0	560.0	1550.0	210,000.0	
" 10								
Influent 10 pCi/L	90/95	161.0	221.0	330.0	696.0	2100.0	275,000.0	
Effluent 1 pCi/L								
1991--Low								
Influent 50 pCi/L								
Effluent 20 pCi/L	60/63	41.4	101.4	195.2	312.0	330.4	30,740.0	
" 10	80/84	48.3	117.0	224.0	383.5	413.0	38,280.0	
" 2.5	95/100	54.6	132.2	244.3	442.8	475.0	46,076.0	
Influent 30 pCi/L								
Effluent 20 pCi/L	33/35	20.2	67.6	137.6	213.2	212.4	18,850.0	
" 10	67/70	42.3	109.2	208.0	331.5	359.9	33,350.0	
Influent 10 pCi/L								
Effluent 1 pCi/L	90/95	54.1	127.4	240.0	416.0	460.2	41,470.0	
Reverse osmosis								
1982	>98/100	5	15	41	4	4	50,586.0	
1986								
Low								
Influent 50 pCi/L								
Effluent 20 pCi/L	70/63	70.0	152.0	310.0	740.0	2400.0	860,000.0	
" 10	80/84	85.0	190.0	380.0	910.0	3400.0	1,080,000	
" 2.5	95/100	108.5	230.0	440.0	1042.0	4589.4	1,328,204	
Influent 30 pCi/L								
Effluent 20 pCi/L	33/35	35.0	90.0	180.0	470.0	1170.0	480,000.0	
" 10	67/70	73.0	158.0	335.0	790.0	2700.0	950,000.0	
Influent 10 pCi/L								
Effluent 1 pCi/L	90/95	105.0	210.0	420.0	1000.0	4000.0	1,260,000	

			<u>POPULATION SERVED</u>						
			Effic./ Treated (%)	25-99	100-499	500- 999	1,000- 3,300	3,300- 10,000	>10 ⁶
Reverse osmosis (Cont.)									
1986									
High									
Influent 50 pCi/L									
Effluent 20 pCi/L			70/63	220.0	330.0	520.0	1200.0	3700.0	910,000.0
" 10			80/84	245.0	385.0	615.0	1400.0	5400.0	1,230,000
" 2.5			95/100	273.3	423.5	695.9	1534.6	6081.4	1,454,105
Influent 30 pCi/L									
Effluent 20 pCi/L			33/35	150.0	249.0	370.0	730.0	1750.0	560,000.0
" 10			67/70	230.0	350.0	550.0	1250.0	4200.0	1,020,000
Influent 10 pCi/L									
Effluent 1 pCi/L			90/95	271.0	400.0	660.0	1540.0	6000.0	1,350,000
1991--Low									
Influent 50 pCi/L									
Effluent 20 pCi/L			60/63	64.4	197.6	496.0	962.0	1,416	249,400.0
" 10			80/84	78.2	247.0	608.0	1,183	2,006	313,200.0
" 2.5			95/100	99.8	299.0	704.0	1,355	2,708	385,179.2
Influent 30 pCi/L									
Effluent 20 pCi/L			33/35	32.2	117.0	288.0	611.0	690.3	139,200.0
" 10			67/70	67.2	205.4	536.0	1,027	1,593	275,500.0
Influent 10 pCi/L									
Effluent 1 pCi/L			90/95	96.6	273.0	672.0	1,300	2,360	365,400.0
Bottled water				0.1	0.4	0.9	5	5	---
Point-of-use				3	10	27	6	6	---
Regionalization				32	37	53	7	7	---
Alternate source				40	48	72	8	8	---

NOTES:

	1	2	3	4	5	6	7	8
1,000-2,499	7.2	--	43	107	2	74	84	122
2,500-4,999	10.3	0.9	81	194	5	178	141	212
5,000-9,999	13.7	1.4	131	306	9	347	180	284
10,000- 99,000	33.2	6.2	611	1,299	---	---	---	1.223
100,000- 999,000	99.5	36.6	4,117	7,806	---	---	---	6,060

Source: Compiled by KEI from EPA-sponsored reports.

TABLE 53
ESTIMATED OPERATING AND MAINTENANCE COST FOR
REMOVING URANIUM FROM GROUND WATER
(\$K/YR)

		POPULATION SERVED					
	Effic./ Treated (%)	25-99	100-499	500- 999	1,000- 3,300	3,300- 10,000	>10 ⁶
Design flow, 1986 (MGD)		0.06	0.14	0.31	0.96	3.06	1504.6
Avg. daily flow, 1986 (MGD)		0.13	0.045	0.133	0.40	1.3	650
Design flow, 1991 (MGD)		0.024	0.087	0.27	0.65	1.8	430
Design flow, 1991 (MGM)		0.730	2.65	8.21	19.8	54.8	13072
Design flow, 1991 (MGY)		8.76	31.8	98.6	237	657	156864
Avg. daily flow, 1991 (MGD)		0.0056	0.024	0.086	0.23	0.7	270
Coagulation/filtration, modified							
1982	>75/100	0.4	1.1	2.6	¹	¹	4,590.0
1986							
Low		8.7	16.2	18.0	21.5	26.6	3445.7
High		4.6	9.3	10.8	14.7	19.8	3956.3
1991-Low		5.7	11.8	14.6	16.1	14.4	1,447.2
Lime softening, modified							
1982	>85/100	---	---	---	²	²	16,254.0
Low							
High							
1986							
Low		5.3	10.1	12.4	17.7	28.9	7574.0
High		8.2	14.5	19.3	30.5	42.7	11410.6
1991-Low		3.5	7.4	10.0	13.3	15.6	3,181.1
Ion exchange							
1982	>95/100	6	18	46	³	³	211,765.0
1986							
Low							
Influent 50 pCi/L							
Effluent 20 pCi/L	60/63	5.2	16.0	48.0	143.0	470.0	225,000.0
" 10	80/84	7.0	22.0	64.0	198.0	640.0	305,000.0
" 2.5	95/100	8.4	26.6	76.1	226.8	770.4	365,572.3
Influent 30 pCi/L							
Effluent 20 pCi/L	33/35	3.1	10.0	27.0	80.0	265.0	125,000.0
" 10	67/70	5.8	18.5	54.0	156.0	520.0	250,000.0
Influent 10 pCi/L							
Effluent 1 pCi/L	90/95	7.6	25.0	73.0	220.0	710.0	335,000.0

		<u>POPULATION SERVED</u>						
		<u>Effic./ Treated (%)</u>	<u>25-99</u>	<u>100-499</u>	<u>500- 999</u>	<u>1,000- 3,300</u>	<u>3,300- 10,000</u>	<u>>10⁶</u>
Ion exchange (Cont.)								
<i>1986</i>								
High								
Influent 50 pCi/L								
Effluent 20 pCi/L	60/63	8.2	20.0	52.0	143.0	512.0	235,000.0	
" 10	80/84	10.0	26.0	68.0	190.0	660.0	320,000.0	
" 2.5	95/100	11.3	29.9	80.4	234.1	798.0	368,821.8	
Influent 30 pCi/L								
Effluent 20 pCi/L	33/35	6.4	13.0	31.0	82.0	255.0	127,000.0	
" 10	67/70	8.9	22.0	57.0	158.0	560.0	260,000.0	
Influent 10 pCi/L								
Effluent 1 pCi/L	90/95	10.8	29.0	76.0	210.0	740.0	350,000.0	
<i>1991-Low</i>								
Influent 50 pCi/L								
Effluent 20 pCi/L	60/63	3.4	11.7	38.9	107.3	253.8	94,500.0	
" 10	80/84	4.6	16.1	51.8	148.5	345.6	128,100.0	
" 2.5	95/100	5.5	19.4	61.6	170.0	416.0	153,540.4	
Influent 30 pCi/L								
Effluent 20 pCi/L	33/35	2.0	7.3	21.9	60.6	143.1	52,500.0	
" 10	67/70	3.8	13.5	43.7	117.0	280.8	105,000.0	
Influent 10 pCi/L								
Effluent 1 pCi/L	90/95	5.0	18.3	59.1	165.0	383.4	140,700.0	
Reverse osmosis								
<i>1982</i>	>98/100	7	19	46	⁴	⁴	108,439.0	
<i>1986</i>								
Low								
Influent 50 pCi/L								
Effluent 20 pCi/L	70/63	7.8	25.0	64.0	155.0	420.0	140,000.0	
" 10	80/84	10.0	33.0	80.0	200.0	460.0	188,000.0	
" 2.5	95/100	12.7	39.4	92.0	244.0	552.0	230,368.7	
Influent 30 pCi/L								
Effluent 20 pCi/L	33/35	4.9	15.0	40.0	96.0	260.0	79,000.0	
" 10	67/70	8.7	28.3	70.0	170.0	450.0	155,000.0	
Influent 10 pCi/L								
Effluent 1 pCi/L	90/95	11.5	37.0	88.0	225.0	520.0	213,000.0	

		<u>POPULATION SERVED</u>						
		Effic./ Treated (%)	25-99	100-499	500- 999	1,000- 3,300	3,300- 10,000	>10 ⁶
Reverse osmosis								
<i>1986</i>								
High								
Influent 50 pCi/L								
Effluent 20 pCi/L	70/63	18.0	44.0	96.0	210.0	470.0	153,000.0	
" 10	80/84	20.8	57.5	114.0	262.0	550.0	208,000.0	
" 2.5	95/100	23.9	65.9	128.5	305.6	600.3	241,549.0	
Influent 30 pCi/L								
Effluent 20 pCi/L	33/35	10.0	28.0	67.0	132.0	330.0	82,100.0	
" 10	67/70	19.0	49.5	103.0	240.0	500.0	170,000.0	
Influent 10 pCi/L								
Effluent 1 pCi/L	90/95	22.0	63.0	125.0	285.0	590.0	232,200.0	
<i>1986-Low</i>								
Influent 50 pCi/L								
Effluent 20 pCi/L	60/63	5.1	18.3	51.8	116.3	226.8	58,800.0	
" 10	80/84	6.6	24.1	64.8	150.0	248.4	78,960.0	
" 2.5	95/100	8.4	28.8	74.5	183.0	298.1	96,754.9	
Influent 30 pCi/L								
Effluent 20 pCi/L	33/35	3.2	11.0	32.4	72.0	140.4	33,180.0	
" 10	67/70	5.7	20.7	56.7	127.5	243.0	65,100.0	
Influent 10 pCi/L								
Effluent 1 pCi/L	90/95	7.6	27.0	71.3	168.8	280.8	8,946.0	
Bottled water			3	10	27	5	5	---
Point-of-use			6	18	46	6	6	---
Regionalization			2	3	6	7	7	---
Alternate source			9	11	18	8	8	15,933

NOTES:

	1	2	3	4	5	6	7	8
1,000-2,499	6.2	---	122	114	73	135	14	34
2,500-4,999	13.1	20	283	247	174	325	27	53
5,000-9,999	23.2	38	537	445	337	630	51	87
10,000-99,000	97	194	2,695	1,962	---	---	---	269
100,000-999,000	642	1,700	22,909	14,035	---	---	---	1,756

Source: Compiled by KEI from EPA-sponsored reports.

NOTE:

- (1) DESIGN CAPACITY OF THE PLANT
USED IN CAPITAL COST ESTIMATES
- (2) ANNUAL AVERAGE WATER
PRODUCTION CAPACITY OF
THE PLANT USED IN O&M AND
TOTAL COST ESTIMATES

TREATMENT COSTS FOR URANIUM REMOVAL
BY COAGULATION / FILTRATION, MODIFIED
(1952)

Figure 3

NOTE

- (1) DESIGN CAPACITY OF THE PLANT
USED IN CAPITAL COST ESTIMATES
- (2) ANNUAL AVERAGE WATER
PRODUCTION CAPACITY OF
THE PLANT USED IN O&M AND
TOTAL COST ESTIMATES

TREATMENT COSTS FOR URANIUM REMOVAL
BY LIME SOFTENING, MODIFIED
(1982)

Figure 4

NOTE.

- (1) DESIGN CAPACITY OF THE PLANT
USED IN CAPITAL COST ESTIMATES
- (2) ANNUAL AVERAGE WATER
PRODUCTION CAPACITY OF
THE PLANT USED IN O&M AND
TOTAL COST ESTIMATES

TREATMENT COSTS FOR URANIUM REMOVAL
BY ION EXCHANGE
(1982)

Figure 5

NOTE:

- (1) DESIGN CAPACITY OF THE PLANT
USED IN CAPITAL COST ESTIMATES
- (2) ANNUAL AVERAGE WATER
PRODUCTION CAPACITY OF
THE PLANT USED IN O&M AND
TOTAL COST ESTIMATES

TREATMENT COSTS FOR URANIUM
REMOVAL BY REVERSE OSMOSIS
(1952)

Figure 6

POINT-OF-USE/POINT-OF-ENTRY TREATMENTS

Point-of-use/point-of-entry treatments are feasible for systems serving fewer than 3,300 persons. The EPA does not currently consider POU/POE an acceptable permanent compliance option for systems serving more than 3,300. This type of treatment is most economically competitive in the very small water systems where the economies of scale for the larger centralized facilities are not apparent. Table 54 compares the 1986 capital, O&M, and total point-of-treatment costs of using in-home reverse osmosis and ion exchange devices instead of a centralized treatment facility.

TABLE 54
ESTIMATED COST OF REMOVING URANIUM BY POINT-OF-USE
TREATMENT

SYSTEM CAPACITY (MGD)	SYSTEM AVERAGE FLOW (MGD)	NO. OF UNITS	REVERSE OSMOSIS			ION EXCHANGE		
			CAPITAL COST (K\$/YR)	O&M COSTS (¢/1000 GAL)	TOTAL COSTS (¢/KGAL)	CAPITAL COST (K\$/YR)	O&M COSTS (¢/1000 GAL)	TOTAL COSTS (¢/1000 GAL)
0.06	0.013	200	273.2	49.6	373.0	260.0	77.6	793.8
0.14	0.045	467	637.5	115.7	373.0	606.7	181.1	493.8
0.31	0.133	1033	1411.5	256.3	373.0	1343.3	400.9	493.8
0.96	0.4	3200	4371.2	793.6	373.0	4161.0	1241.6	493.8

Source: *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by Malcolm Pirnie, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., EPA project officer: Stephen W. Clark, Dec. 30, 1986.

The 1982 costs of point-of-use treatment for the smaller communities, where population determines the number of households, and each household has a point-of-use device installed, are presented in Figure 7. Refer to Figures 1 and 2, which compare POU total costs with the centralized treatment alternatives.

NOTE:

(1) ANNUAL AVERAGE WATER PRODUCTION CAPACITY OF THE PLANT IS USED FOR COST ESTIMATES

TREATMENT COSTS FOR URANIUM
REMOVAL BY POINT-OF-USE
(1982)

Figure 7

OTHER COST ESTIMATES

ADSORPTION RECOVERY

Generally speaking, an adsorption recovery system's initial costs are relatively high. However, the return on the investment is also high. Operating and maintenance costs are typically low in comparison with the value of the recovered solvent. Small systems can be manually operated with efficiency equal to that of the larger systems, which are generally automatic. Costs associated with adsorption can be broken down into three categories: capital cost of contacting system including adsorbers and piping; capital cost of reactivation facility (if part of the system); and ongoing costs associated with operation and maintenance.

The economics of five odor-removal processes were evaluated in a 1981 Calgon brochure entitled "Effective Odor Control With Calgon GAC Systems." Although this report addresses uranium removal from water, the major components of the adsorbent systems should be the same as those described here. The five systems compared by Calgon were: chemical scrubber, ozone, and adsorbent systems using alumina, standard carbon, and Calgon IVP Carbon.

According to Calgon, from a capital standpoint, all five processes cost essentially the same and the real economic comparison must be made on an overall operating cost basis. Operating expenses include adsorbents or other chemicals, labor, maintenance, utilities, and amortization. For a 10,000 cfm system, annual operating and maintenance costs were estimated to be \$24,000 for Calgon IVP carbon, \$28,000 for a chemical scrubber, \$39,000 for ozone, \$66,000 for standard carbon, and \$68,000 for an alumina system.

Activated Carbon

Much of the information in the following sections was obtained from two articles, both published in *Chemical Engineering*. One of the articles was submitted by Calgon Carbon and the other by ENSR Consulting and Engineering. Table 55 is a cost summary of a water treatment system that was installed by the city of Afton, OH.

TABLE 55
COST OF GRANULAR ACTIVATED CARBON WATER
TREATMENT SYSTEM

EXPENSE	COST, \$
Capital Costs	
Calgon set-up (including activated carbon)	60,400
Piping (material only; labor by district employees)	20,000
Installation cost	
Miscellaneous (chemical feeder, alarms, fence, etc.)	6,400
Foundation and site work	5,500
Crane rental	1,100
Total	93,400
Monthly Operating Costs	
Calgon rental	4,945
Electricity for well pump	1,800
Sampling and testing	2,000
Total	8,745

Source: "Activated Carbon Treatment Restores Afton Water Supply," *American City & County*, Nov. 1983.

Capital Costs and Amortization

Installed equipment costs were published in the Calgon article for two-stage, fixed-bed, downflow contacting systems of various capacities. A contact time of 30 minutes per vessel was assumed and the company's estimates include: epoxy-lined, carbon-steel pressure adsorbers; lined carbon-steel pipe; engineering and installation; and initial carbon inventory. Bulk storage equipment must be specified if either throwaway or off-site reactivation is chosen. Winterization costs were not included. This article presents estimates for the installed cost of an on-site reactivation and carbon-handling system. These costs provide for a multiple-hearth reactivation furnace, spent-and reactivated-carbon storage tanks, dewatering screw, quench tank, carbon motive system, engineering and installation, and initial carbon inventory. Furnace sizing is based on a feed rate of 75 pounds of carbon per square foot of hearth area per hour and an operating factor of 0.75. The costs are based on January 1976 dollars and do not include winterization. Again, because of time constraints, it was not possible for KEI to update these costs.

Major capital expenditures are avoided if monthly service arrangements are made with the carbon supplier. The annual fees can, in some instances, be less than the total annual costs of other methods of adsorption. Another advantage is that many of the risks associated with designing, procuring, installing, operating, and maintaining a system are eliminated.

Capital Annualization

Most industrial carbon-adsorption systems are depreciated over an 8- to 15-year period. Over 11 years, at an interest rate of 10 per cent, the annualizing factor is about 6.5, where capital annualization equals installed capital costs/annualizing factor.

Operating Costs

Results from 31 operating plants that use Calgon Carbon's granular carbon to remove toxic organic compounds from ground water supplies were published in an article published in *Water/Engineering & Management* (May 1983). These plants have been treating contaminated flows ranging from 5 to 2,250 gpm. Operating costs associated with GAC treatment depend on a number of factors. These include flow rates, concentration and type of organics, type of application (potable or other), site requirements, timing requirements, and length of the processing project. These factors together can define equipment, carbon, and reactivation needs. Generalizations about costs are difficult when comparing a variety of applications, but some observations by Calgon are: 1) the operating cost for GAC treatment was lower for projects with lower average influent levels of contaminants, 2) treatment costs ranged from approximately \$0.22 to \$0.55 per 1,000 gallons, and 3) operating costs of the facilities ranged from \$0.45 to \$2.52 per 1,000 gallons.

The level of contamination was reduced to less than detectable levels in each project. The cost figures listed for the 31 cases include allowances for all equipment installation costs and the supply of granular carbon as required. According to Calgon, cost of treatment with granular carbon is well within the range of conventional process costs. The 31 treatment systems studied and documented have shown that GAC usage rates as low as 0.1 pound of carbon per 1,000 gallons of water treated have been achieved. Table 56 summarizes the cost categories associated with the four carbon-handling options.

TABLE 56
MAJOR ANNUAL COST CONSIDERATIONS FOR ADSORPTION OPTIONS

ON-SITE REACTIVATION	OFF-SITE REACTIVATION	THROWAWAY CARBON	SERVICE
Carbon makeup	Carbon makeup	Carbon disposal	Electricity
Depreciation	Depreciation	Carbon makeup	Labor
Electricity	Electricity	Depreciation	Service fee
Fuel	Interest	Electricity	
Interest	Labor	Interest	
Labor	Maintenance	Labor	
Maintenance	Monitoring	Maintenance	
Monitoring	Reactivation cost	Monitoring	
Steam	Transportation		

Source: *Water/Engineering & Management* (May 1983).

Adsorbent Makeup

Adsorbent makeup requirements run about 5-10 per cent (by weight) for on-site carbon reactivation and about 10-15 per cent for off-site reactivation. Obviously, with throwaway carbons, adsorbent makeup is 100 per cent.

Fuel, Steam, Electricity

Because the only fuel that is required is for steam generation, overall fuel costs are low. According to ENSR Consulting and Engineering, this runs about \$10,000-\$20,000 per year for a 10,000-cfm system.

Oil, natural gas, or propane can be burned in reactivation furnaces. According to Calgon, heat loads range from 6,000 to 8,000 BTU/lb of reactivated carbon, including the afterburner use. The steam demand for on-site reactivation systems averages one pound of steam per pound of carbon. The steam is introduced into the activating section of the furnace to help control volatilization and oxidation. Electricity is needed for waste water pumping, carbon reactivation, and control instrumentation. Pumping and instrumentation demands should be calculated for each case. That for reactivation can be estimated from the following correlation: Electricity demand = $0.015(C/1000) - 0.7$, where C is activation rate in lb/day, and the electricity demand is in kWh/lb of carbon.

Reactivation

According to the Tigg Corp., the cost effectiveness of reactivated versus virgin carbons varies with performance requirements, the comparative volume service life, and the volume cost of the material. Cost per unit weight may be misleading, as reactivated carbons frequently have higher apparent densities than virgin ones. As mentioned previously, reactivation can be effected either on-site or off-site. According to Calgon, the fee charged by an off-site service firm typically ranges from 25 to 35 cents per pound of carbon. The cost of transportation, handling, and makeup carbon should be added to this figure.

Maintenance, Disposal, Insurance, and Taxes

According to ENSR Consulting and Engineering, the disadvantages of carbon activation systems are potentially higher operating and maintenance costs for the disposal of the two waste streams. For example, for a 10,000-cfm unit not requiring disposal of a solvent, costs would be about \$50,000-\$70,000 per year, but they would rise to as much as \$500,000 per year if a solvent must be disposed. Calgon estimates that these items average about 7-15 per cent of the fixed investment per year.

Labor and Monitoring

According to Calgon, labor and monitoring requirements depend upon the degree of automation and the system's size. Large on-site reactivation systems may require as much as four man-years of operating and monitoring labor annually. Small throwaway or off-site reactivation systems may need as little as one man-year.

NEW DOE TECHNOLOGIES

Table 57 is an overview of estimated costs associated with DOE-developed technologies. This listing, which was compiled from the *Crosswalk* database, includes the Technology Needs Assessment ID number, the project title, and cost information that was gleaned from the assessment sheets. Refer to Appendix 7 for contacts associated with each of these technologies.

TABLE 57
OVERVIEW OF ESTIMATED COSTS FOR EACH DOE-DEVELOPED
TECHNOLOGY

TNA ID	TECHNOLOGY IDENTIFICATION	ESTIMATED COSTS
TAL009	Electrochemical Decontamination by Electromigration & Capture	Costs of electrochemical decontamination are estimated to be about \$6/m ³ of soil. Over 90% removal from soils and ground waters is expected.
TAL011	Selective Extraction/Leaching ¹	\$50-100/ton exclusive of excavation costs.
TAL046	Electrokinetic Remediation	Electrokinetic remediation has been estimated to cost less than half of <i>ex situ</i> soil washing (\$50/ton vs. \$100/ton).
TAL054	Evaluation of the Hydraulic Cage Concept in Containment Systems of Hazardous Waste Materials-Germany ²	Not discussed.
TAL064	Sequestering Agents for Removal of Transuranics from Radioactive Waste	Disposal costs using this technology: low-level drums costs about \$500/drum and the cost of a TRU drum for WIPP is estimated at \$10,000 (a very uncertain number). Annual savings at LANL were estimated to be \$195,000, which did not include savings from simpler operations or the lower capital cost of the polymer extraction system compared to the precipitation system for a new facility. Cost savings of nitric acid recycle and more complete Pu and Am removal were estimated based on 1988 operating data at RFP. The annual disposal costs of \$36 million were reduced to \$24 million with nitric acid recycle and \$14 million with nitric acid recycle and enhanced actinide removal (e.g., using polymer extractants or TRUEX processing). Note that while RFP will not manufacture weapons components as in 1988 in the likely future, this technology can potentially be used during D&D activities at RFP and other sites.
TAL065	Australia/Kuwait--Cleanup of Heavy Metals ¹	Not discussed.
TCH013	Ground Water Decontamination of VOCs ³	Operation costs of air stripping with vapor-phase activated carbon are typically \$0.5/m ³ of liquid treated. Based on preliminary data of MASX/MADS Energy Consumption, this operating cost could be up to 50% lower.

TNA ID	TECHNOLOGY IDENTIFICATION	ESTIMATED COSTS
TCH021	Minimum Additive Waste Stabilization (MAWS) Program	Not discussed.
TID002	Soil Treatment Equipment ¹	Most contaminated soils are placed in land disposal facilities with associated costs ranging from \$200/cu.yd. at the Nevada Test Site low-level repository to thousands of dollars per cubic yard at a facility such as WIPP. Mineral separation technology equipment can supposedly achieve separation (cleaning) efficiencies of 90 per cent at costs of approx. \$10/cu.yd.
TID011	Bioprocessing Technologies for Uranium-Contaminated Solid	Based on low-grade ores (uranium and copper) bioleaching is about 10 per cent of the cost of conventional mining/milling.
TID018E	Pad A Treatability Study	Not discussed.
TID018F	Pad A Treatability Study	Not discussed.
TNV001	Plutonium Contaminated Soil Cleanup Demonstrated ¹	Disposal at NTS RWMS is \$10 ft ³ (FY-91). Disposal at private landfill is \$30-300 ft ³ .
TNV004	Physical Methods for Soil Decontamination ¹	Not discussed.
TOR009	Base-Catalyzed Destruction of PCBs in Mixed Wastes ¹	Projected to cost \$250/ton, which is about half the cost of incineration (per EPA projections).
TOR027	Selective Extraction/Leaching of U from Soil ¹	Cost comparisons based on known operating facilities are not available. Assuming cost for retrieval and storage off-site is \$500/yd ³ , the cost for selectively extracting is estimated to be less than \$200/yd ³ and could even be less than \$50/yd ³ . A medium-scale production unit should be able to treat 25-50 ton/hr and meet <35 pCi/g limits for soils not containing uranium concentration >1000 pCi/g.
TOR028	Uranium Soils ID Performance Assessment ¹	Project will cover costs from cradle to grave.
TOR030	Development of Inorganic Membranes for Mixed Waste ID ³	The operating cost will be essentially limited to pumping costs.
TOR034	Removal of Uranium by Biosorption—Germany	Not discussed.

TNA ID	TECHNOLOGY IDENTIFICATION	ESTIMATED COSTS
TOR036	Uranium Soils Integrated Demonstration Management ¹	Not discussed.
TOR042	Secondary Waste Treatment/Disposal for Uranium Soils ID ¹	Not discussed.
TRL016	TCE & PCE Membrane Separation Tests ³	Membrane system cost is \$2-5/lb organic removed. Activated carbon cost is \$40-50/lb organic removed. Spent activated carbon requires regeneration or disposal. Secondary waste from membrane separation is recyclable. Membrane technology removes 95 per cent of volatile organics from 0.5 to 5 volume per cent in air flowing up to 100 SCFM.
TRL033	Decontamination of GW from Arid Site Demo Using Supported Liquid Membranes ³	The operating cost for reverse osmosis has been estimated to be \$1.7/1000 gal. of feed with a volume of secondary waste of 50-100 gal/1000 gal. If the secondary waste is disposed of without further testing as a mixed radioactive waste for RO the disposal cost would be \$1800-3600/1000 gal of feed. The operating costs for reverse osmosis/coupled transport are estimated to be about \$25/1000 gal. of feed. If the secondary waste is disposed of without further testing as a mixed radioactive waste the disposal cost is estimated to be less than \$7.2/1000 gal. feed.
TRL034	VOC Off-Gas Membrane Separation ³	Membrane system: \$2-4/lb VOC removed. GAC: \$40-50/lb VOC removed. 95% removal of VOCs from 35 SCFM vapor stream.
TRL038	Continuous Cesium Recovery ³	Not discussed.
TRL051	Solid Sorbents for Selective Separation of Radioactive Nuclides	Baseline costs of disposing wastes without preliminary separation is \$34 billion. Cost with preliminary separation using new technology is \$2 billion, for a savings of \$32 billion. In addition, without preliminary separation using new technology, another repository could be needed, which could cost hundreds of billions.
TSR007	Soil Contaminant Extraction/Leaching ¹	Not discussed.
TSR010	Bioremoval of Heavy Metals from Aqueous Solutions	Not discussed.

TNA ID	TECHNOLOGY IDENTIFICATION	ESTIMATED COSTS
TSF011	Method of Removing Chloroform & TCE from Ground Water & Waste Water ³	Because the cost of manufacturing a large hollow-fiber unit is unknown, it is not possible to currently estimate costs. However, the cost of the fiber itself is nominal (about \$2K per unit). So the expected cost of a unit with the associated hardware (pumps, etc.) is less than \$50K for a unit that processes 20 million gal./yr of contaminated water.

¹ Soil/solid treatment technology.

² Included because relates to Germany.

³ Included because Statement of Work specifically requests information on membranes.

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

SORBENT MATERIAL PRICES

While not to be ignored, price per pound is rarely the primary factor in selecting a sorbent. With most processes, price is generally interpreted in terms of cost effectiveness. Cost effectiveness, in turn, may relate to the material and the equipment to which it will be applied, since even the optimum sorbent will not overcome a deficiency in equipment. However, when the application is radionuclide removal, materials costs become important if the sorbent must be disposed after a short period of time in order to avoid concentrating the radioactive material on the sorbent.

Absorbent—Forager Sponge

Dynapore estimates (1993) the treatment cost of using this technology to be \$0.001 to \$0.02 per gallon. This does not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals. Dynapore's president indicates that the above estimate, which was obtained from an EPA database, is high. He claims that one cubic foot of sponge, which currently sells for \$95 per cubic foot, is capable of absorbing 50-200 grams of cation. The price of the product is expected to drop to \$75 per cubic foot in a few years due to economies of scale. In those treatment modes wherein the sponge is destroyed after one-time use, the cost of the sponge in relation with the metals removed would be in the range of \$100-300 per pound of metal removed.

Adsorbents

Activated Carbon

According to Atochem's 1992 telephone quote, the price range for activated carbon is from \$0.50 per pound for low quality powders up to \$2.00 per pound or more for impregnated carbons and pellets. However, typical prices are \$0.80 per pound for large quantities of liquid phase GACs and \$1.40 for gas phase GACs. Calgon's price estimate is \$0.75-\$1.00 per pound for granular liquid phase carbons and \$1.25-\$2.50 per pound for granular vapor phase carbons. In 1992, Calgon's industrywide estimates for powders is \$0.35-\$0.65 per pound.

Activated Alumina

The *Chemical Marketing Reporter* listed the 1992 price of activated alumina as \$820 per short ton delivered in 100-pound bags with a 40,000-pound minimum. Smaller quantities from Johnson Matthey's 1991/92 Alfa Products listed for approximately \$22/kg and \$82/5-kg.

Chemisorption—Ion Exchange

According to Harry Anthony of URI, Inc., a uranium-solution mining company, the company uses Dowex 21K to remove uranium. Dow Chemical's Brian Powers confirmed that Dowex 21K is the anion resin most often used today to remove uranium in mining operations processes. The material currently lists for \$161.50/ft³ for truckload quantities (700 ft³). A high performance product, Dowex XLT, has recently been introduced that has a greater capacity for uranium and lowers consumption of regenerate chemicals. This resin lists for \$220/ft³. These are delivered prices that include freight. Large customers such as uranium mines sometimes get discounts of 5-10 per cent. However, this depends on market conditions and there is sometimes no discounting.

Styrene Divinylbenzene

Bio-Rad Corp.'s Bio-Bead ion styrene divinylbenzene ion exchange media (not a biological-based product) 1992 list price ranged from \$65/25 g to \$160/100 g. Note that Bio-Rad targets the research market that uses small quantities rather than industrial users.

Zeolite

Prices for the natural zeolite, chabazite, ranged from \$0.20/lb. in 1992 for 20,000-30,000 pound quantities of crude ore and \$0.10 for quantities greater than 30,000 pounds of crude. The price for the lowest priced processed material (-20 tyler mesh) ranges from \$0.40/lb. for less than 2,000 pounds of to \$0.20 for greater than 30,000 pounds, F.O.B. the processing facilities, in this case located in Tucson, AZ (GSA Resources, Inc.). The highest priced material (-20 +50 tyler mesh) ranges from \$1.50/lb. for less than 2,000 pounds of to \$0.99 for greater than 30,000 pounds.

WASTE TREATMENT, TRANSPORTATION, AND DISPOSAL COSTS

Waste disposal represents a great unknown in terms of regulatory requirements and, hence, compliance costs. To date, water utilities with treatment-related residuals of radioactive content typically have had little difficulty disposing of their wastes. This situation may change dramatically, however, resulting in appreciable new administrative and cost burdens for utilities that need to manage and dispose of treatment residuals laden with uranium or radium. There is a high degree of uncertainty associated with disposal of waste streams from uranium- and radium-removal processes.

Effect of Waste Concentrations

The options considered by EPA in developing the proposed regulations are conventional alternatives widely used by the water treatment industry for disposing sludges and other treatment byproducts. They are acceptable from both the current regulatory and public perspectives because these waste streams do not have high concentrations of hazardous or radioactive materials.

If water treatment processes are used that selectively concentrate radionuclides in a liquid form, two consequences will significantly affect the water utility's ability to meet the regulations. The first consequence is that the radiological nature of the waste may require management as a radioactive material, resulting in additional health and safety considerations, new and additional monitoring criteria, and most importantly, stringent handling, packaging, and disposal requirements. The additional direct costs of disposing of uranium-bearing wastes as LLW is estimated to be between \$0.10/1000 gallons and \$0.60/1000 gallons and will produce two to three 55-gallon drums per year for a 0.7 million-gallon-per-day plant. A high degree of uncertainty is associated with this figure due to impending closure of at least one of the three operating low-level radwaste disposal facilities in the country. At present the indirect costs associated with training and monitoring for health and safety, waste packaging, and management have not been quantified.

Treatment and Disposal

The treatment and disposal of waste by-products generated by the treatment processes increases overall water treatment costs, especially for small systems. However, in establishing BAT, EPA identifies the treatment and disposal technologies that are reasonably available for large metropolitan regional drinking water systems (i.e., systems that service 50,000 to 75,000 persons). Disposal of wastes from treatment for radionuclides does not significantly increase the total treatment costs for large systems.

For uranium removal, a low-level radioactive waste is expected to result, whether spent resin is disposed of directly or regenerated. Waste container surface dose rates from <1 mrem/hour to about 6 mrem/hour will result. These dose rates can be easily managed to ensure that personnel exposures are within radiation protection limits in 10 CFR 10. The increase in water treatment costs resulting from disposal of the uranium-bearing wastes as LLW are from \$0.10/1000 gallons to about \$0.60/1000 gallons. The annual waste production for a 0.7 million gallon/day (an average treatment rate) is two or three 55-gallon drums per year. Waste processing and packaging can be performed without significant equipment, chemical storage, or waste storage capital expense.

Several waste disposal techniques and estimates of associated costs are identified in Table 58. Technologies and costs related to the disposal of granular activated carbon that may in some cases be used for radon and uranium removal have not been determined by EPA.

TABLE 58
RANGE OF BRINE AND SLUDGE DISPOSAL COSTS IN REMOVAL
OF RADIONUCLIDE CONTAMINANTS¹

TREATMENT PROCESS	DIRECT DIS- CHARGE	DISCHARGE TO SEWER	EVAPORATION POND/ LAND	CHEMICAL PRECIPITATION
Brine disposal				
Ion exchange	²	4-110	20-250	30-350
Reverse osmosis	2-95	10-230	²	³
TREATMENT PROCESS	DISCHARGE TO SEWER	NON-MECHANICAL DEWATERING AND LAND DISPOSAL ⁴	DEWATERING AND LAND DISPOSAL ⁵	
Sludge disposal				
Coagulation/ filtration	1-190	65-360	75-2,800	
Lime soft- ening	²	30-600		

1 From "Technologies and Costs for the Treatment and Disposal of Waste By-Products from Water Treatments for the Removal of Inorganic and Radioactive Contaminants (EPA, 1986d). Cost ranges represent disposal costs for very large to very small water systems.

2 Data not available.

3 Disposal option too expensive.

4 Mechanical dewatering may include utilization of pressure filtration.

5 Non-mechanical dewatering alternatives for sludges include sand-drying beds and dewatering lagoons.

Source: *Federal Register*, Vol. 56, No. 138, Thursday, July 18, 1991.

The following comments regarding disposal were gleaned from the *Crosswalk* database: Most contaminated soils are placed in land disposal facilities with associated costs ranging from \$200/cu.yd. at the Nevada Test Site (NTS) low-level repository to thousands of dollars per cubic yard at a facility such as WIPP. Disposal at NTS RWMS is \$10 ft³ (FY-91). Disposal at private landfill is \$30-300 ft³.

The following are other statistics that were gathered from the EPA: EPA (1990b) cites a figure of \$1,500/ton for disposal at a low-level waste facility. No basis for this cost was given. LLW disposal costs, based on the Rocky Flats Plant transportation and package costs and Beatty NV's tipping and surcharge costs, of \$2,700/ton were calculated by Pierce and Thompson in 1991. (For lime and soda ash sludges solidified with Portland cement grout, there are 7.5 ft³/ton.)

Transportation

According to *The Cost of Compliance With the Proposed Federal Drinking Water Standards for Radionuclides* (1991), there are presently only three low-level waste disposal sites in the U.S., none of which is centrally located. One-way transportation distances of 1,500 miles are likely. Eventually, a number of interstate compacts will have additional LLW repositories, and generator-to-repository distances will decrease. Regulations (and public perception) require that transporters used for radioactive waste shipments not be used for transporting other shipments. As a consequence, transportation costs for radioactive waste should be estimated on round-trip distances rather than one-way. For example, low-level waste shipments from the Rocky Flats facility to the Nevada Test Site (approximately 750 miles one-way) cost \$1.40/mile, with each truck carrying 80 to 100 55-gallon drums of waste. Transuranic waste shipments from the Rocky Flats Plant to the Waste Isolation Pilot Plant (700 miles one-way) are expected to cost approximately \$3/mile, with each truck carrying 42 55-gallon drums of waste (Pierce and Thompson, 1991).

ORNL Liquid Waste Operations Costs

Table 59 lists operating and maintenance costs as of Jan. 5, 1994, by treatment system as estimated by J.S. Baldwin, Liquid and Gaseous Waste Operations Department (LGWOD).

TABLE 59
ORNL LIQUID WASTE OPERATIONS COSTS

COST CATEGORY	LOW-LEVEL LIQUID WASTE	PROCESS WASTE¹	NON-RADIO- LOGICAL WASTE	GROUND WATER
LGWOD labor	1,357,000	1,626,000	988,000	520,000
Maintenance labor	650,000	1,100,000	155,000	220,000
Maintenance materials	437,000	350,000	60,000	70,000
Chemical analysis	350,000	1,350,000	45,000	15,000
Engineering support	6,000	120,000	30,000	100,000
Chem Tech support	450,000	150,000	0	5,000
Misc. services	18,000	60,000	10,000	20,000
Total	3,268,000	4,756,000	1,288,000	950,000
Estimated gallons treated	440,000	75,000,000	160,000,000	Gaseous waste, 135,000 ft ³ /min
Cost/gallon (without overhead)	7.43	0.0634	0.00805	
Cost/gallon (with overhead)	10.92	0.0932	0.0118	

1 This collection system and ion exchange treatment plant. Treatment plant is probably 80 per cent of the total.

Source: Chris Scott, ORNL

APPENDIX 1. LIST OF ABBREVIATIONS

FIELD OFFICES

AL	Albuquerque Operations Office
CH	Chicago Operations Office
FN	Fernald Office
ID	Idaho Operations Office
NV	Nevada Test Site
OR	Oak Ridge Operations Office
PE	Pittsburgh Energy Technology Center
RL	Richland Operations Office
RF	Rocky Flats Plant
SF	San Francisco (Oakland) Operations Office
SR	Savannah River Operations Office

OTHER

BAT	Best available technology
CERCLA	Comprehensive Environmental Response, Compensations, and Liability Act of 1980 (Superfund)
CFR	Code of Federal Regulations
CRADA	Cooperative research and development agreement
D&D	Decontamination and decommissioning
DERP	Defense Environmental Restoration Program
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
FRDS	Federal Data Reporting System
FUDS	Formerly used defense site
HEPA	High-efficiency particulate air
ID	Identification
IMWIR	Unknown
KEI	KapLine Enterprises, Inc.
FUSRAP	Formerly Utilized Sites Remedial Action Program
M	Million
MCL	Maximum concentration level
MGD	Million gallons per day
MGM	Million gallons per month
MGY	Million gallons per year
MHD	Melton Hill Dam
NESHAP	National Emission Standards for Hazardous Air Pollutants
NIRS	National Inorganics and Radionuclides Survey
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O&M	Operating and maintenance
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations
PCB	Polychlorinated biphenyl
PID	Problem unit identification number
POE	Point-of-entry
POU	Point-of-use

APPENDIX 1. LIST OF ABBREVIATIONS (CONT.)

PWS	Public water systems
RWMS	Unknown
SVOC	Semi-volatile organic compounds
SWMU	Solid waste management unit
TDS	Total dissolved solids
TID	Technology identification number
TNA	Technology needs analysis
TPO	Technical Programs Officer
TSDF	Treatment, Storage, or Disposal Facility
UMTRA	Uranium Mill Tailing Remediation Act
UST	Underground storage tank
VOC	Volatile organic compound
WAG	Waste area grouping
WIPP	Unknown
WOC	White Oak Creek
WOD	White Oak Dam

APPENDIX 2: DISPOSAL REGULATIONS OVERVIEW

At the present time, no federal regulations specifically address the disposal of water treatment wastes containing radionuclides. However, the selection of waste by-product disposal alternatives may be determined by federal, state, and local regulatory constraints and site-specific conditions. Regulatory constraints may include industrial pretreatment requirements for sanitary sewer discharges (including requirements applicable to sewage sludge use and disposal under section 405 of the Clean Water Act), requirements under the Underground Injection Control (UIC) program, RCRA requirements for hazardous waste disposal and protection of ground water, and effluent limitations and water-quality-based limits for the discharge of some contaminants into local receiving waters (ground waters and surface waters) under the NPDES program. Site-specific conditions that influence waste management include the availability of sewage disposal, location of disposal sites, climatic factors, cost of land, and other local or regional factors including available manpower and infrastructure characteristics.

The disposal method should be determined case by case. Methods that comply with EPA's standards for disposal of uranium mill tailings should be considered (40 CFR 192). A decision not to fully employ such methods should be based on a demonstration of significant differences between the quantity and potential for migration of uranium mill tailings versus water treatment wastes. The disposal method should be augmented by long-term institutional controls to avoid future misuse of disposal sites. Such controls are not normally already in place at sanitary landfills. At a minimum, disposal in RCRA permitted hazardous waste units should be considered.

Liquid wastes, or brines, are generated by ion exchange, reverse osmosis, and activated alumina. The most economical disposal method for concentrated brines is discharge to a sanitary sewer, and for reverse osmosis, direct discharge of the concentrated waste stream to a receiving body of water, if these methods are acceptable to applicable regulatory agencies and meet Clean Water Act requirements for direct and indirect discharges to surface water. Underground injection may be an option, subject to the requirements of the Underground Injection Control Program. Other possible though more expensive alternatives include evaporation pond dewatering followed by land disposal, and chemical precipitation followed by non-mechanical drying and land disposal.

Sludges are generated by coagulation/filtration, greensand filtration, and lime softening. The most economical disposal method for sludges is discharge to a sanitary sewer. Again, this method may be restricted by state or local requirements and pretreatment requirements under the Clean Water Act (see generally 40 CFR, part 403). An alternative option may be non-mechanical drying (lagoons or drying beds) followed by land disposal. Mechanical methods tend to be higher in cost, though technically feasible, for all sludges.

EPA's report entitled *Suggested Guidelines for the Disposal of Naturally Occurring Radionuclides Generated by Drinking Water Treatment Plants* (EPA, 1990a) outlines the Agency's understanding of the technical issues and the existing regulatory framework that may be relevant to systems that remove naturally occurring radioactive substances from drinking water supplies. In this report, EPA recommends types of treatment and disposal options and institution controls that would be pertinent for solid and liquid wastes containing radioactive contaminants at various ranges of concentration. The report also makes recommendations regarding radiation in the water treatment plant and protection of workers at the plant during waste disposal operations. EPA solicits public comment on its waste disposal guidance, and waste disposal issues in general.

EPA guidelines were developed for disposal of liquid wastes or brines, which result from the treatment of drinking water containing radionuclides. These are summarized in Table 2-1 below. Note that the EPA solicits comments on the waste disposal guidance and estimated disposal costs.

Table 2-2 outlines the options for sludge disposal suggested in the EPA guidelines and 2-3 describes the options for liquid waste. Notwithstanding these suggested guidelines, solid wastes and liquid wastes generated by drinking water treatment plants should be disposed of in compliance with federal, state, and local requirements. State-adopted criteria of 40 CFR, part 257 that contains RCRA ground water protection criteria, and municipal solid waste landfill regulations under 40 CFR, part 250.

TABLE 2-1
SUMMARY OF WATER TREATMENT DATA ON WASTES
CONTAINING NATURAL RADIONUCLIDES

TREATMENT WASTES	CONCENTRATION RANGE	REFERENCES
Ion exchange		
Chemical clarification	57-171 pCi/g (dry)	EPA, 1987f
filter cake, uranium		
Brine/regen	up to 610 pCi/L	Schliekelman, 1976 and EPA, 1985d

Source: Adapted from *Federal Register*, Vol. 56, No. 138, Thursday, July 18, 1991.

TABLE 2-2
DISPOSAL GUIDELINES FOR RADIOACTIVE SOLID WASTES
RESULTING FROM DRINKING WATER TREATMENT PROCESSES¹

WASTE CHARACTERISTICS	DISPOSAL OPTION
Solids/sludges containing less than 30 pCi/g uranium (<50 ug/g dry weight)	Sludge should be dewatered and mixed in landfill. ²
Solids/sludges containing less than 30 to 500 pCi/g uranium (50 to 500 ug/g dry weight)	Sludge should be dewatered and disposed of within a stabilized landfill to isolate and to avoid inappropriate usage of the site.
Solids/sludges containing 500 to 2,000 pCi/g uranium	Case-by-case determination, to include consideration of standards for uranium mill tailings (40 CFR 192), NARM disposal, and long-term institutional control of disposal sites. RCRA hazardous waste units should also be considered. NRC provisions may apply.
Solids/sludges containing more than 2,000 pCi/g of natural radioactivity	Should be disposed of in a low-level radioactive waste disposal facility operated under the provisions of the Atomic Energy Act, as amended, or at a state or EPA-permitted facility for NARM disposal. Uranium recovery may be possible. NRC provisions may apply. Dept. of Transportation regulations would apply.

Note: Water treatment facilities should keep records of the amount and composition of radioactive wastes they generate and the manner and location of disposal.

¹ From EPA Suggested Guidelines (EPA, 1990a).

² Provisions under 40 CFR 257, 258, and 260-266 may apply.

Source: *Federal Register*, Vol. 56, No. 138, Thursday, July 18, 1991.

TABLE 2-3
DISPOSAL GUIDELINES FOR RADIOACTIVE LIQUID WASTES
GENERATED BY WATER TREATMENT PLANTS¹

DISPOSAL OPTION	REQUIREMENTS (FEDERAL AND OTHER)
Disposal into surface water	Federal, state, and local discharge limits and NPDES permit requirements apply, buildup of radioactivity will not occur.
Discharge into sanitary sewers total uranium less than 1 uCi/L, and yearly total discharge less than 1 curie	(1) State limits on discharge of hazardous or radioactive wastes. (2) Limits on discharge of radium and uranium into sanitary sewers--per NRC standards for discharge by licensees (10 CFR 20, part 303). (3) Federal, state, and local pretreatment requirements.
Disposal of radioactive wastes through injection wells (under conditions consistent with 40 CFR 144 classifications of wells). Shall injection banned	Authorization of any injection of liquid wastes under the Underground Injection Control (UIC) program regulations in 40 CFR 144.6(a)(2) and 144.12(c)
Evaporation, precipitation, drying, or other treatment	Residual solids should be disposed per solid waste regulations and per EPA guidelines for water treatment solid wastes (EPA, 1990a).

¹ From EPA Suggested Guidelines (EPA, 1990a).

* Bold type indicates actual regulatory requirements.

Source: *Federal Register*, Vol. 56, No. 138, Thursday, July 18, 1991.

In states where lower concentration NARM disposal is licensed permitted, that option should be considered for uranium-bearing solids containing 50 to 500 ug/g (dry weight) uranium. Recovery of the uranium resource (i.e., at uranium milling site) may be considered. However, NRC may require licensing the material recovered (greater than 0.05%) as a "source material" under the provisions of the Atomic Energy Act. Disposal at a licensed low-level radioactive waste facility should also be considered.

Wastes exceeding 500 ug/g (dry uranium should be disposed of in a low-level radioactive waste disposal facility or at a facility that is permitted by EPA or a State to dispose of NARM wastes. Recovery of the uranium resource may be considered. NRC licensing requirements may apply.

APPENDIX 3. GENERAL WATER-TREATMENT TECHNOLOGY DISCUSSION

Ground waters are found in porous formations below the surface. They depend for their long-term availability on replenishment (or recharge) from the surface. Water-bearing layers suitable for economical extraction by means of wells are called aquifers. They operate simultaneously as reservoirs and as flow media. Economically important amounts of water may vary from less than a gallon per minute for cattle water in the desert to thousands of gallons per minute for industrial, irrigation, or municipal use. Ground water pollution is a major problem today. The source of this pollution is from migration of contaminants through the soil and directly from surface waters. Effective remediation of ground water is an especially difficult problem.

According to *Evaluation of Ground Water Extraction Remedies* (EPA/54-/2-89/054), ground-water extraction, referred to as pump-and-treat or withdrawal-and-treatment technology, is the most commonly used remedial technology for contaminated aquifers. In this process, the water is removed from the ground, treated using a technology appropriate for aqueous media, then placed back in the ground. However, the effectiveness of pump-and-treat for ground water restoration, as opposed to well-head treatment prior to use, has been questioned.

Table 3-1 summarizes ground water remedies at NPL sites through 1991. These remedies included those for VOCs and other contaminants, not just uranium. Most ground water remediation involves extraction processes, rather than methods to treat aquifers in place. However, these pump-and-treat technologies often cannot achieve desired ground water cleanup goals.

TABLE 3-1
GROUND WATER REMEDIES AT NPL SITES THROUGH FY91

TREATMENT METHOD	NUMBER OF SUPERFUND SITES WHERE USED	PER CENT
Established technologies:	414	73
<i>Ex situ</i> treatment		
Treatment to be determined	73	13
Non-treatment remedies	71	12
Innovative technologies:	12	2
<i>In situ</i> bioremediation	9	1
Other <i>in situ</i> treatment	3	<1

Note: Often more than one ground water technology is selected.

Source: U.S. EPA

Until recently, contaminants in unsaturated soils were considered to be the most significant source of ground water contamination. However, studies indicate that non-aqueous phase liquids (NAPLs) and contaminants captured or sorbed by soils in the aquifer are released slowly into the ground water. Consequently, improved *in situ* ground water techniques are needed to treat this residual subsurface contamination.

EXTRACTION/PUMP-AND-TREAT

The extraction method of remediation, also referred to as the "pump-and-treat method," usually includes three steps: 1) extraction (i.e., **removal** from the ground--not solvent extraction) of contaminated ground water from the aquifer via recovery wells, 2) treatment of the extracted water using treatment technologies, and 3) disposal or treatment of the contaminants and discharge of the treated water. One of the objectives of this study is to evaluate the treatment technologies that are used for step 2 of the remediation process for removing uranium from aqueous media.

TREATMENT METHODS

Three broad areas of treatment possibilities can be used in step 2, the selection of which depends on the contamination and costs associated with treatment: 1) physical, which includes adsorption, density separation, filtration, reverse osmosis, air and steam stripping, and incineration; 2) chemical, which includes precipitation, oxidation/ reduction, ion exchange, neutralization, and wet air oxidation, and 3) biological, which includes activated sludge, aerated surface impoundments, land treatment, anaerobic digestion, trickling filters, and rotating biological discs. Table 3-2 lists the technologies that can be used to treat contaminated aqueous media. This table also indicates the contaminants it is used for and the status of the technology (i.e., available, innovative, or emerging). This list is provided because often treatment technologies are combined into treatment "trains" to effect a remediation solution for mixtures of contaminants. This section also presents information regarding specific technologies that KEI believes might possibly be useful for uranium removal and other miscellaneous material of interest.

TABLE 3-2
TREATMENTS FOR AQUEOUS MEDIA

TYPE	TREATMENT TECHNOLOGY	APPLICABLE CONTAMINANTS/ QUALIFYING FACTORS	STATUS
Biological	Activated Sludge	Soluble organics in dilute aqueous waste streams (<1% suspended solids). BOD <11,000 ppm. Requires low concentrations of heavy metals, PCBs, pesticides, oils, and grease. Output sludge contains heavy metals and refractory organics, which require further treatment.	Available
	Aerobic Treatment	Aqueous waste with low levels of non-halogenated organics and certain halogenated organics (i.e., phenols, formaldehyde, PCB. BOD <10,000 ppm. Requires consistent, stable operating conditions.	Available
	Anaerobic Treatment	Aqueous slurry with low to moderate levels of non-chlorinated organic compounds containing <7% solids. Requires consistent, stable operating conditions. Unsuitable for oil grease, aromatics, and long chain hydrocarbons. Output sludge requires incineration.	Available
	Composting	Aqueous sludge with <50% solids, non-chlorinated hydrocarbons, high organic wastes including oils, tars, and industrial processing sludges. Requires nutrient supplementations. Output sludge contains heavy metals.	Available
	Enzyme Treatment	Soluble organics in dilute aqueous waste streams. Requires stable influent concentration.	Emerging
	Lagoons and Ponds	Industrial wastewater, organics with slow biodegradation potential, soluble organics in dilute aqueous waste streams. Requires large area. Unsuitable for solids. Requires a temperate climate. Output sludge contains heavy metals and refractory organics that require further treatment.	Available
	Rotating Biological Contactor	Biodegradable dilute aqueous organic waste including solvents and halogenated organics. Limited to low concentrations of heavy metals and concentrated refractory organics. Unsuitable for sludges or solids.	Available
	Trickling Filter	Soluble organics in dilute aqueous waste streams with <1% suspended solids including solvents and halogenated organics. BOD <5,000 ppm. Output sludge contains heavy metals and refractory organics that require further treatment.	Available

TYPE	TREATMENT TECHNOLOGY	APPLICABLE CONTAMINANTS/ QUALIFYING FACTORS	STATUS
Chemical	Hydrolysis	Liquids, solids, soils, or sludges contaminated with organic compounds. Requires careful handling of strong acids and alkalines. Reaction is performed at high temperatures and pressure requiring close monitoring.	Available
	Ion Exchange	Aqueous organic or inorganic waste streams, principally metals. Suitable for liquid waste only.	Available
	Lignin Adsorption	Aqueous organic or inorganic waste streams. Qualifying factors not known.	Emerging
	Oxidation	Dilute aqueous waste (<1% waste) containing organic/inorganic compounds. Requires controlled reaction conditions. Suitable for liquids and sludges only.	Available
	Precipitation	Aqueous organic and inorganic waste containing metals. Requires optimization of the reaction pH for the specific mix of metals present. Output sludge requires further treatment. Cross-reactivity may occur for mixed-metals-content waste. Unsuitable for sludges, tars, and slurries.	Available
	Reduction	Dilute aqueous waste stream containing inorganic compounds, especially metals (<1% heavy metal concentration). Applicable to inorganic liquid waste only.	Innovative
	UV/Photolysis	Liquid waste containing dioxins. Suitable for liquids only.	Emerging
Physical— Component Separation	Air Flotation	Liquid waste containing oils or light suspended solids. Liquid effluent may require further treatment.	Available
	Centrifugation	Organic/inorganic liquids, slurries, and sludges containing suspended or dissolved solids or liquids where one component is non-volatile. For example, waste water sludge, wastes containing immiscible liquids, or wastes containing three distinct phases. Unsuitable for tars, solids, dry powders, or gases. Not applicable for small-size or low-density particles.	Available
	Filtration Granular Media Filtration	Liquid waste containing suspended solids and/or oils. Requires pretreatment for suspended solids with concentration <100 mg/l. Requires frequent backwashing.	Available

TYPE	TREATMENT TECHNOLOGY	APPLICABLE CONTAMINANTS/ QUALIFYING FACTORS	STATUS
Physical- Phase Separation (Cont.)	Gravity Separation	Liquid waste containing settleable suspended solids, oils, and/or grease. Liquid effluent may require further treatment. Unsuitable for heavy slurries, sludges, or tars.	Available
	Air Stripping	Aqueous and adsorbed organic and inorganic wastes with relatively high volatility and low water solubility such as chlorinated organics, aromatics, and ammonia. Limited to VOC concentration <100 ppm. Suspended solids may clog tower.	Available
	Carbon Adsorption	Aqueous organic wastes (containing <1% total organics and <50 ppm solids) with high molecular weight and boiling point, and low water solubility, polarity, and ionization. Unsuitable for metals, oil, or grease.	Available
	Evaporation	Organic/inorganic liquid solvents contaminated with non-volatile impurities (i.e., oils, grease, paint solvents, polymeric resins). Liquids must be volatile. Unsuitable for tars, solids, dry powders, or gases. Energy-intensive process.	Available
	Freeze Crystallization	Dilute aqueous organic/inorganic waste solutions containing <10% total dissolved solids. Unsuitable for foamy, viscous, or high solid-content waste streams.	Emerging
	Metal Binding	Metal-contaminated aqueous waste streams, leachate, or ground water. Limited to metal concentrations between 500-1,000 ppm.	Emerging
	Resin Adsorption	Aqueous waste streams containing soluble organics, particularly phenols, and explosive materials. Limited to low concentrations of organics (<8%) and suspended solids (<50 ppm).	Available
	Reverse Osmosis	Aqueous waste streams containing <400 ppm heavy metals, high molecular weight organics, and dissolved gases. Unsuitable for oxidants. Requires controlled pH, low concentration of suspended solids.	Innovative

TYPE	TREATMENT TECHNOLOGY	APPLICABLE CONTAMINANTS/ QUALIFYING FACTORS	STATUS
Physical— Phase Separation (Cont.)	Solvent Extraction	Aqueous stream contaminated with single- or multi-component dissolved organic wastes. Sludge contaminated with oils, toxic organics, and heavy metals. Extracting solvent must be immiscible in the liquid and differ in density so gravity separation is possible. Suitable for sludges containing <20 wt% oil/organics and <20 wt% solids.	Available, Innovative
	Steam Stripping	Aqueous solutions of volatile organics with low metal concentration. Effluent may require further treatment. Suitable for waste streams with low metal concentration.	Available
	Supercritical Extraction	Liquids, sludge, or solids contaminated with organics. Effluent may require further treatment.	Emerging
	Ultrafiltration	Removes oils, metals, and proteins from aqueous solutions with dissolved organics, emulsions, and colloidal particles. Limited to low concentrations of suspended solids.	Available

Source: *Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites*, U.S. EPA, Office of Environmental Engineering and Technology Demonstration, EPA/540-2-89/052, March, 1989.

Biological

A number of biological treatment processes exist that may be applicable to the treatment of contaminated ground water, including various forms of activated sludge treatment, surface impoundments or lagoons, trickling filters or biological towers, rotating biological discs, fluidized bed reactors, land treatment, and anaerobic digestion. Although these methods are described for organic applications, there are some organisms that work for uranium.

Activated Sludge

This method consists of passing the contaminated waste stream through an aeration basin where it is aerated for several hours. During this time, an active microbial population develops, which degrades organic matter in the waste. In the process, a portion of the activated sludge is recycled and along with new developing cells the microbial population is maintained for further degradation of the waste stream. Activated sludge costs are high with intensive operation and maintenance costs. It is sensitive to suspended solids and metals. The process generates sludge high in metals and refractory organics and is fairly energy intensive.

Surface Impoundments

Surface Impoundments or lagoons are similar to activated sludge units without sludge recycle. Aeration may be supplied passively by wind action or, in aerated surface impoundments, by mechanical aerators. Surface impoundments are sensitive to shock loadings and temperature effects. Gas generation and chemical volatilization are problems with anaerobic lagoons.

Trickling Filters, Biological Tower, Rotating Biological Disk System, and Fluidized Bed Reactor

Trickling filters are a form of biological treatment in which a liquid waste (<1% suspended solids) is trickled over a bed of rocks or synthetic material upon which a slime layer of microbial organisms develops. The microbes metabolize the organics in the waste while oxygen to the microorganisms is provided as air moves counter current to the water flow.

A modification of the trickling filter is the biological tower. The medium (e.g., of polyvinyl chloride, polyethylene, polystyrene, or redwood) is stacked into towers that typically reach 16 to 20 feet. The contaminated water is sprayed across the top of the tower and, as it moves downward, air is pulled upward through the tower. A slime layer of microorganisms develops on the media and removes the organic contaminants as the water flows over the slime layer.

The rotating biological disk system consists of a series of rotating discs, connected by a shaft, set in a basin or trough. Approximately 40 per cent of each disc's surface area is submerged in the basin and as the contaminated water passes through the basin, the microorganisms growing on the disc metabolize the organics in the waste water. As the discs rotate, the microorganisms are brought in contact with the air where oxygen is obtained for growth.

Another fixed-film process is the fluidized bed reactor. Particles of substances such as sand or coal are fluidized by the action of the aeration gas stream and the waste water stream. These particles support a dense growth of microorganisms, which give rapid treatment to the waste water. The process is still largely experimental.

Trickling filters, rotating biological discs, and fluidized bed reactors require an energy source and are vulnerable to below-freezing temperature and require long recovery times if disrupted. They also have the potential for odor problems and have limited flexibility (i.e., minimize variations in operating conditions such as flow and composition).

Chemical

Chemical treatment processes alter the chemical structure of the constituents of the waste to produce either an innocuous or a less hazardous material. Chemical processes are attractive because they produce minimal air emissions, they can often be carried out on the site of the waste generator, and some processes can be designed and constructed as mobile units.

Precipitation

Precipitation is a physicochemical process whereby a substance in solution is transformed to the solid phase. It can be accomplished by 1) adding a chemical that will react with the contaminant in a solution forming a sparingly soluble compound, 2) adding a chemical that changes the solubility equilibrium of a waste thus reducing the solubility of the specific contaminants, and 3) changing the temperature to decrease the solubility of the contaminants. Removal of metals as carbonates, hydroxides, or sulfides is the most common application of precipitation in waste water treatment.

Many precipitation reactions (e.g., metal sulfides) do not readily form floc (large fluffy precipitates) particles, but rather precipitates very fine and relatively stable colloidal particles. In these cases, flocculating agents (e.g., alum and/or polyelectrolytes) must be added to cause flocculation of the metal sulfide precipitates. The effectiveness of precipitation/flocculation reactions is dependent upon the nature and concentration of the contaminants and upon the process design. The design must consider the optimum chemicals and dosages, suitable chemical addition systems, optimum pH and mixing requirements, sludge production, sludge flocculation, and settling and dewatering characteristics.

Precipitation can be limited by the presence of complexing agents in the waste and the precipitate itself may be a hazardous waste.

Reduction

Reduction using sulfur dioxide, sodium borohydride sulfite salts, or ruthenium tetroxide is an innovative chemical treatment technology for remediating dilute aqueous waste streams containing inorganic compounds, especially metals (<1% heavy metal concentration).

Ion Exchange

Ion exchange is a process whereby toxic ions are removed from the aqueous phase by being exchanged with relatively harmless ions held by the ion exchange material. It is used to remove a broad range of ionic species from water to include 1) all metallic elements when present as soluble species, either anionic or cationic, 2) inorganic ions such as halides, sulfates, nitrates, cyanides, etc., 3) organic acids such as carboxylics, sulfonics, and some phenols, and 4) organic amines in sufficient acidity to form the acid salt. Ion exchange systems function well in dilute waste streams of variable composition provided the effluent is monitored to determine when ion exchange resin bed exhaustion has occurred. Limitations of resin sorption are that it is more expensive and usually has less capacity than carbon adsorption. Resin is intolerant of strong oxidizing agents and the effectiveness of ion exchange is reduced by high suspended solids and/or high concentrations of certain organics. Ion exchange is discussed more in Chapter 5.

Physical

Physical treatments separate components of a waste stream or change the physical form of the waste without altering the chemical structure of the constituent materials. Physical techniques are often used to separate the materials within the waste stream so that they can be reused or detoxified by chemical or biological treatment or destroyed by high-temperature incineration. These processes are very useful for separating hazardous materials from an otherwise non-hazardous waste stream so that they may be treated in a more concentrated form, separating various hazardous components for different treatment processes and preparing a waste stream for ultimate destruction in a biological or thermal treatment process.

Adsorption

The two major sorbent treatment methods are adsorption by granular activated carbon (GAC, which includes powdered activated carbon) and chemisorption (i.e., ion exchange) by synthetic resins. Refer to Chapter 5, which discusses these treatments in terms of uranium removal. Both GAC and resins remove dissolved contaminants from water.

Sorption systems, whether adsorbent GAC or chemisorbent resin, consist of a large vessel partially filled with sorbent. There is an inlet for contaminated water and an outlet for treated water. Influent water enters and is in contact with the sorbent for a specified period of time and then exits for collection, recharge, or further treatment. Often systems are arranged with several tanks in parallel or in series to allow for the most efficient treatment possible.

Once the micropore surfaces of the sorbent are saturated with contaminants, the material must either be replaced or regenerated, thermally or chemically. Sorption is an effective and reliable means of removing low solubility organics and some metals and inorganic species. It can be used for treating a wide range of contaminants over a broad concentration range.

Carbon

Carbon adsorption, however, is intolerant of high suspended solids. It can be poisoned by high heavy metals concentrations and requires pretreatment for oil and grease greater than 10 ppm. This process has high operation and maintenance costs.

Activated carbon is an amorphous form of carbon characterized by high adsorptivity for many gases, vapors, and colloidal solids. Activated carbons are a very versatile group of adsorbents, with capability of selectively adsorbing thousands of organic, and certain inorganic materials. A large variety of organic materials can be used to make it. Different types of activated carbon can be made by varying pyrolysis and oxidation conditions. As a result, carbons with widely varying selectivities for hydrocarbon species can be produced. Carbon is an effective adsorbent of organic molecules and sulfur-bearing compounds. As a result, one of its primary applications is odor removal. Note, however, that it is not effective in removing ethylene.

GAC is generally used for the removal of tastes, odors, and organic chemicals from water; however, its effectiveness for adsorption of noble gases (including radon) is well known. The process generally involves adhesion of dissolved gas to the surface of the carbon and subsequent diffusion into the interior of the granules where the majority of free surface area

exists. It has been determined that a small volume GAC contactor can remove 96 per cent of the radon supplied to a home.

This technology is considered most effective for small water systems because of its relative simplicity and because costs of multiple, large volume contactors needed in larger systems may be prohibitive. An advantage to the use of this technology involves the fact that, because of decay, the effective life of the GAC bed is extended many times over that expected from the adsorption isotherm. However, because the decay of radon gas in the carbon results in an accumulation of daughter progeny within the contactor, the possibility exists of an elevated gamma radiation hazard. Note that no mention was made by the EPA of using carbon to remove uranium, although personal communication with some sources indicate that it has been used.

Membranes

Dialysis

Dialysis is a process for separating components in a liquid stream by using a membrane. Components of a liquid stream will diffuse through the membrane if a stream with a greater concentration of the component is on the other side of the membrane. Dialysis is used to extract pure process solutions from mixed waste streams.

Reverse Osmosis

In the process of reverse osmosis, a uranium-removal BAT, a solvent spontaneously flows from a dilute solution, through a semipermeable membrane, to a more concentrated solution by osmotic pressure. If enough pressure is placed on the concentrated solution to overcome the osmotic pressure, water will flow toward the dilute phase thereby creating reverse osmosis. In this process, the contaminants are allowed to build up in a circulating bath on one side of the membrane while relatively pure water passes through the membrane.

Basically, a reverse osmosis unit is composed of the membrane, a membrane support structure, a containing vessel, and a high-pressure pump, with the most critical elements being the membrane and the membrane support structure. The process is used to separate ions and small molecules in true solution from water, and to decrease the dissolved solids concentration, both organic and inorganic. Advances in membrane technology have made it possible to remove low molecular weight organics such as alcohols, ketones, amines, and aldehydes.

Reverse osmosis units are subject to chemical attack, fouling, and plugging and can require extensive pretreatment such as removal of suspended solids, pH adjustments, and removal of oxidizers, oils, and grease.

Ultrafiltration

Ultrafiltration is an established technology used to remove oils, metals, and proteins from aqueous solutions with dissolved organics, emulsions, and colloidal particles. This technology is limited to low concentrations of suspended solids. Ultrafiltration is similar to reverse osmosis, but the separation begins at higher molecular weights. The result is that dissolved components with low molecular weights will pass through the membrane with the bulk liquid while the higher-molecular-weight components become concentrated through the loss of solvent. These systems can handle much more corrosive fluids than reverse-osmosis units.

Metal Binding

Metal binding is a phase-separation physical-treatment technology used for metal-contaminated aqueous waste streams, leachate, or ground water. It is limited to low concentrations of organics (<8%) and suspended solids (<50 ppm).

REMEDATION ALTERNATIVES

As more experience has been gained from the long-term operation of ground-water extraction systems, it has become apparent that their performance often does not meet initial expectations. This is particularly true of systems that have been installed with the intention of cleaning up aquifers to health-based concentration goals. Cases where performance goals for aquifer cleanup have been met or exceeded are quite rare. As a result, questions have been raised concerning the general feasibility of aquifer remediation to health-based standards, how it is affected by site conditions, and how long remediation should be expected to take.

Aquifer Restoration

Several physical phenomena have been identified that tend to interfere with the aquifer cleanup performance of extraction systems. One of them is adsorptive partitioning of contaminants between the ground water and the aquifer materials. If adsorption is neglected, projections of system effectiveness are likely to be over optimistic. Aquifer homogeneity can also reduce effectiveness by making it difficult to control the ground-water flow patterns in the area to be remediated. Aquifer cleanup where residual contaminant sources are present is difficult and often infeasible. Examples of residual contaminant sources include unremediated disposal areas, contaminated soils above the water table, and the presence of contaminants in a non-aqueous phase.

Migration Control

Aquifer restoration is not the only objective of ground-water extraction systems. Another commonly expressed goal is migration control, or hydraulic containment of the contaminant plume. In most aquifer restoration systems, plume containment is listed as a secondary goal. Indeed, it is usually necessary to establish control of contaminant migration if the aquifer is to be cleaned up. (Exceptions to this are sites where the aquifer can restore itself naturally by discharging to surface water bodies or through chemical or biological degradation of the ground-water contaminants.)

Well-head Treatment

Another form of ground-water extraction, called the well-head treatment system, is sometimes found at well fields where production wells have become contaminated. Here it has been found to be cost effective to continue producing contaminated water but to remove the contaminants by treatment before delivering it to the users. There are several variations of this approach. At some sites the source of the contamination is known, and an auxiliary extraction system has been installed there. This auxiliary system may be intended either to clean up the contaminated aquifer or simply to prevent continued migration toward the well field. In other cases, the source of the contamination may be unknown, and the well-head treatment system may be the only practical alternative.

***IN SITU* TREATMENTS**

New *in situ* ground-water treatment technologies are needed to address residual contamination in the aquifer. Although 79 per cent of Superfund sites with Records of Decisions (RODs) require ground-water remediation, *in situ* remedies make up less than 2 per cent of the technologies selected at Superfund sites. Of the 210 innovative technologies selected at Superfund sites, only 9 are for the treatment of ground water *in situ*. Of the nine sites, five contain non-chlorinated volatiles (i.e., benzene, toluene, ethyl benzene, xylene), five contain SVOCs, and one has chlorinated VOCs. One *in situ* technology discovered by KEI is the absorbent sponge, which is discussed in Chapter 5.

APPENDIX 4: SAMPLE SITE ANALYSIS-- OAK RIDGE RESERVATION

The information presented in this section was extracted from the *Oak Ridge Reservation Environmental Report for 1992* (ES/ESH-31/V1,2). Table 4-1 is an overview of the test results (minimum and maximum are listed where appropriate) for uranium in water discharges from the Oak Ridge Reservation sites. Note that this information was compiled from several tables in the source document. As a result, the units are sometimes inconsistent. Statistics were usually given in pCi/L, but were also given in mg/L and per cent. Table 4-2 lists the flow rates for discharges on the Oak Ridge Reservation.

**TABLE 4-1
1992 RADIONUCLIDE WATER DISCHARGES AT THE OAK RIDGE
RESERVATION**

Source	pCi/L (unless otherwise noted)					
	Gross Alpha, pCi/L	Total U, mg/L	U-234	U-235	U-236	U-238
Surface Water						
<i>Discharge</i>						
Y-12						
East Fork Poplar Creek	NL	NL	0.039 Ci	0.0019 Ci	NL	0.046 Ci
Bear Creek	NL	NL	0.020 Ci	0.0012 Ci	NL	0.038 Ci
K-25	NL	NL	0.026 Ci	0.00078 Ci	0.00035 Ci	0.014 Ci
<i>Radiological data</i>						
ORNL						
<i>Nearby surface waters</i>						
Melton Hill Dam	-0.14-7*	NL	NL	NL	NL	NL
White Oak Creek Headwaters	-0.27-11*	NL	NL	NL	NL	NL
<i>NPDES locations</i>						
Sewage Treatment Plant (X01)	0.65-0.65	NL	NL	NL	NL	NL
Non-radiological Waste Water Treatment (X-12)	4.6*-27*	NL	NL	NL	NL	NL
White Oak Dam (X-14)	1.4*-18*	NL	NL	NL	NL	NL
Y-12						
Upper Bear Creek km 11.97	0.07-318	<0.055-0.752	NL	0.33-0.44%	NL	NL
Upper Bear Creek km 12.4	0.17-750	0.017-0.844	NL	0.28-0.4%	NL	NL
Diversion ditch	NL	NL	NL	0.010-0.050 mg/L (total U-235); 0.31-0.85% pCi/L; 0.26-5.1%	NL	NL
Station 17	0.02-83	0.011-0.108	0.22-110	0.01-4.3 pCi/L; 0.19-3.48%	NL	0.39-67
Sanitary sewer	-18.07-141.75	-0.02-0.02	0.00-11.97	0.19-3.48%	NL	-33.84-4.13

pCi/L (unless otherwise noted)						
Source	Gross Alpha, pCi/L	Total U, mg/L	U-234	U-235	U-236	U-238
Surface water (Cont.)						
Y-12 (Cont.)						
Discharge Pt. 109	8.8-13	0.002-0.004	4.8-11	0.18-0.37 pCi/L; 3-4.1%	NL	0.9-1.4
Discharge Pt. 135	-0.84-12	0.004-0.008	1.7-3.9	0.11-0.31 pCi/L; 0.71-1.7%	NL	1.5-2.4
Discharge Pt. 147	0-52	<0.001-0.008	0.13-10	0-0.45 pCi/L; 1.2-9.5%	NL	0.004-2.7
Discharge Pt. 302, Rogers Quarry	-3.1-15	0.001-0.001	0.02-1.9	-0.03-0.07	NL	NL
Discharge Pt. 304, Bear Creek	-3.9-39	0.009-0.062	NL	NL	NL	NL
Discharge Pt. 501, Central Pollution Control Facility	-64-170	0.002-0.23	0.58-39	0-2.1 pCi/L; 0.32-0.6%	NL	0-77
Discharge Pt. 502, West End Treatment Facility	-35-280	0.001-0.016	-0.05-6.4	-0.05-0.14 pCi/L; 0.26-0.52%	NL	0.22-5.8
Discharge Pt. 503, Steam Plant Waste Water	-100-200	0.001-0.001	-0.02-24	-0.05-1.5 pCi/L; 0.29-0.29%	NL	-0.004-6.4
Discharge Point 504, Plating Rinse Water Treatment	-1.3-48	0.001-0.079	0.23-12	-0.01-0.75 pCi/L; 0.38-0.64%	NL	0.63-30
Discharge Point 512, Ground Water Treatment Facility	37-380	0.051-0.933	9.9-53	0.28-4.7 pCi/L; 0.2-0.43%	NL	16-350
City Monitoring	-4.4-130	0.003-0.017	2-11	0.22-2.56%	NL	0.9-7.8
Union Valley Monitoring	<-1.8-84	0.003-0.136	-1.4-11	0.15-1.2%	NL	0.31-75
K-25						
K-1203	7.33-36.1	0.002-0.006	1.23-3.70	0.04-0.17	0.01-0.04	0.67-1.98
K-1700	7.51-17.4	0.009-0.023	6.17-21.6	0.29-0.99	0.13-0.45	3.29-11.5
K-1007-B	-2.27-3.41	0.001-0.001	0.62-1.23	0.024-0.049	0.006-0.013	0.33-0.66
K-901-A	-0.60-7.38	0.002-0.004	1.23-3.09	0.03-0.076	0.012-0.032	0.662-1.65
K-1407-J	-43-186	0.017-0.43	15.40-222	0.3-5.79	0.16-2.29	8.29-119
West Fork Poplar Creek	-1.45-4.07	NL	-0.456-0.419	32.2-62.0	NL	NL
K-1710	-0.64-4.64	0.001-0.005	0.432-1.31	0-70	NL	0.436-2.18
K-1513	-1.80-4.82	NL	NL	NL	NL	NL
K-1770	-0.60-4.89	0.001-0.002	NL	NL	NL	NL
Clinch River at Brashear Island	-1.19-0	NL	NL	NL	NL	NL
Mitchell Branch	-0.89-5.63	0.007-0.007	NL	NL	NL	NL
K-1070-C/D	3.23-9.99	NL	NL	NL	NL	NL

pCi/L (unless otherwise noted)						
Source	Gross Alpha, pCi/L	Total U, mg/L	U-234	U-235	U-236	U-238
Surface water (Cont.)						
Other						
Gallaher Water Treatment Plant	-0.22-6.5*	0.00017-0.00025; 0.11-0.17 pCi/L				
Kingston Water Treatment Plant	0.43-1.9*	0.00010-0.00019; 0.066-0.13 pCi/L				
Ground Water						
ORNL Downgr.						
WAG 1	-0.62-300*					
WAG 2	-0.11-14*					
WAG 3	-0.16-41*					
WAG 4	3.0*-160					
WAG 5	-0.14-27*					
WAG 6	-1.3-4.3*					
SWSA 6	-0.76-7.3*					
WAG 7	0.54-140*					
WAGs 8 & 9	0.054-6.8*					
WAG 17	3.5*-21*					
ORNL Upgr.						
WAG 1	0.73-3.2*					
WAG 2	1.1-21*					
WAG 3	1.3*-7.6*					
WAG 4	0.41-1.9*					
WAG 5	0.32-1.5*					
WAG 6	-1.0-4.1*					
WAG 7	2.3*-3.5*					
WAGs 8 & 9	2.7*-32*					
WAG 17	1.4-23*					
Y-12						
Bear Creek						
Background	7.8-55	0.033-0.28	3.5-50	1.9-3.5	NL	4.4-64
Springs	7.8-55	0.033-0.28	3.5-50	1.9-3.5	NL	4.4-64
Surface Water	6.4-130	0.020-0.031	3.0-14	1.2-2.2	NL	2.5-38
Exit Pathway						
Traverse A	2.3-28	0.0020-0.098				
Traverse B	2.3-89	0.0010-0.30				
Traverse C	1.9-34	0.0010-0.0080				
Traverse W	2.3-8.8	0.0010-0.0020				
Lysimeter Demo	6.3-92	0.0010-0.0010				
Oil Landfarm	1.6-60	0.0010-0.051				2.6-2.6
Rust Spoil Area	1.7-5.1	0.0020-0.0020				
S3 Ponds	2.5-24,000	0.0010-36	20-2,000	180-550	NL	29-4,900
Spoil Area 1	1.5-17	0.0010-0.0020				
Y-12 Burial Grounds	1.5-110	0.0010-0.090	8.0-13	NL	NL	11-26

Source	Gross Alpha, pCi/L	Total U, mg/L	pCi/L (unless otherwise noted)			
			U-234	U-235	U-236	U-238
Ground water (Cont.)						
Y-12 (Cont.)						
Chestnut Ridge						
Ash Disposal Basin	1.9-3.1	0.0010-0.0010				
East Waste Pile	3.0-3.1	0.0010-0.0010				
Kerr Hollow Quarry	2.0-28	0.0010-0.016				
Landfill II	3.5-18	0.0010-0.0060				
Landfill II Expansion	1.5-52	0.0010-0.0040				
Landfill III	1.4-39	0.0010-0.0040				
Landfill IV	1.8-36	0.0010-0.0010				
Rogers Quarry	2.0-7.3	0.0010-0.0010				
Security Pits	1.5-89	0.0010-0.0070				
Sediment Disposal Basin	1.7-17	0.0010-0.019				
United Nuclear Site	2.0-4.4	0.0010-0.0010				
Upper East Fork						
Poplar Creek						
Background	1.6-69	0.0010-0.0080				
Beta-4 Security Pit	2.8-12	0.0010-0.031				
Exit Pathway--Traverse J	2.4-3.6	NL				
Grid E-1	4.6-43	0.0010-0.0010				
Grid G-1	2.6-5.7	0.0040-0.0060				
Grid G-2	2.1-3.0	0.0030-0.0030				
Grid J-1	4.3-4.3	0.0010-0.0010				
Grid J-2	7.9-7.9	0.0010-0.0010				
Grid J-3	2.2-3.9	NL				
Grid K-1	1.7-39	0.0020-0.0020				
Grid K-2	4.7-8.5	0.0010-0.0010				
Grid K-3	2.4-2.4	NL				
J-Primary	2.8-2.9	NL				
New Hope Pond	1.6-76	0.0010-0.18				
Rust Garage Area	1.7-20	0.0080-0.016				
S2 Site	2.1-28	0.0010-0.0080				
S3 Ponds	1.5-13	0.0010-0.0020				
U.S. Geological Survey Sites	2.3-100	0.0010-0.0030				
Underground Storage Tank Program	0.62-550	0.0010-0.11				

		pCi/L (unless otherwise noted)				
Source	Gross Alpha, pCi/L	Total U, mg/L	U-234	U-235	U-236	U-238
Ground water (Cont.)						
Y-12 (Cont.)						
Waste Coolant Facility Area	2.9-3.2	0.0010-0.0040				
K-25						
Well Grouping 1 ²	-0.803-90.6	0.077-4.34 ug/L				
Well Grouping 5	14.6-14.6					
Well Grouping 6	-0.158-52.9		0-4.56	0-4.56		0-13.9
Well Grouping 8	0.218-2.3					
Well Grouping 9	-1.13-106					
Well Grouping 10	0.533-23.6	0.223-5.27 ug/L				
Well Grouping 12	-1.79-36.8					
Well Grouping 13	1.38-37.4					
Off-Site Residential	1.4*-5.7*	0.00015-0.00018				

• These individual concentrations were indicated to be significantly greater than zero.

² Filtered

Note: Gross alpha activity above 15 pCi/L exceeds the maximum contamination level for gross alpha activity. This indicates that one or more of the alpha-emitting radionuclides are present in the sample. Total uranium results should not exceed 0.020 mg/L; 13 pCi/L. To convert Ci to Bq, multiply by 3.7E+10.

Source: *Oak Ridge Reservation Environmental Report for 1992, Vol.2*, F.C. Kornegay (Project director), ES/ESH-31/V2.

TABLE 4-2
1992 FLOW RATES FOR THE OAK RIDGE RESERVATION

LOCATION	AVERAGE FLOW	MINIMUM FLOW	MAXIMUM FLOW
K-25 Effluent Permit Discharges			
K-1700 (001)			
Surface runoff once-through cooling	0.58 galx10 ⁶ /d	NL	NL
Metals cleaning facility/uranium recovery	0.12 galx10 ⁶ /d	NL	NL
K-1407-J (001)			
Chemical Process Development Facility/TSCA Incinerator/Steam plant and coal yard effluents	NL	NL	NL
K-1407-E/F (010)			
Steam plant and coal yard effluents/Surface runoff	0	NL	NL
K-901-A (007): Surface runoff	0.1 galx10 ⁶ /d	NL	NL
K-1203 (005)			
Sanitary waste waters/Organic industrial waste waters	0.43 galx10 ⁶ /d	NL	NL
K-1007-B (006)			
Potable water from once-through cooling system/Fire water from once-through system/Surface runoff	1.04 galx10 ⁶ /d	NL	NL
K-1515-C (009)			
Water from sludge and backwash systems associated with potable water plant/Surface runoff	0.22 galx10 ⁶ /d	NL	NL
Melton Branch 1	NL	0.068 x 10 ⁹ liters	0.51 x 10 ⁹ liters
White Oak Creek	NL	0.31 x 10 ⁹ liters	1.1 x 10 ⁹ liters
White Oak Dam	NL	0.43 x 10 ⁹ liters	1.6 x 10 ⁹ liters
Clinch River	NL	100 x 10 ⁹ liters	610 x 10 ⁹ liters

Source: *Oak Ridge Reservation Environmental Report for 1992, Vol.2*, F.C. Kornegay (Project director), ES/ESH-31/V1.

Y-12 SITE

Water at Y-12, as at other sites, can be divided into three categories: effluents, ground water, and surface water. Note that in some cases surface water and ground water are hydraulically connected. This is the case for the Maynardville Limestone, which is primary exit pathway for ground water exiting the Bear Creek regime and for surface water within this area. Therefore, refer to the Y-12 ground water discussion for information regarding surface water.

EFFLUENTS

Personnel at the Y-12 Plant operate five on-site waste water treatment plants and numerous waste water collection facilities.

SURFACE/GROUND WATERS

Principal ground water contaminants that exceed applicable reference standards at the Y-12 Plant include volatile organics, nitrates, heavy metals, and radioactivity. Of these, nitrate and volatile organic compounds are the most common, although data obtained since 1988 suggest that the extent of some radionuclides may also be significant. Trace metals, the least extensive ground water contaminants, generally occur in a small area of low pH ground water at the west end of the plant in the vicinity of the S-3 site.

The *1992 Oak Ridge Environmental Report, Vol. 2* contains analytical summaries for all monitoring wells included within the comprehensive monitoring plan. The tables show all analytical parameters that exceeded detection limits in CY1992. Analytical data from multiport-instrumented coreholes are currently maintained in a separate database and are not presented in the summary tables. These data may be found in Dreier et al. (1993) pending incorporation into the ground water monitoring program historical database.

Radionuclide Contamination

The primary alpha-particle-emitting radionuclides found in the Bear Creek and East Fork Poplar Creek regimes are uranium, isotopes of radium, neptunium, and americium. The primary beta-particle-emitting radionuclide is technetium. Other sources of beta are tritium and strontium. Note that beta-emitting contaminants are not discussed in the following sections.

In the Chestnut Ridge regime, volatile organics and trace metals are the only categories in which findings currently consistently exceed background levels. Gross alpha and beta activities sporadically exceeded screening levels in samples taken from wells at the Chestnut Ridge Security Pits, Industrial Landfill III, and in wells up-gradient of Landfill II. No discernible pattern or consistency to the data was noted.

East Fork Poplar Creek

Ground water with gross alpha activity above 15 pCi/L occurs in scattered points within the East Fork regime. Gross alpha activity consistently above 15 pCi/L occurs only in two wells near the Salvage Yard and the S-2 Site (GW-633 and GW-251, respectively), one well (GW-204) at Tank 0134-u, and one well west of New Hope Pond (GW-605). Previous data have also suggested an area of elevated gross alpha activity west of New Hope Pond. Gross alpha activity exceeding the maximum contamination level is most extensive in ground water in the unconsolidated zone. During 1992, in bedrock-monitoring wells, gross alpha activity exceeded 15 pCi/L only at one location, west of New Hope Pond.

Bear Creek

Uranium, neptunium, americium, and naturally occurring isotopes of radium (Ra-236) have been identified as the primary alpha-particle-emitting radionuclides in this regime. Evaluations of the extent of these radionuclides in ground water during 1992 were based on gross alpha activity. If the annual average gross alpha activity in well samples exceeded 15 pCi/L, the maximum contamination level for gross alpha activity, then one or more of the alpha-emitting radionuclides were assumed to be present in the well.

Elevated gross alpha activity occurs in ground water in the vicinity of the S-3 Site, the Bear Creek Burial Grounds, and the Oil Landfarm waste management areas. In the bedrock interval gross alpha activity exceeds 15 pCi/L in ground water in the Nolichucky Shale near the S-3 Site and the western sides of the Bear Creek Burial Grounds and the Oil Landfarm waste management areas. Data obtained from exit-pathway wells installed in 1991 and 1992 show that gross alpha activity in ground water in the Maynardville Limestone exceeds the maximum contamination level for several thousand feet west of the S-3 Site. Elevated gross alpha activities were observed in six exit pathway spring and stream monitoring locations.

Exit-pathway monitoring began in 1989 to provide data on the quality of ground water and surface water exiting the Bear Creek regime. The Maynardville Limestone is the primary exit pathway for ground water. Bear Creek, which flows across the Maynardville Limestone in much of the Bear Creek regime, is the principal exit pathway for surface water. Various studies have shown that surface water in Bear Creek and ground water in the Maynardville Limestone are hydraulically connected.

Ground water quality data obtained during 1992 from the exit-pathway monitoring wells suggest that the horizontal and vertical extent of ground water contamination in the Maynardville is greater than previously reported. Nevertheless, the 1992 data obtained from wells located along the western-most picket (Picket W) indicated that contaminated ground water generally does not occur beyond the western side of Bear Creek Burial Grounds waste management area.

A preliminary review of the 1992 surface water data collected indicates that spring discharges and water in upper reaches of Bear Creek contain many of the compounds found in the ground water. Concentrations in the creek and spring discharges, however, decrease rapidly with distance downstream of the waste disposal sites.

Based on the 1992 data, uranium and strontium are the most common trace metal contaminants in Bear Creek. Concentrations of both metals exceeded background levels throughout reaches of the creek upstream of BCK 9.40. Moreover, uranium concentrations in the creek exceeded background levels at the farthest downstream sampling point (BCK

0.63). Uranium concentrations in spring effluents exceed background levels as far west as the SS-5 location. Annual average gross alpha activity exceeded 15 pCi/L at all the sampling points along Bear Creek with the exception of BCK 0.63, and in spring discharges west as far as SS-5.

Chestnut Ridge

Gross alpha activities from four wells were above 15 pCi/L in samples from a maximum of one quarter during 1992. Samples from two wells exhibited elevated gross alpha activities during two quarters in 1992.

Exit-pathway monitoring in this regime follows a different approach from that for the other two regimes. Contaminant and ground water flow paths in the karst bedrock underlying the regime are not best identified through conventional monitoring techniques. Dye-tracer studies are used to identify exit pathways; springs and surface streams that represent discharge points for ground water can be identified for water-quality monitoring. Two such studies have been done. The second study shows no conclusive occurrences of dyes at the monitoring points and does not corroborate data for detection points in the first study. Work is underway to improve future dye-tracer studies in this regime.

Sources of Uranium Contamination

Upper East Fork Poplar Creek Regime

Operable unit (OU) 2, the abandoned **Nitric Acid Pipeline**, was used to transport a nitric acid/depleted uranium waste stream from Building 9215 to the S-3 Ponds for disposal. It has been determined that numerous leaks occurred during the period of its use, which was 1951 to 1983.

OU 3 consists of several sites that are responsible for ground water contamination. The **S-2 Site**, an unlined earthen reservoir used from 1945 to 1951, contained waste materials, which include natural and enriched uranium. The **Salvage Yard Scrap Metal Storage Area** has been used from 1950 to the present to store scrap metal, some of which contains low-level depleted or enriched uranium. Some minor contamination of surficial soils at the site has been recorded. Waste oils containing contaminants, including uranium, are stored in **Salvage Yard Oil/Solvent Drum Storage Area**. Some spills and leaks of these waste oils have occurred. The **Coal Pile Trench** was used to dispose of materials, including uranium and depleted uranium alloys.

Other sites are sources of ground water contamination as well. Sediments found in the **New Hope Pond** contain contaminants, including uranium. The **Beta-4 Security Pits** site was used for classified disposal of uranium and uranium alloys, scrap metal containing depleted and enriched uranium, and other wastes.

Bear Creek Regime

OU 1 consists of several sites that are responsible for ground water contamination. The nature and extent of soil contamination within each of the OU 1 units, and the nature and extent of sediment and surface water contamination within each associated tributary to Bear Creek, will be determined during the CERCLA investigation.

The **S-3 Site** originally consisted of four unlined surface impoundments for waste, which included uranium in nitric acid solution. Nitrates and uranium were the primary contaminants. The **Oil Landfarm** consisted of three areas where waste oils and collants were applied to nutrient-adjusted soil during dry months of the year to enhance biodegradation. These oils and coolants contained contaminants, including depleted uranium. About one million gallons of waste oil were applied to soils between 1973 and 1982. The **Boneyard/Burnyard** consists of about eight acres used from 1943 to 1970 as a disposal site for waste from the Y-12 Plant. Burning and disposal of radioactive wastes are known to have occurred. **Bear Creek Burial Grounds** waste management area includes several waste disposal units designated as Burial Grounds A, B, C, D, E, and F, and two ponds (Oil Retention Ponds Nos. 1 and 2). Burial Grounds A and C received liquid wastes and solid wastes, including uranium metal, metal oxides, and metal saw-fines.

OU 2 consists of the Rust Spoil Area, Spoil Area 1, and the SY-200 Yard (not used for disposal or storage of waste materials). The **Rust Spoil Area** was used between 1975 and 1983 for the disposal of Y-12 solid wastes, which may have included uranium. Although **Spoil Area 1** has been used primarily for non-radioactive construction debris, past plant practices indicate that some of the material may have been contaminated with trace amounts of contaminants, including uranium.

OU 3 consists of the Bear Creek floodplain sediments. Bear Creek has received contaminated surface water and ground water discharges from past waste management practices in the Bear Creek and S-3 waste management areas. While contamination has been drastically reduced since these operations ceased, principal contaminants, including uranium, remain in floodplain soils and sediments.

OU 4 addresses contamination within the coupled ground water/surface water system and downstream transport of Bear Creek channel deposits. Channel sediments are not included in OU 3 because, once in the stream channel, sediments are directly coupled with the surface water flow pathway. Primary ground water contaminants are nitrates, VOCs, radionuclides, and (to a lesser extent) trace metals. DNAPLs have been discovered at a depth of 270 feet below the Burial Grounds.

Chestnut Ridge (CR)

Of the waste disposal sites located in this regime, only the OU 1, which consists of the **Security Pits**, has been confirmed as a source for ground water contamination. The Security Pits were operated between 1973 and 1988. The site was a series of trenches used for disposing classified hazardous and non-hazardous wastes, including uranium.

The impact of OU 2, which consists of the **Filled Coal Ash Pond** (Ash Disposal Basin) and **Upper McCoy Branch**, is of concern to surface water, stream sediments, and ground water from metals, including uranium. Biomonitoring of aquatic organisms in McCoy Branch and Rogers Quarry has shown a potential biological impact from the ash pond operations.

OU 3, or the **United Nuclear Corp. (UNC) Site**, received nitrate-contaminated low-level radioactive wastes and contaminated equipment packaged in 55-gallon drums and in boxes in 1987. About 33,000 barrels of waste were placed in the site. Ground water data from 1989 did not suggest contamination. Contaminated soils from the off-site Elza Gate Site cleanup were placed as fill into the UNC disposal site prior to capping in 1992.

OU 4 consists of **Rogers Quarry** and **Lower McCoy Branch**, which begins at the surface water discharge point of the quarry. Fly ash and bottom ash from the Y-12 steam plant and other plant process materials were disposed in the Quarry beginning in the 1960s. Impacts to surface water, stream sediments, and ground water from metals, including uranium, are of concern. Biomonitoring of aquatic organisms in Rogers Quarry has shown a potential biological impact from the ash disposal operations.

Other waste sites are the CR Sediment Disposal Basin, Kerr Hollow Quarry, East CR Waste Pile, Industrial Landfill II, Industrial Landfill III, and Industrial Landfill IV. The **Sediment Disposal Basin** received soil and sediment that was periodically dredged from New Hope Pond beginning in 1973 as well as mercury-contaminated soils from the Y-12 Plant. Ground water monitoring is continuing under RCRA interim status. The **Kerr Hollow Quarry** was used for the disposal of reactive materials from the Y-12 Plant and ORNL. Ground-water monitoring is continuing under RCRA interim status. The **East CR Waste Pile** is a lined RCRA-permitted hazardous waste storage facility constructed in 1987 as a storage site for contaminated soils from the Y-12 Plant. **Industrial Landfill II**, also known as the Y-12 Plant Centralized Sanitary Landfill II, is a TDEC-permitted solid waste disposal facility. It is used as a disposal site for combustible and decomposable solid wastes. **Industrial Landfill III**, also known as the CR Borrow Area Waste Pile, was constructed as a storage facility for soils removed from the Oak Ridge Civic Center properties and the Oak Ridge Sewer Line Beltway. Soils in both areas contained mercury and other metals (and possibly VOCs) that originated from the Y-12 Plant. Contaminant releases to the ground water system have not been detected since monitoring began in 1986. **Industrial Landfill IV** is a TDEC-permitted solid waste disposal facility that has operated since 1989 for disposal of non-hazardous, non-radioactive industrial wastes.

K-25 Site

EFFLUENTS

One of two effluent streams from the Central Neutralization Facility (CNF) contains small quantities of uranium contamination from the uranium recovery facility. This stream also contains metals from the metal cleaning facility and effluents from the TSCA Incinerator. The other stream contains only coal pile and steam plant effluents. These waste streams are treated at the CNF before discharge.

SURFACE WATER

Reference surface waters of the K-25 site are sampled and analyzed to determine the impact of the plant to the public and environment and to differentiate the impacts from other ORR operations. Perimeter surface waters that were tested in 1992 were the Clinch River, West Fork Poplar Creek, and Mitchell Branch. According to the *1992 Oak Ridge Environmental Report*, data do not indicate any effects from the K-25 Site operations to the perimeter surface water.

Surface waters that have the greatest potential for radioactive emissions because of the facilities operating nearby are K-1700 and K-1407-J NPDES points. The K-1203 sewage plant has the second greatest potential for radioactive emissions, followed by the K-1407-E/F ponds. The K-1007-B and K-901-A ponds have the least potential because no process effluents entering these ponds should contain radioactivity. The K-1515-C point receives backwash from the sanitary water plant. Its intake is on the Clinch River, so the potential for contamination from K-25 does not exist. However, contamination from the Clinch River may concentrate in the filter backwash.

The isotopic analyses for radioactivity in both ambient surface water and NPDES programs are based on past and current plant operations. Isotopic analyses include U-234, U-235, U-236, Tc-99, Cs-137, Np-237, Pu-238, and Pu-239. Only the K-1407-J outfall (011) is monitored for total uranium, total radioactivity, and isotopes analysis for NPDES reporting purposes. Most of the values are well below the DCGs, and the sum of the fractions of the DCGs are all less than 1.0 (see Table 4.84, Vol.2).

GROUND WATER

The K-25 Site Ground Water Program consisted of 206 ground water quality monitoring wells in 1992. Organics are the most commonly detected contaminants in ground water at the K-25 Site. Elevated levels of gross alpha and gross beta radioactivity have been detected in a number of wells. Uranium and ⁹⁹Tc, respectively, appear to be primarily responsible for the elevated gross alpha and beta activities. The metals chromium, lead, arsenic, and barium have been detected in a number of wells at levels exceeding drinking water standards. Elevated levels of fluoride have been detected in some wells; polychlorinated biphenyls (PCBs) have also been detected at a few wells.

K-25 LOGIC DIAGRAM INFORMATION

Technology Needs

If uranium must be removed from ground water at the K-25 Site, the concentrations are expected to be so low that an adsorbent or ion exchange material may be used. The priority for development should be aimed in that direction. Decisions to treat ground water or surface waters at the K-25 Site for uranium removal should be based on the potential risk of human exposure, and that depends on the water flow path as well as the uranium concentration in the water.

Anion exchangers, which remove uranyl complexes are very specific for uranium and are likely to remove only a few other metals such as iron. However, they would require adding ligands to complex the uranium and additions would be undesirable, especially for large streams.

Cation exchangers can be expected to remove essentially all soluble uranium, but their selectivity would be limited. That means that large fractions of the other cations in the stream would also be removed, often including more Ca, Na, etc., than uranium. When the uranium is removed for disposal, either by disposing the resin or eluting the uranium and disposing salts of the eluted cations. These additional salts will add to the waste volume.

Another option may be to precipitate and coagulate the uranium like conventional water treatment. After digesting the uranium, it could be precipitated or adsorbed on the coagulant. The concentration of uranium in the ground water at the K-25 Site is believed to be so low that precipitation of the uranium alone would not be practical. Although coagulants are usually inexpensive, coagulation by itself may not result in the lowest potential waste volume. This option would have to be considered because of the cost for the disposal of uranium-contaminated solids.

With reverse osmosis, there will generally be little separation of uranium from other dissolved mineral matter. Therefore, it would be advantageous to separate the uranium from the other salts stream. A number of recovery options such as solvent extraction could be explored for this highly concentrated solution. Other reagents can be used to aid the separation. In high sulfate or chloride solutions, uranium can be separated from most other metals by anion exchange. In chloride solutions, ferric iron will also follow uranium in ion exchange separations.

Evaporation could be used to concentrate the salts to dryness and packaging for disposal. Evaporation can be used for moderate-sized streams, and natural evaporation in surface waters will be significant.

Process waste water at the K-25 Site is processed in the Central Neutralization Facility. Priority pollutants are removed through neutralization and coprecipitation (with the addition of appropriate chemicals), clarification, and filtration. The facility includes mixing tanks, chemical addition equipment, pumps, piping, monitoring equipment, dewatering equipment, and settling basins. CNF processes approximately 100,000 gallons per month of hazardous and non-hazardous aqueous wastes.

Costs

Existing ion exchange materials can remove uranium effectively, but new methods could reduce the cost. Costs for ground water is usually given in dollars per 1,000 gallon. Technology costs for soil treatment of greater than 100 to a few hundred dollars/ton were considered high. Costs in this range were considered medium and costs significantly lower than this range were considered low. For ground water treatment, costs of a few dollars per 1,000 gallon were considered medium, and costs above or below this range were considered high or low. It is important to realize that many costs are higher within DOE facilities because of such factors as additional safety, regulatory documentation, etc., required when there is the potential for even traces of radioactivity being present.

ORNL SITE

EFFLUENTS

ORNL effluents were not specifically addressed.

SURFACE WATER

Melton Hill Dam (MHD) and White Oak Creek (WOC) headwaters, two locations above ORNL discharge points, serve as references for other water sampling locations at the ORNL site. Water samples are collected from the reference sites and from six on-site streams: WOC, Melton Branch, First Creek, Fifth Creek, Northwest Tributary, and Raccoon Creek. Sampling for radiological analyses is conducted at six ambient stations around ORNL and at five NPDES locations.

In 1992, Gallaher and Kingston station testing included an analysis for total uranium. If gross alpha test results of MHD, WOC Headwaters, and White Oak Dam were >1 Bq/L, the samples were also analyzed for Am-241, Cm-244, Pu-238, Pu-239, Th-228, Th-230, Th-233, U-234, U-235, and U-238. Refer to Table 4.53 in Vol. 2. Only three ambient stations showed average radionuclide concentrations greater than 5 per cent of the appropriate derived concentration guide (DCG). No average radionuclide concentration exceeded 30 per cent of its DCG. Total radioactive strontium was the only radionuclide concentration greater than 5 per cent of DCG at the three ambient stations.

Total uranium at Gallaher was significantly greater than zero. At Kingston, Cs-137, Co-60, and total uranium were significantly greater than zero. Note, however, that drinking water standards for total uranium, Cs-137, and Co-60 have not been established. The laboratory method used for total uranium does not permit a test of significance for the maximum and minimum, but the average concentrations at Gallaher and Kingston are less than 0.9% of the gross alpha standard. The total uranium measurement is converted to an activity by assuming natural abundance of uranium isotopes U-234, U-235, and U-238.

GROUND WATER

At ORNL, about 250 known potential waste sites are grouped into 20 waste area groupings (WAGs), of which 11 are being monitored along their boundaries for ground water quality. WAGs allow a suitably comprehensive ground water and surface water monitoring system to be established in a far shorter time than one required to handle every facility, site, and solid waste management unit (SWMU) individually. Some WAGs share common boundaries, but each WAG represents distinct small drainage areas within which similar contaminants may have been introduced.

Ground water quality monitoring wells for the WAGs are designated as upgradient or downgradient (perimeter), depending on their location relative to the general direction of ground water flow. Upgradient wells are located to provide samples that are not expected to be affected by possible leakage from the site. Downgradient wells are positioned along the perimeter of the site to detect possible ground water contaminant migration from the site. One hundred seventy-three perimeter monitoring wells have been installed.

Of the 20 WAGs identified by the RCRA Facilities Assessment, 13 have been identified as potential sources of ground water contamination. Additionally, there are a few areas where

potential remedial action sites are located outside the major WAGs. Sampling and analyses have been conducted for several years at WAG 6 and WAG 1. WAG 6 is an active disposal area, and WAG 1 is considered a high-priority location for investigation. The investigations at the other WAGs have been initiated to collect preliminary data, but are lower-priority sites.

In an effort to provide a basis for evaluation of analytical results and for assessment of ground water quality at ORNL WAGs, drinking water limits and DOE-derived concentration guides have been used in preparation of the data presented in Volume 2. Note, however, that the authors emphasize it is unrealistic to assume that members of the public are going to drink ground water from ORNL WAGs.

WAG 1

WAG 1, the ORNL main plant area, contains about one-half of the remedial action sites identified to date by the Environmental Restoration Plan. Most of the WAG 1 sites were used to collect and to store low-level waste in tanks, ponds, and waste treatment facilities. Some also include landfills and spill and leak sites identified during the last 40 years. Because of the nature of cleanup and repair, it is not possible to determine which spill or leak sites still represent potential sources of release. Most of the solid waste management units are related to ORNL's solid and liquid radioactive waste management operations.

Radionuclides have been detected in a number of the wells: H-3, total radioactive strontium, gross alpha, and gross beta activities above drinking water limits. The highest levels of radioactivity continue to be observed in Well 812. Gross alpha activity (300 pCi/L unfiltered and filtered) has been determined in the past to consist mainly of U-234, U-235, and U-238. However, alpha isotopic analyses were not performed in 1992.

WAG 2

WAG 2 is composed of WOC discharge points and includes the associated floodplain and subsurface environment. It represents the major drainage system for ORNL and the surrounding facilities. There is little doubt that WAG 2 represents a source of continuing contaminant release (radionuclides and/or hazardous chemicals) to the Clinch River. While it is known that WAG 2 receives ground water contamination from other WAGs, the extent to which WAG 2 may be contributing to ground water contamination is yet to be determined.

WAG 3

WAG 3 is composed of three solid waste management units: solid waste storage area (SWSA) 3, the Closed Scrap Metal Area (1562), and the currently operating Contractors' Landfill (1554). SWSA 3 and 1562 are inactive landfills known to contain radioactive solid wastes and surplus materials generated at ORNL from 1946 to 1979. Records of the composition of radioactive solid waste buried in SWSA 3 were destroyed in a fire in 1961. Sketches and drawings of the site indicate that alpha and beta-gamma wastes were segregated and buried in separate areas or trenches. Chemical wastes were probably also buried in SWSA 3 because there are no records of disposal elsewhere. It is not possible to estimate the amount of contamination that exists in this solid waste management unit.

The Contractors' Landfill was opened in 1975 and is used to dispose of various uncontaminated construction materials. No contaminated waste or asbestos solid waste is to be buried at the site.

WAG 4

WAG 4 is comprised of the SWSA 4 waste disposal area, liquid low-level waste (LLLW) transfer lines, and the experimental Pilot Pit Area (Area 7811). SWSA 4 has received a wide variety of poorly characterized wastes (including radioactive waste) from about 50 agencies. LLLW was transported from storage tanks at the main ORNL complex to waste pits and trenches in WAG 7, and later to the hydrofracture site through underground transfer lines. Area 7811 has three large concrete cylinders containing experimental equipment embedded in the ground. It has a control building and asphalt pad that have been used for storage.

WAG 5

WAG 5 contains 28 sites, 13 of which are tanks that were used to store LLLW prior to disposal by the hydrofracture process. It also includes the surface facilities constructed in support of both the old and new hydrofracture facilities. The bulk of the area is SWSA 5 and the Transuranic Waste Storage Area. The remaining sites are support facilities for ORNL's hydrofracture operations, two LLW pipeline leak/spill sites, and an impoundment in SWSA 5 used to dewater sludge from the original Process Waste Treatment Facility. At present, LLW tanks at the new hydrofracture facility are being used to store evaporator concentrates pending a decision regarding ultimate disposal of these wastes.

WAG 6

WAG 6 consists of three SWMUs: SWSA 6, the emergency waste basin, and the explosives detonation trench. Various radioactive and chemical wastes were buried in trenches and auger holes at the 68-acre SWSA 6 site. SWSA 6 is the only currently operating disposal area for low-level radioactive waste at ORNL. The emergency waste basin, which has never been used, was constructed to provide storage of wastes that could not be released from ORNL to White Oak Creek. Nevertheless, radiological sampling of the small drainage from the basin has shown the presence of some radioactivity, the source of which is not known.

WAG 7

The major WAG 7 sites are the seven pits and trenches used for the disposal of liquid LLW. It also includes a decontamination facility, three leak sites, a storage area containing shielded transfer tanks and other equipment, and seven fuel wells used to dispose acid solutions containing primarily enriched uranium from Homogeneous Reactor Experiment fuel.

WAG 8

WAG 8 is composed of 35 SWMUs that are associated with the reactor facilities in Melton Valley. They consist of active LLLW collection and storage tanks, leak/spill sites, a contractors soils area, radioactive waste ponds and impoundments, chemical and sewage

waste treatment facilities, a chemical-waste SWSA, and a mixed-waste SWSA. WAG 8 includes the Molten Salt Reactor Experiment facility and the High Flux Isotope Reactor, the Transuranium Processing Plant, and the Thorium-Uranium Recycle Facility. Radioactive wastes from these facilities are collected in on-site LLLW tanks and periodically pumped to the main plant area (WAG 1) for storage and treatment. Because of the small number of ground water monitoring wells in WAG 8 (9 wells) and WAG 9 (2 wells), they are sampled together. The analytical results for the two WAGs are also reported together.

WAG 9

WAG 9 is composed of three SWMUs: the Homogeneous Reactor Experiment pond, which was used to hold contaminated condensate and shield water from the reactor; LLLW collection and storage tanks; and a septic tank for treating sewage from Building 7501. Because of the small number of ground water monitoring wells in WAG 8 (9 wells) and WAG 9 (2 wells), they are sampled together. The analytical results for the two WAGs are also reported together.

WAG 10

WAG 10 consists of the injection wells and grout sheets associated with two hydrofracture process experimental locations: the Old Hydrofracture Facility (OHF) and the New Hydrofracture Facility (NHF). The facilities themselves are associated with WAGs 5, 7, and 8. Waste injected in Hydrofracture Experiment Site 1 was water tagged with Cs-137 and Ce-141. Grout consisted of diatomaceous earth and cement. Experiments at Site 2 used radioactive tracers instead of actual waste. Cs-137-tagged water, cement, and bentonite were used in the grout. Wastes used in experiments at the OHF included concentrated LLLW, Sr-90, Cs-137, Cm-244, transuranics, and other unidentified radionuclides. Wastes used in NHF experiments were concentrated LLLW and sludge removed from Gunit tanks, Sr-90, Cs-137, Cm-244, transuranics, and other nuclides.

WAG 11

The White Wing Scrap Yard (WAG 11) was used for the aboveground storage of alpha-, beta-, and gamma-contaminated equipment and material from ORNL, the K-25 Site, and the Y-12 Plant. Information regarding possible hazardous waste contamination has not been found and the amount of material or contaminated soil remaining in the area is not known.

WAG 17

WAG 17 served as the major craft and machine shop area for ORNL. The area includes the receiving and shipping departments, machine shops, carpenter shops, paint shops, lead-burning facilities, garage facilities, welding facilities, and material storage areas. It is composed of eight SWMUs; a former septic tank now used as a sewage collection/pumping station for the area; and seven tanks used for waste oil collection and storage and for storage of photographic reproduction wastes.

RESERVATION TREATMENT FACILITIES

The following information was obtained from the *Conceptual Site Treatment Plan for Mixed Wastes on the U.S. DOE Oak Ridge Reservation*, which was prepared for DOE Office of Environmental Restoration and Waste Management by Energy Waste Management Organization (Oct. 1993). According to this study, there are two classes of wastes for which treatment technology exists but the following condition applies: there is no on-site treatment capacity yet shipment for off-site treatment is prohibited. These two classes are: 1) mixed wastes that require pretreatment prior to treatment at existing facilities and 2) wastes that are potentially contaminated with radionuclides and, by default, mixed waste.

The wastes in the latter group were previously sent off-site for treatment and disposal. However, concerns about the unrestricted release of potentially contaminated materials has resulted in these wastes being stored on-site. There are currently 188,700 kg aqueous liquid and slurry waste contaminated with both organic and inorganic hazardous constituents in storage on the ORR. The quantity generated annually is estimated to be 75,000 kg. These wastes include all or portions of IMWIR streams 2098, 2100, 2104, 2110, 2115, 2116, 2461, 2462, 2475, 2476, 2488, 2494, 2496, 2519, 2520, 2551, and 2604, plus one stream not included in the IMWIR, FFCA 1B-34.

Five existing facilities will be used for neutralization treatment of mixed waste. These facilities are described below. Table 4-3 provides an overview of all of the onsite treatment facilities at the ORR.

1. The Central Neutralization Facility (CNF), located in Building K-1407H at the east end of K-25 Site, will be used to process certain liquid wastes generated from ORR operations. The CNF operates in a batch mode involving physical and chemical processing steps, including pH adjustment, precipitation, centrifugation, filter press filtration, and carbon adsorption. This facility is designed to process 0.9 million kg/day of liquid waste. About 50 to 60 per cent of the design capacity is currently being used to process waste water at the K-25 Site. The CNF is permitted under the National Pollutant Discharge Elimination System (NPDES) of the Clean Water Act. The NPDES permit for CNF was reissued on October 1, 1992.
2. The K-1232 Treatment Facility, located on the southwest corner of the K-25 Site, can be used to provide custom treatment in a batch mode. Capabilities include neutralization, centrifugation, and carbon filtration. This facility is permitted by rule as the liquid effluents are transferred to CNF for further treatment. K-1232 has a design capacity of approximately one million gallons/year, but presently is in a standby mode.
3. The Central Pollution Control Facility (CPCF) located in Building 9623 at the Y-12 Plant will be used to process some liquid wastes generated from ORR operations. The CPCF is designed to treat mop water and concentrated wastes and operates in batch and semi-batch modes. The processing steps include oil/water separation, neutralization, precipitation, flocculation, coagulation, settling and decanting, carbon adsorption, and cartridge filtration. Building 9623 also houses the Plating Rinsewater Treatment Facility, which employs pH adjustment, electrochemical reduction, and filtration to remove contaminants from plating rinsewater. Advance treatment processes may be used in the future. The CPCF is permitted under the NPDES of the Clean Water Act, which was issued in November 1985. The CPCF is designed to process waste water at the rate of 0.03 million kg/day. Currently, the CPCF is operating at 50 to 60 per cent of design capacity.

4. The WETF, located in Building 9616-7 at the Y-12 Plant, will be used to process various liquid waste waters that are not treated at the CPCF. The treatment scheme at the WETF includes biological treatment, pH adjustment, coagulation, flocculation, sedimentation, filtration, and carbon adsorption. Advanced treatment options may be added as necessary in the future. The WETF is designed to process waste water at a rate of 0.03 million kg/day. Currently, the WETF is operating at 50 to 60 per cent of design capacity. This facility is permitted under the NPDES of the Clean Water Act.
5. The Non-radiological Wastewater Treatment Plant (NRWTP), located in Building 3608 at ORNL, will be used to process identified corrosive wastes generated from ORR operations. The processing steps include pH adjustment, chemical precipitation, air stripping, and carbon adsorption. The NRWTP is designed to process waste water at a rate of 4.1 million kg/day. Currently, the NRWTP is operating at 50 to 60 per cent of design capacity. This facility is permitted under the NPDES of the Clean Water Act. Neutralization of corrosive mixed wastes at this facility may be feasible and is being considered as a possible treatment option.

TABLE 4-3
OAK RIDGE RESERVATION ON-SITE TREATMENT
SYSTEMS OF INTEREST¹

FACILITY	SYSTEM STATUS	TREATMENT TYPE	OPERATING COST, \$/M ³	MAX. TECH. CAPACITY MIXED WASTES	
				M ³ (MGAL)/YR	KG/YR
Y-12 West End Treatment Facility ²	Existing	Neutralization, biodenitrification, clarification, cyanide destruction	2,000	9,469 (2.50)	9,469,000
Y-12 Pollution Control Facility (CPCF)	Existing	Neutralization, Oil/water separation, carbon adsorption	677	10,227 (2.70)	10,227,000
K-25 K-1232 Treatment Facility	Standby	Chemical precipitation, neutralization	325	7,000 (1.85)	7,000,000
K-25 Central Neutralization Facility	Existing	Neutralization, precipitation, carbon adsorption	71	120,000 (31.7)	120,000,000
ORNL Non-radiological Waste Treatment Facility	Existing	Chemical precipitation, filtration, carbon adsorption	5.3	1,511,941 (399)	1,511,949,000
Oak Ridge Mixed Waste Treatment Facility	Planned but unapproved	Acid dissolution for uranium removal	NA	2,206 (0.582)	3,750,200

¹ Includes facilities for which treatments that may apply to uranium removal (chemical precipitation, carbon adsorption, etc.) were listed.

² The West End Facility treatments do not seem to apply, but uranium is removed by precipitation.

Source: Extracted from *Conceptual Site Treatment Plan for Mixed Wastes on the U.S. DOE Oak Ridge Reservation*, prepared for DOE Office of Environmental Restoration and Waste Management by Energy Waste Management Organization, Oct. 1993, DOE/OR-1093.

APPENDIX 5: SAMPLE SITE ANALYSIS—FERNALD

EFFLUENTS

The Fernald site controls liquid effluents and treats them as necessary before they eventually enter Manhole-175. There, the effluents combine to form a single liquid stream before flowing to the Great Miami River.

DISCHARGES

In 1992, the site discharged an average of 2.2 million liters (580,000 gallons) of effluent into the river each day. Therefore, on average, each liter (0.26 gallon) of effluent discharged was combined with about 3,100 liters (820 gallons) of river water.

Approximately 436 kilograms (961 pounds) of uranium were discharged to the Great Miami River from Manhole-175. This was a reduction of 34 per cent (mass basis) as compared to 1991. Note that the amount discharged has been decreasing since 1988, at which time over 850 kg (1870 lbs) were discharged.

Approximately 159 kg (350 lbs) of uranium reached Paddy's Run through uncontrolled storm water runoff during 1992. This estimate is based on the amount of precipitation recorded at the airport rather than site data due to a software error at the site. An estimate of uranium in uncontrolled storm water runoff into Paddy's Run is made to the U.S. EPA. Fernald site personnel developed a general estimate of 2.8 kg (6.3 lbs) of uranium in the runoff to Paddy's Run for every inch of rain. This estimate reflects the completion of the Waste Pit Area Runoff Control Removal Action that now directs contaminated runoff from the waste pit areas to the BSL and has eliminated that source of contamination to Paddy's Run.

An Advanced Wastewater Treatment Facility is presently under construction to provide "best available technology" treatment of both storm water and process waste water before their discharge to the Great Miami River. An interim facility using similar technology was placed into operation at the SWRB in July 1992. Another interim system is expected to begin operation in 1993 to extract uranium from waste water discharged from the BSL.

SOURCES OF EFFLUENT

The first two sources of liquid effluent are **controlled contaminated storm water runoffs from the waste pit area**, which are collected and pumped to the Bionitrification Surge Lagoon (BSL).

The third source of liquid effluent is **perched ground water**, which is treated for VOCs and sent on to the Plant 8 Sump for further treatment. Following treatment at Plant 8, the liquid is sent to the contaminated side of the General Sump, and the leftover solids are drummed and stored as a low-level radioactive waste.

The combination of **plant effluent and pad storm water** is the fourth source of effluent, and it is sent directly to the contaminated side of the General Sump. All liquids from the contaminated side of the General Sump are combined and, if needed, are sent to the Plant 8 Sump where they are treated. If treatment is not required, they are sent on to the BSL.

At the BSL, runoff mixes with liquid from the contaminated side of the General Sump and the combined liquid effluent is treated in the Bionitrification Facility (BDN) towers to reduce nitrates. From there, the liquid flows through the BDN effluent treatment system, after which the combined treated effluent flows to the Interim Advanced Waste Water Treatment (IAWWT) System, where uranium may be removed before it flows to Manhole-175 and on to the Great Miami River.

The fifth through the eighth sources of effluent are all collected in the non-contaminated side of the General Sump. **Boiler plant blowdown** and **coal pile runoff** are collected in the coal pile runoff basin and, after clarification, are sent to the non-contaminated side of the General Sump. **Water plant effluent** and **Lime Sludge Ponds decants** are sent directly to the non-contaminated side of the General Sump. After settling, the liquids are then sent to Manhole-175, and the sludge is sent to the North Lime Sludge Pond.

The ninth and tenth sources of effluent are **sanitary sewage** and **liquid from the laundry**, which are processed at the Sewage Treatment Plant to remove biological contaminants. After treatment, the effluent is sent to Manhole-175 and on to the Great Miami River.

The eleventh and twelfth sources of effluent are produced from rain that has been collected by the **production area storm sewers** and **parking lot runoff**. Storm water runoff from the former production area is collected by a network of storm sewers that converge at Manhole-34. During dry weather, effluent is pumped to Manhole-175 by the Storm Sewer Lift Station (SSLS). During storm situations, the SSLS is deactivated and all runoff is permitted to flow to the Storm Water Retention Basin (SWRB). Here it mixes with runoff from the parking lot storm sewers and is allowed to settle. From the SWRB, the effluent is treated at the IAWWT before it is eventually pumped to Manhole-175 and on to the Great Miami River.

SURFACE WATER

During 1992, on an average day, 6.9 billion liters (1.8 billion gallons) of Great Miami River water flowed past the site's effluent line. The liquid effluent discharged to the Great Miami River resulted in a slight increase in downriver uranium concentration from the upriver location. However, the downriver concentrations were consistent with 1991. Paddy's Run continued to show effects of storm water runoff from the site through higher uranium concentrations. Although the average uranium concentration at the nearest offsite sampling location was just slightly higher than in 1991, it was only 1.2% of the DOE guideline for drinking. Table 5-1 lists statistics for the uranium that was discharged to the Great Miami River in 1992. Table 5-2 lists results of environmental monitoring activities in 1992.

TABLE 5-1
URANIUM DISCHARGED TO THE GREAT MIAMI RIVER:
FERNALD 1992

ISOTOPE ^a	TOTAL CURIES 1991	TOTAL CURIES 1992	1992 AVG. CONCENTRATION (pCi/L) ^b	STANDARD (pCi/L) ^c	% OF STANDARD ^d
Uranium-234	0.17	0.099	130 ^e	500	26.5
Uranium-235	0.0084	0.0057	7.7 ^e	600	1.3
Uranium-236	0.0061	0.0040	5.3 ^e	500	1.1
Uranium-238	0.22	0.14	180 ^e	600	30.2

^a Radionuclide concentrations in the plant effluent discharged to the Great Miami River through the effluent pipeline are determined from monthly or quarterly composites of daily, 24-hour continuous samples at Discharge 001 (Manhole-175).

^b Averages are flow weighted. To obtain Bq/L, multiply pCi/L by 0.037.

^c As stated in DOE Order 5400.5, "Radiation Protection of the Public and Environment."

^d Percent of standard relates to the average concentration. Where "less than" (<) is reported, the maximal possible value is assumed.

^e Average does not include May values. Insufficient sample to complete analysis.

Source: *Fernald Site Report for 1992*, prepared for U.S. DOE by the EPA, June 1993.

TABLE 5-2
TOTAL URANIUM IN SURFACE WATER: FERNALD 1992

GREAT MIAMI RIVER SAMPLING LOCATION

	W1: Upstream of Effluent Line	W3: Downstream of Effluent Line	W4: Downstream of Effluent Line
Number of samples	51	51	51
Concentration (pCi/L)			
Minimum	0.81	0.81	0.88
Maximum	1.6	1.7	1.7
Average	1.1	1.2	1.3
Standards* (pCi/L)	550	550	550
Percent of standard			
Minimum	0.15	0.15	0.16
Maximum	0.29	0.31	0.31
Average	0.21	0.23	0.23
pH**			
Minimum	7.7	7.7	7.7
Maximum	8.9	9.0	8.4
Average	8.4	8.4	8.4

PADDY'S RUN SAMPLING LOCATION

	W5: Upstream of the Site	W9: On-site	W10 US: On-site
Number of samples	48	50	38
Concentration (pCi/L)			
Minimum	0.47	0.68	0.81
Maximum	1.2	6.8	810
Average	0.74	2.0	85
Standards* (pCi/L)	550	550	550
Percent of standard			
Minimum	0.085	0.12	0.15
Maximum	0.21	1.2	150
Average	0.13	0.36	15
pH**			
Minimum	7.7	7.7	NL
Maximum	8.2	8.2	
Average	7.9	8.0	NL
	W10: On-site	W10DD: On-site	W10DS: On-site
Number of samples	38	46	38
Concentration (pCi/L)			
Minimum	0.81	0.41	1.1
Maximum	730	1800	680
Average	86	480	94
Standards* (pCi/L)	550	550	550
Percent of standard			
Minimum	0.15	0.015	0.20
Maximum	130	340	120
Average	16	87	17
pH**			
Minimum	7.5	NL	NL
Maximum	8.3	NL	NL
Average	8.1	NL	NL

	W11: On-site	W7: Downstream of the Site	W8: Downstream of the Site
Number of samples	21	21	48
Concentration (pCi/L)			
Minimum	1.3	2.2	1.2
Maximum	12	11	19
Average	6.3	6.4	2.8
Standards* (pCi/L)	550	550	550
Percent of standard			
Minimum	0.23	0.39	0.22
Maximum	2.2	2.1	3.4
Average	1.1	1.2	0.51
pH**			
Minimum	7.9	7.9	7.5
Maximum	8.3	8.4	8.2
Average	8.2	8.2	7.8

* Standards as listed in DOE Order 5400.5, "Radiation Protection of the Public and Environment." The standards are based on drinking 730 liters (about 200 gallons of water per year). The Fernald site compares data from the Great Miami River and Paddy's Run to these standards even though neither is designated as a public water supply by OEPA (OEPA Regulations, Vol. 1, 3475-1-21).

** Acceptable range, as defined in OEPA Regulation 3745-1-21, is 6.5-9.0.

GROUND WATER

Of the 844 analyses for total uranium at 216 on- and off-site wells, 85 showed concentrations above the proposed guideline. All off-site locations were in the South Plume area. Of the 26 Primary Drinking Water Standards, seven were detected above the standards in more than one well, and one showed an isolated detection at a single well in 1992. Also, detections above the Secondary Drinking Water Standards for iron, manganese, sulfate, and total dissolved solids were found in several wells.

ON-SITE WELL RESULTS

The highest concentration of uranium was 3,243 pCi/L, well above the proposed U.S. EPA standard of 13.5 pCi/L. This sample was drawn from Well 1085 in the glacial overburden directly beneath the northeast corner of the production area. Other above-guideline detections at this same location were 2,714 pCi/L and 2,702 pCi/L. Most above-guideline detections at the other sampled wells were below 689 pCi/L. Uranium concentrations in 82 other samples at 25 on-site and 12 off-site locations were also above the U.S. EPA drinking water guideline. (All 12 off-site locations were in the South Plume area, currently being addressed by a RI/FS removal action. Table 5-3 lists the results of the ground water environmental monitoring.

TABLE 5-3
COMPREHENSIVE FERNALD GROUND WATER SAMPLES WITH URANIUM
CONCENTRATIONS ABOVE 13.5 pCi/L (20 ppb)

WELL	LOCATION	SAMPLE DATE	CONCENTRATION (pCi/L)	CONCENTRATION (ppb)
1027	Pit 6	1/21	470	700
"	Pit 6	4/8	230	330
"	Pit 6	7/9	230	340
"	Pit 6	10/14	130	190
1031	SW side of Clearwell	4/21	34	51
1042	Production area	5/4	16	24
"	Production area	8/3	16	24
1076	K-65 silo area	6/30	39	57
1081	Pit 5	1/22	26	39
"	Pit 5	4/23	16	24
"	Pit 5	7/16	19	28
"	Pit 5	10/26	18	26
1082	Pit 6	1/22	460	680
"	Pit 6	4/23	430	640
"	Pit 6	7/16	390	580
"	Pit 6	10/26	370	550
1083	Pit 6	1/23	70	100
"	Pit 6	4/28	74	110
"	Pit 6	7/28	53	78
"	Pit 6	10/26	51	76
1085	Production area	4/9	2,700	4,000
"	Production area	7/13	3,200	4,800
"	Production area	10/15	2,700	4,000

WELL	LOCATION	SAMPLE DATE	CONCENTRATION (pCi/L)	CONCENTRATION (ppb)
1276	Production area	8/5	23	34
"	Production area	10/15	15	22
1336	Production area	6/25	98	150
"	Production area	9/16	95	140
"	Production area	12/2	110	160
1352	Production area	6/23	74	110
1357	Production area	6/23	30	45
1359	Production area	6/23	220	320
1360	Production area	6/23	23	34
"	Production area	6/23	24	35
"	Production area	12/2	200	290
1361	Production area	6/25	18	26
1523	Production area	5/12	15	22
"	Production area	8/11	16	24
"	Production area	10/13	20	29
1643	Pit 5	1/28	260	380
"	Pit 5	4/28	76	110
"	Pit 5	10/27	81	120
1644	Pit 4	1/28	78	120
"	Pit 4	4/28	60	89
"	Pit 4	10/27	59	87
1645	Pit 4	1/28	22	32
"	Pit 4	4/28	16	24
1646	Pit 4	1/28	690	1,000
"	Pit 4	4/28	290	430
"	Pit 4	10/27	490	730
1676	Pit 4	11/23	16	23
2008	South of BSL	5/4	14	21
2009	South Plume, on-site	9/2	17	25
2015	South Plume, on-site	2/18	80	120
"	South Plume, on-site	5/4	120	180
"	South Plume, on-site	8/19	110	170
2046	South Plume, on-site	8/31	160	240
"	South Plume, on-site	11/19	140	200
2084	Pit 4	1/23	14	20
"	Pit 4	4/15	14	21
2095	South Plume, off-site	9/1	88	130
"	South Plume, off-site	12/3	81	120
2106	South Plume, on-site	2/6	46	69
"	South Plume, on-site	5/20	41	60
"	South Plume, on-site	8/6	51	75
2125	South Plume, off-site	2/12	34	50
"	South Plume, off-site	3/17	29	42
"	South Plume, off-site	9/8	20	30
"	South Plume, off-site	12/2	17	25
2385	South Plume, on-site	11/3	100	150
"	South Plume, on-site	11/3	110	160
2387	South Plume, on-site	11/10	280	410

WELL	LOCATION	SAMPLE DATE	CONCENTRATION (pCi/L)	CONCENTRATION (ppb)
2545	South Plume, off-site	7/21	26	39
"	South Plume, off-site	9/23	35	52
"	South Plume, off-site	12/15	29	43
2546	South Plume, off-site	7/21	28	42
2550	South Plume, off-site	12/2	49	73
2551	South Plume, off-site	12/3	24	36
2552	South Plume, off-site	12/2	15	22
2624	South Plume, off-site	7/21	66	98
"	South Plume, off-site	9/22	55	82
"	South Plume, off-site	12/15	68	100
2821	K-65 silo area	10/22	22	32
2822	K-65 silo area	10/27	45	67
3001	K-65 silo area	1/15	14	20
3014	South Plume, on-site	5/26	14	21
3019	Pit 4	1/22	74	110
3019	Pit 4	7/15	38	56
3062	South Plume, off-site	3/17	22	32
"	South Plume, off-site	6/1	26	38
"	South Plume, off-site	9/8	27	40
3069	South Plume, on-site	2/6	24	35
"	South Plume, on-site	5/11	14	20
"	South Plume, on-site	8/11	14	20
"	South Plume, on-site	10/13	16	24
3084	Pit 5	1/23	100	150
"	Pit 5	1/23	100	150
"	Pit 5	4/27	320	470
"	Pit 5	4/24	320	480
"	Pit 5	7/15	110	160
"	Pit 5	10/22	42	62
3125	South Plume, off-site	9/2	41	60
"	South Plume, off-site	12/2	51	76
3689	South Plume, off-site	9/22	26	39
"	South Plume, off-site	9/22	28	41
"	South Plume, off-site	12/1	26	38

Source: *Fernald Site Report for 1992*, prepared for U.S. DOE by the EPA, June 1993.

PRIVATE WELL RESULTS

Four private wells had average concentrations of uranium above the proposed U.S. EPA standard of 13.5 pCi/L. Site personnel also monitored private wells for 16 different metals. Iron and manganese were found in many wells. These detections are not unusual for an area with high natural concentrations of these metals such as near the Fernald site.

Only wells 12, 13, 15, and 17 exceeded the U.S. EPA proposed standard in 1992. Well 12 had a high reading of 170 pCi/L in 1988, but has dropped to 102 pCi/L in 1992. Well 13 has showed increasing uranium concentrations over the last several years. It jumped from 3.5 pCi/L in 1991 to 20 in 1992. In 1992, an ion exchange system was installed at this location. Results from this system indicate that uranium concentration in the treated water is within the background range for this area. Well 13 is located just south of the site, in an area of known ground water contamination. The uranium-contaminated water in this area, known as the South Plume, will be pumped from the aquifer as part of the South Ground Water Contamination Plume Removal Action. Well 15 had a high reading of 190 pCi/L in 1988, but has dropped to 154 pCi/L in 1992. Well 17 had a high reading of 38 pCi/L in 1988, but has dropped to 25 pCi/L in 1992.

TABLE 5-4
URANIUM IN PRIVATE WELLS: FERNALD 1992

WELL NUMBER	NUMBER OF SAM- PLES	CONCENTRATION (pCi/L)			% OF STANDARD ^a		
		MIN.	MAX.	AVG.	MIN.	MAX	AVG.
1	12	0.07	0.20	0.09	0.50	1.5	0.67
3	12	0.07	0.27	0.10	0.50	2.0	0.71
4	12	0.88	1.14	1.2	6.5	11	8.8
7	12	1.1	1.4	1.2	8.0	11	8.9
8	12	0.41	0.74	0.61	3.0	5.5	4.5
9	12	0.81	1.5	1.0	6.0	11	7.7
10	12	0.14	0.68	0.41	1.0	5.0	3.0
11	12	0.95	1.8	1.2	7.0	14	9.2
12*	12	31	207	102	230	1,500	760
13*	24	9.5	3.4	20	70	255	150
14	12	1.2	1.7	1.5	9.0	13	11
15*	12	135	176	154	1,001	1,300	1,100
16	11	0.27	1.1	0.52	2.0	8.5	3.9
17*	9	19	34	25	140	250	180
18	12	0.27	0.47	0.31	2.0	3.5	2.3
19	12	0.07	0.20	0.08	0.50	1.5	0.63
21	12	0.20	0.27	0.25	1.5	2.0	1.8
22	12	0.61	3.3	0.96	4.5	24.5	7.1
23	12	0.34	0.74	0.52	2.5	5.5	3.8
24	12	0.20	0.47	0.37	1.5	3.5	2.8
25	4	0.20	0.34	0.29	1.5	2.5	2.1
26	12	0.07	0.41	0.18	0.50	3.0	1.3
27	10	0.27	0.54	0.44	2.0	4.0	3.3
28	4	0.61	0.68	0.66	4.5	5.0	4.9
29	11	0.95	1.6	1.3	7.0	12	10
30	4	0.27	0.34	0.29	2.0	2.5	2.1

WELL NUMBER	NUMBER OF SAM- PLES	CONCENTRATION (pCi/L)			% OF STANDARD ^a		
		MIN.	MAX.	AVG.	MIN.	MAX	AVG.
32	12	0.07	0.41	0.11	0.50	3.0	0.83
33	9	0.27	0.47	0.35	2.0	3.5	2.6
35	12	1.1	1.4	1.2	8.0	10	8.9
36	12	0.47	1.1	0.70	3.5	8.0	5.2
37	1	---	---	0.68	---	---	5.0
38	3	0.20	0.41	0.29	1.5	3.0	2.2
39*	12	3.2	5.9	4.5	24	44	33
40*	12	1.8	2.9	2.2	14	22	16
41	12	0.20	0.74	0.41	1.5	5.5	3.0
55	4	0.20	0.34	0.29	1.5	2.5	2.1
56	2	0.41	0.41	0.41	3.0	3.0	3.0

* Wells 12, 13, 15, 17, 39, and 40 are used for monitoring purposes only.

^a Proposed U.S. EPA standard of 13.5 pCi/L (20 ppb).

Source: *Fernald Site Report for 1992*, prepared for U.S. DOE by the EPA, June 1993.

APPENDIX 6: POTENTIAL SOURCES OF FUTURE WATER CONTAMINATION

SOIL AND RELATED MEDIA (SLUDGE, SEDIMENTS, BURIED MATERIALS)

The problem units listed in Table 6-1 resulted from a search of the *Crosswalk* database using the keyword combination "uranium and soil." This table also includes related problem units that were identified through other keyword searches. Also included are those that were discovered as a result of other keyword searches but also met the criteria for this category. Those not specifically listing uranium as a contaminant are indicated by an asterisk.

**TABLE 6-1
SOIL AND RELATED MEDIA PROBLEM SUMMARY**

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PAL011*	Discrete Sites	Soil	Organics, LLW, TRU, metals	Unknown
PAL012	Firing Sites	Soil	Metals, LLW, depleted U, PCB, organics, high explosives (TNT, PBX, RDX)	Widespread low level
PAL014*	Outfalls	Soil	Unknown	Unknown
PAL018	Explosives/Weapons Test Sites	Soil	Metals	Locally high
PAL047	Firing Sites	Soil	HE, metals, and possibly depleted uranium	Unknown
PCH017	Chemical Disposal Site	Soil	LLW, metals (Th, U); inorganics (Cr, Hg, Tl, Th, U, CN, Be); asbestos	Low
PCH024*	Waste Concentra- tion Facility Storage Tanks and Under- ground Pipelines	Potentially contaminated soil; metals (debris); and ground water	LLW. The tanks previously held sludge from BGRR with mixed fission products (Cs137 and TRU).	Unknown
PCH026*	Current Landfill	Sediments	LLW, Fe, Pb, Mn, H3	Drinking water standards exceeded for Fe, Pb, Mn, H3, trichloroethane
PCH027*	Former Landfill	Soil, ground water	LLW	Unknown
PCH030*	Hazardous Waste Management Area-- Soil	Soil	LLW, organics	Unknown

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PCH037*	Upland Meadow Marsh	Soil, ground water	H3, possible organics and metals in soil	H3 below NYS standard
PCH051*	Recharge Basin HN	Soil, ground water, surface water	Radionuclides, metals	Not provided
PFN040	Operable Unit 1	Buried material	U, Th, F, sulfates	Low-level waste
PFN044	Operable Unit 3	Soil	U, minor Th, PCBs, DCE, TCE, Pb	Low level
PFN051	Berm Soils	Soil	U, Th, Ra likely, possible Pb, As, Cr, Cd	Undetermined
PFN055	Operable Unit 5--Environmental Media	Soil	LLW (U, Th, Tc)	64 pCi/g onsite (mostly U); 13 pCi/g offsite (mostly U)
PFN056	Operable Unit 5--Environmental Media	Sludges	LLW (U, Th, Tc)	None given
PID011	ICPP—High-level Waste Tank Farm (WAG 3)	Soil	Cr, Hg, Ag, Cd, Se, I129, Sr90, Cs137, U234, Pu239, Pu241, sulfuric and nitric acids	Locally very high
PNV019	Underground Nuclear Test Locations	Soil	Sr90, Zr95, Nb95, Ru103, Sb124, I131, Ba140, Ce141, Ce144, Nd147, Te132, Cs136, Np239, U237, Pb, Be, heavy metals, organics	Classified, not fully identified. Millions of curies.
POR001	Buried Material in the K-25 Area	Buried material	TCE, U, Tc99, PCB, Th232, solvents, oils, heavy metals, toluene, asbestos	Unknown
POR003	Soil in the K-25 Area	Soil	TCE, U, Tc99, Se, Cr3, Cr6, Th, PCB, PCP, As, oils, toluene, asbestos, solvents, heavy metals, radioactive PCB	18 to 22 ppm chromate

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
POR009	Soil at Non-New Jersey FUSRAP Sites	Soil	U, Ra226, Th232, PCB, Pb, As, heavy metals, some RCRA waste	PCB: none to 100 ppm; heavy metals: background to <10,000 ppm; 70% by volume total activity 5 to 1000 pCi/g; 30% by volume total activity 1,000 to 200,000 pCi/g Not provided
POR011	Drums of Material at Non-New Jersey FUSRAP Sites	Process sludges	U, Ra226, Pb, As, PCB, asbestos	
POR012	Soil at New Jersey FUSRAP Sites	Soil	Th232, U, Ra226, As, heavy metals, PCBs	80% of volume, total activity 1,000 pCi/g; 20% of volume, total activity 100 to 10,000 pCi/g. Heavy metals 1,000 to 10,000 ppm. PCBs: ND to 100 ppm
POR015	Weldon Spring RAP Raffinate Pit Sludge/Quarry Bulk Waste	Sludge	U, Th230, Ra, heavy metals, nitroaromatics, PCBs	U up to 6,000 pCi/g; nitroaromatics up to 20,000 mg/kg. Ra up to 3,600 pCi/g; Th230 up to 270,000 pCi/g; As up to 6,271 (average 500) mg/kg; and Pb up to 644 (average 130) mg/kg Up to millions of Curies, high concentrations
POR021	Buried Materials at X-10	Buried material	Cs137, Sr90, H3, U, Co60, Hg, Pb, Cr, Cd, heavy metals, I129, Tc99, TRU, asbestos, radioactive biological waste, some solvents	
POR023*	On-site Sediments at X-10	Sediments	Cs137, PCB, Co60, As, Hg, Sr90, H3, TRU	Cs: 100,000 pCi/g; PCB: low ppm to 100 ppm; As: 5 to 100 ppm; Hg: >100 ppm
POR027	Soil at Portsmouth	Soil	PCB, U, TCE, Pb, UF6, petroleum products, heavy metals	PCB>200 ppm; TCE>200 ppm
POR029	Buried Materials at Paducah	Buried material	TCE, Tc99, U, PCB, radioactively contaminated PCB	Unknown
POR032	Sediments at Paducah	Sediments	PCB, U, Cr	Unknown

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
POR033	Soil at Paducah	Soil	TCE, PCB, U, BETX, Cr, radioactively contaminated PCB, DNAPL	Unknown
POR035	Buried Material at Y-12	Buried material	PCB, U, Hg, Pb, Cr, Cd, Th232, Be, pyrophoric U, chlorinated solvents, creosote, heavy metals	Unknown
POR037	Soil at Y-12	Soil	PCB, Hg, U, Th, Be, Pb, Cd, Cr, TCE, DNAPLs, chlorinated solvents, heavy metals, long-chain hydrocarbons, creosote	Not available
PRF004	903 Pad	Soil	Pu, Am, U, chlorinated solvents, Se	Up to 500 pCi/g plutonium at the outside lip of the pad
PRF005	903 Pad	Buried material	Pu, U, organics, metals	Pu at 55 pCi/L, U at 1.2×10^6 pCi/L; VOC: 100s ppb
PRF009	Off-site	Soil	Pu, Am, U	< 1 to 7 pCi/g (state standard 0.9 pCi/g)
PRF011	Solar Evaporation Ponds	Soil	Organics, U, nitrates, metals, sulfates	10 to 1,000 times background for metals
PRF014	700 Area	Soil, ground water	Acids, algicides, bases, Be, CCl4, chromate, caustics, fluorides, hydrocarbons, metals, nitrates, organics, solvents, and radionuclides	Unknown
PRL007	100 Area Burial Grounds	Buried material	H3, Cr, Sr90, Tc99, U, Hg, nitrates, PCB, TCE. Many other contaminants in lower concentrations	Not listed

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PRL014	200 Area Single-Shell Tanks (SSTs)	Sludges	Al, Cr, F, Fe, FeCN, Mn, Ni, nitrites, nitrates, phosphates, OH, Cs137, Sr/Y90, Pu239, Am241, U238, C14, Tc99, and I129; TRUs present	1.2E08 curies
PRL015	200 Area Cribs/Liquid Disposal Units/Vadose Zone	Soil	Extensive list of metals, inorganics and organics, and radionuclides	Locally very high
PRL016	200 Area Cribs/Liquid Disposal Units/Vadose Zone	Soil	Extensive list of metals, inorganics and organics, and radionuclides	Locally very high
PRL021	200 Area Piping	Soil	Extensive list of metals, radionuclides, inorganics and organics	Locally high
PRL023	200 Area Burial Grounds	Buried material	LLW (may be some HLW or TRU)	Varies
PRL025*	200 Area Waste Waters	Ground water, sludges	Organics, metals, TRU, LLW, ammonia, nitrates, mixed waste	Unknown
PRL026	300 Area Ponds/Trenches/Cribs/Vadose Zone	Soil	U, other radionuclides, metals, trace PCB	Unknown
PSR011	F&H Inactive Process Sewer Lines	Soil, ground water	H3, Cd, Pb, Hg, U234, U238, I129, Tc99, Cs137, Sr90, Ra226, Np237, nitrate, chromium	High (tritium)
PSR014*	Burial Ground Complex	Buried material	Hg, C14 on resin, TRU, organics, LLW, Ag, Pb, Cd, waste oil, solvent rags, H3 in crucibles	Up to very high locally (total 19E06 curies)

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PSR016	Miscellaneous Basins	Soil	U, Cs, Sr, Ag, As, Ba, Cd, Cr, Pb, Se, Hg, SO ₄ , Zn, Ni, Mn, Mg, Am, Ra, Th, Cl, Cu, Na	Above background
PSR017	R-Area Seepage Basin	Soil, ground water	Sr90, Cs137	2700 Ci disposed in 1954 through 1964; half-decayed

* Does not specifically list uranium as a contaminant but are included because KEI believes they are likely to have it or are contaminated by components that may be potential candidates for removal by biosorbents

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

OTHER SOLID MEDIA

The information in Table 6-2 is included in this study because KEI believes that these problem units may eventually result in contaminated ground water, surface water, or effluents. Note that most of these were obtained as a result of other keyword searches. KEI did not specifically attempt to identify sources of future contamination as this is beyond the scope of this project.

TABLE 6-2
OTHER SOLID MEDIA PROBLEM SUMMARY

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
PCH024*	Waste Concentration Facility Storage Tanks and Underground Pipelines	Metals (debris), potentially contaminated soil and ground water	LLW. The tanks previously held sludge from BGRR with mixed fission products (Cs137 and TRU).	Unknown
PFN043	Fly Ash Pile/ Southfield	Other	U, Th, Ra, PCBs, Pb, and other heavy metals	Unspecified
PFN046	Operable Unit 3	Metals (debris)	U, Th, asbestos	Low level
PFN047	Operable Unit 3	Metals (debris)	U, Th	Low level

PU ID	PROBLEM UNIT	MEDIA	CONTAMINANT	CONTAMINANT CONCENTRATION
POR006	D&D for all ORO Gaseous Diffusion Plants	Masonry (debris)	U, PCB, Cr, Tc, Pb, As, PCP, dioxin, asbestos, daughter products, oils	U trace to Class C
POR008	D&D for the X-10 Area	Masonry (debris)	U, Pu, TRU, PCB, H3, asbestos, biological contaminated radioactive waste, various radionuclides, daughter products	Very high concentrations. Hot cells > 100 nCi/g

* Does not specifically list uranium as a contaminant but are included because KEI believes they are likely to have it or are contaminated by components that may be potential candidates for removal by biosorbents

Source: Extracted from *DOE Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.

APPENDIX 7: DEPARTMENT OF ENERGY CONTACTS

**TABLE 7-1
DOE OPERATIONS OFFICES**

Albuquerque Operations Office	P.O. Box 5400	Albuquerque	NM	87115	505-845-6307
Chicago Operations Office	9800 S. Case Ave.	Argonne	IL	60439	708-252-2428
Fernald Operations Office	P.O. Box 398705	Cincinnati	OH	45239- 8705	513-648-3101
Idaho Operations Office	785 DOE Place	Idaho Falls	ID	83402	208-526-1148
Nevada Operations Office	P.O. Box 98518	Las Vegas	NV	89193- 8518	702-295-0844
Oak Ridge Operations Office	200 Administrative Rd.	Oak Ridge	TN	37831	615-576-0715
Richland Operations Office	P.O. Box 550	Richland	WA	99352	509-376-7277
Rocky Flats Operations Office	P.O. Box 928	Golden	CO	80402	303-966-4888
San Francisco Operations Office	1301 Play St.	Oakland	CA	94612	510-637-1809
Savannah River Operations Office	P.O. Box A	Aiken	SC	29802	803-725-3966

TABLE 7-2
CONTACTS WITHIN DOE PROBLEM UNITS

PU ID	Facility/ Affiliation	ADDRESS	TELEPHONE/FAX	CONTACT
PAL001	Albuquerque Field Office (ALO)	5301 Central Ave. NE, Albuquerque, NM 87498,	505-845-5701/505-845-4053	G.L. Hartmann
PAL011 PAL012 PAL014	Los Almos National Laboratory (LANL)			Kelly Bitner
PAL018	Sandia National Laboratories (SNL)			Julianne Levings
PAL047	Pantex Plant/ Amarillo Area Office-DOE	P.O. Box 30030, Amarillo, TX 79120	806-477-3056/806-477-3185	Ted J. Taylog
PCH017	Ames Laboratory	115 Spedding, Ames, IA	515-294-2153/515-294-2155	Lowell Mathison
PCH024	Brookhaven National Laboratory (BNL)	BNL, Bldg. 51-M, Upton, NY 11973	516-282-5672/516-282-7776	A. Tope
PCH026 PCH027 PCH030 PCH037	Brookhaven National Laboratory (BNL)	BNL, Bldg. 51-M, Upton, NY 11973	516-282-7513/516-282-7776	J. Brower A. Raphael
PCH035	Brookhaven National Laboratory (BNL)	BNL, Bldg. 51-M, Upton, NY 11973	516-282-3806/516-282-7776	W.H. Medeiros
PCH051	Brookhaven National Laboratory (BNL)	BNL, Bldg. 51-M, Upton, NY 11973	516-282-2818/516-282-7776	Thomas Burke
PFN040	Fernald Environmental Management Project		513-738-6112/513-738-6184	Rod Gimpel
PFN043 PFN044 PFN046 PFN047	Fernald Environmental Management Project			Not provided

PU ID	Facility/ Affiliation	ADDRESS	TELEPHONE/FAX	CONTACT
PFN045 PFN054	Fernald Environmental Management Project/ WEMCO		513-738-6146	Ken Broberg. Steve Oberjohn
PFN051	Fernald Environmental Management Project/ WEMCO		513-738-6182/513-738-8943	W.G. Tope
PFN055	Fernald Environmental Management Project/ WEMCO	P.O. Box 398704, Cincinnati, OH 45239	513-738-6144	Steve Oberjohn
PFN056	Fernald Environmental Management Project/ WEMCO		513-738-6997	R.W. Kneip M.W. Griffin, 513- 738-9266
PID004	Idaho National Engineering Laboratory (INEL)/ EG&G Idaho, ERD	P.O. Box 1625, Idaho Falls, ID 83415	208-525-5892/208-525-5980	J.R. Zimmerle
PID005	Idaho National Engineering Laboratory (INEL)/ EG&G Idaho, ERD	P.O. Box 1625, Idaho Falls, ID 83415	208-525-3935/208-525-5980	A Baumer C.S. Blackmore, ERD-208-525-3940
PID011 PID013	Idaho National Engineering Laboratory (INEL)/ WINCO	P.O. Box 4000, Idaho Falls, ID 83415-3202	208-526-1114/208-526-0665	D. Williamson
PID022	Idaho National Engineering Laboratory (INEL)/ EG&G Idaho, Inc.	P.O. Box 1625, Idaho Falls, ID 83415	208-525-5958/208-525-5960	L.V. Street
PNV019 PNV020 PNV021	Nevada Field Office		702-295-0160	Monica Salazar
POR001 POR002 POR003 POR004	K-25 Site/ER	P.O. Box 2003, MS 7256, K-25, Oak Ridge, TN 37831	615-576-3692/615-576-4048	Patty Goddard

PU ID	Facility/ Affiliation	ADDRESS	TELEPHONE/FAX	CONTACT
POR006	Oak Ridge Operations/MMES	P.O. Box 2003, Oak Ridge, TN 37831- 7325	615-576-0101/615-576-2390	R.K. Kibbe
POR008	Oak Ridge National Laboratory (ORNL)- D&D	Not listed	Not listed	Not listed
POR009 POR011 POR012	Formerly Utilized Site Remedial Action Project (FUSRAP)/DOE- ORO FSRD	P.O. Box 2001, Oak Ridge, TN 37831- 8723	615-576-9634/615-576-0956	Dave Adler Grady Maraman, 615-576-3948
POR015	Weldon Spring Remedial Action Project/WSSRAP ED/CD	Not listed	314-441-8086/314-447-0803	John Enger
POR017	Weldon Spring Remedial Action Project/WSSRAP, Env. Compliance	Not listed	314-441-8086/314-447-0803	Shawn Murray Glen Schmidt
POR021 POR022 POR023	Oak Ridge National Laboratory (ORNL)	P.O. Box 2003, Oak Ridge, TN 37831- 7298	615-574-6795/615-574-9538	Jack Watson
POR027 POR028	Portsmouth Gaseous Diffusion Plant/ MMES Portsmouth	P.O. Box 628, Piketon, OH 45601	615-897-2331/614-897-3752	Jim Campbell
POR029 POR030 POR031 POR032 POR033	Paducah Gaseous Diffusion Plant/ MMES	Not listed	614-355-6126	Dennis Cope
POR035 POR036 POR037 POR039	Nuclear Weapons Component Facility	Not listed	615-576-5364	Steve Walker Gary Boldenstein
PRF003	Rocky Flats Site Office/EG&G Rocky Flats	P.O. Box 464, Bldg. 080, Golden, CO 80402	303-966-8550	C.B. Gee J. Koffer
PRF004 PRF005 PRF006	Rocky Flats Site Office/EG&G Rocky Flats	P.O. Box 464, Bldg. 080, Golden, CO 80402	303-966-8550	E. Dille

PU ID	Facility/ Affiliation	ADDRESS	TELEPHONE/FAX	CONTACT
PRF009	Rocky Flats Site Office/EG&G Rocky Flats	P.O. Box 464, Bldg. 080, Golden, CO 80402	303-966-8557/303-966-8556	M. Guillaume
PRF010 PRF011 PRF014B PRF013 PRF016 PRF019			303-966-8659/303-966-8556	Bruce Peterman
			303-966-7000	Randy Ogg
			303-966-8709	D. Schubbe
			303-966-8550	J. Koffer
PRL007 PRL015 PRL016 PRL017 PRL021 PRL023 PRL026 PRL029 PRL014	Richland Field Office (RLO)/WHC, Environmental Engineering	P.O. Box 1970, Richland, WA 99352	509-376-3753	J.G. Field
	Richland Field Office (RLO)/DOE- RL	Not listed	509-376-8409/509-376-9118	Steve Burnum
PRL025	Richland Field Office (RLO)	Not listed	Not listed	Not listed
PSF010	Laboratory for Energy-Related Health Research/DOE/SF	1333 Broadway, Oakland, CA 94612	510-273-7963/510-449-1737	R.H. Liddle
PSR009	Savannah River Field Office (SRO)/ER/ERT	MLB	404-821-7902	Michael Welty
PSR011 PSR017	Savannah River Field Office (SRO)/WSRC-ERD	1995 Centennial Ave. #4, Aiken, SC 29803	803-644-6777/803-644-6922	Tom Gagnan

PU ID	Facility/ Affiliation	ADDRESS	TELEPHONE/FAX	CONTACT
PSR012 PSR015 PSR023	Savannah River Field Office (SRO)/WSRC	SRS	803-644-6750	Cathy Lewis Scott Surovchak, 803-725-9762
PSR014	Savannah River Field Office (SRO)/ Assessments, Engineering	MLB 344	404-821-8014	Rana Frye-O'Bryan Doug Wyatt
PSR016	Savannah River Field Office (SRO)/ DOE-SR	Not listed	803-725-5912	Daniel Taylor
PSR021A	Savannah River Field Office (SRO)/ DOE-SR	P.O. Box A, Aiken, SC	803-725-9762/803-725-3611	Scott Surovchak

Source: KEI

TABLE 7-3
CONTACTS FOR URANIUM-CONTAINING LIQUID
WASTE STREAMS

Ames Laboratory	Contaminated vacuum pump oil	Robert Staggs	515-294-7922
Argonne National Lab.	Radioactive corrosive waste--TRU	Paul Day	708-972-7966
	Radioactive flammable waste	Same	Same
Bettis Atomic Power Laboratory	PCB oil; MSF-002	James D. Sage	412-476-7293
	Spent M-192 solvent; MSF-006	Same	Same
Fernald Environmental Management Project	Cleanout sludges (gen. sump, MEF#50068)	C.S. Waugh	513-738-6777
	Contaminated solvents (MEF#50096)	Same	Same
	Contaminated water (MEF#50022)	Same	Same
	Non-recoverable trash (MEF#50002, 50010, 50014)	Same	Same
	Sludges, salt, soft, chloride (MEF#50175)	Same	Same
	Solvent sludges (MEF#50071)	Same	Same
	Sump water and hydraulic oil (MEF#50072)	Same	Same
	GJPO remedial action project waste	David Naski	303-248-6064
	Sandia aquifer sample	Tom Kirkpatrick	303-248-6587
	Miscellaneous acids	Elizabeth C. Elliott	502-441-6319
Paducah Gaseous Diffusion Plant	PCB flush solvent	Debra L. Smith	Same
	PCB waste oil/oily solutions	Same	Same
	PCB wastewater	Same	Same
	PCB water	Same	Same
	PCB liquid (slurry)	Same	Same
Portsmouth Gaseous Diffusion Plant	Waste oil	Terry Acox	614-897-6415

Source: HAZWRAP Information and Data Systems

TABLE 7-4
CONTACTS FOR DOE-DEVELOPED TECHNOLOGIES

TNA ID	Site/ Affiliation	ADDRESS	TELEPHONE/FAX	CONTACT
TAL009	Los Alamos National Laboratory (LANL)	Inc.-1, M/S J514 , Los Alamos, NM 87545	505-665-1755/505-665-4955	Ines Triay
TAL011	Los Alamos National Laboratory (LANL)	Inc.-1, M/S C346, Los Alamos, NM 87545	505-667-0150/505-665-3166	James Brainard
TAL046	Sandia National Laboratories (SNL)	P.O. Box 5800, Dept. 6622, Albuquerque, NM 87185	505-844-3820/505-844-8170	Eric R. Lindgren
TAL054	Sandia National Laboratories (SNL)	P.O. Box 5800, Dept. 6907, Albuquerque, NM 87185	505-844-5571/505-844-1480	Art DuCharme Charlie Voss, 206- 833-0777
TAL064	Los Alamos National Laboratory (LANL)/ Nuclear Matl. Tech. Div.	Inc.-1, M/S E501, Los Alamos, NM 87545	505-665-0822/505-665-1780	Gordon Jarvinen
TAL064	Pantex Plant/ Amarillo Area Office-DOE	P.O. Box 30030, Amarillo, TX 79120	806-477-3056/806-477-3185	Ted J. Taylog
TAL065	Los Alamos National Laboratory (LANL)	Not listed	505-665-5338/505-665-4355	B.R. Erdal
TCH013	Argonne National Laboratory (ANL)	9700 S. Cass Ave., Argonne, IL 60439	708-252-4513/708-252-5246	George Vandegrift
TCH021	Argonne National Laboratory (ANL)	9700 S. Cass Ave., Argonne, IL 60439	708-252-6677/708-252-5912	N. Beskid
TID002	Idaho National Engineering Laboratory (INEL)/ MSE, Inc.	Not provided	W. Goldberg	406-723-8213
TID011	Idaho National Engineering Laboratory (INEL)/ EG&G Idaho	P.O. Box 1625, Idaho Falls, ID 83415	208-526-6991/208-526-5142	Don Maiers G. Andrews P. Wichlacz
TID018	Idaho National Engineering Laboratory (INEL)/ EG&G Idaho, Inc., Sci. & Tech.	P.O. Box 1625, Idaho Falls, ID 83415	208-526-5917/208-526-6802	Peter Shan
TNV001	Nevada Test Site/ REECo	Not listed	702-575-0536	Wayne A. Bliss
TNV004	Nevada Test Site/ REECo	Not listed	702-575-0536	Harrison Kerschner
TOR009	Oak Ridge National Laboratory (ORNL)	P.O. Box 2008, Oak Ridge, TN 37831- 6044	615-574-2210/615-576-4195	T.L. Donaldson
TOR027	Oak Ridge National Laboratory (ORNL)	P.O. Box 2008, B- 3504, MS-6317, Oak Ridge, TN 37831	615-574-1857/615-574-1420	C.W. Francis

TNA ID	Site/ Affiliation	ADDRESS	TELEPHONE/FAX	CONTACT
TOR028	Oak Ridge National Laboratory (ORNL)	P.O. Box 2008, MS-6492, Oak Ridge, TN 37831-6492	615-576-1555/615-574-2673	Anthony Armstrong
TOR030	Oak Ridge National Laboratory (ORNL)	Not listed	615-576-0484	B.D. Faison
TOR036 TOR042	Oak Ridge Operations (ORO)/WEMCO	Not listed	513-738-6677	K.R. Nuhfer
TRL016 TRL034	Richland Field Office (RLO)/Westinghouse Hanford Co.	P.O. Box 1970, MISN S4-25, Richland, WA 99352	509-373-2967/509-373-5044	Craig V. King
TRL033	Richland Field Office (RLO)/Westinghouse Hanford Co.	P.O. Box 1970, Richland, WA 99352	509-373-3513/509-373-5044	Kent Hodgson
TRL038	Richland Field Office (RLO)/PNL	P.O. Box 999, MS P-7-43, Richland, WA 99350	509-376-0467/509-376-1867	James Duncan
TRL051	Richland Field Office (RLO)/PNL	P.O. Box 999, MS P-7-43, Richland, WA 99350	509-376-3777	John R. Morrey
TSR007	Savannah River Field Office (SRO)/WSRC	Not listed	803-725-3515	L.O. Dworjanyan
TSR010	Savannah River Field Office (SRO)/SRTC	Westinghouse Savannah River Co., SRS, Aiken, SC 29808	803-725-5212/803-725-7673	Ed Wilde
TSF011	Lawrence Livermore National Laboratory (LLNL)	P.O. Box 808, L-524, Livermore, CA 94550	510-423-2043/510-422-8020	Kevin Langry

Source: KEI

TABLE 7-5
CONTACTS AT THE DOE TREATMENT FACILITIES

Site/ Affiliation	FACILITY	CONTACT-	TELEPHONE
Energy Technology Engineering Center	Radioactive Materials Disposal Facility	B. Bassatt	818-586-5556
Fernald Env. Man. Project	Plant 8 VOC Treatment System	Barry Ko	513-738-6786
Fernald Env. Man. Project	UMM Treatment Facility	Same as above	Same as above
Hanford Site	242-A Evaporator	Dale Black	509-376-8458
Hanford Site	242-A/Purex Effluent Treatment Facility	Not listed	Not listed
Hanford Site	Pu Finishing Plant	Dan McBride	509-373-5698
Hanford Site	Water Disposal		
	Waste Receiving and Processing Facility	Dale Black	509-476-8458
Idaho National Engineering Lab	INEL Waste Generator Treatment	Jack Depperschmidt	208-526-5053
Idaho National Engineering Lab	Mixed Low-level Waste Treatment Facility (MLLWTF)	Not listed	Not listed
Idaho National Engineering Lab	Portable Water Treatment System (PWTU)	Dave Eaton	208-526-7002
Idaho National Engineering Lab	TAN 726-A Treatment	Same as above	Same as above
Lawrence Livermore National Lab	Area 514-1	Not listed	Not listed
Los Alamos National Lab	Hazardous Waste Treatment Facility	Stan Zygaunt	505-667-2245
Oak Ridge K-25 Site	K-1232 Wastewater Treatment Facility	T. Bowers	615-576-2629
Oak Ridge National Lab	Process Waste Treatment Plant	Chris Scott	615-574-7057
Oak Ridge National Lab	Non-radiological Waste Treatment Plant	Not listed	Not listed
Oak Ridge Y-12 Plant	Central Pollution Control Facility (CPCF)	J. Prazniak	615-574-6873
Oak Ridge Y-12 Plant	Ground Water Treatment Facility	K.R. Crow	615-574-6876
Oak Ridge Y-12 Plant	West End Treatment Facility	N.A. Valentine	615-576-1567
Paducah Gaseous Diffusion Plant	C-400-D Lime Precipitation Unit	R.G. Kuenhn	502-441-6913
Paducah Gaseous Diffusion Plant	Wastewater Treatment System	N.A. Valentine	615-574-7083
Portsmouth Gaseous Diffusion Plant	X-622 Ground Water Treatment Facility	T.A. Acox	614-897-6415
Portsmouth Gaseous Diffusion Plant	X-622T Ground Water Treatment Facility	Same as above	Same as above

Site/ Affiliation	FACILITY	CONTACT	TELEPHONE
Portsmouth Gaseous Diffusion Plant	X-623 Ground Water Treatment Facility	Same as above	Same as above
Portsmouth Gaseous Diffusion Plant	X-624 Ground Water Treatment Facility	Same as above	Same as above
Portsmouth Gaseous Diffusion Plant	X-701E Ground Water Treatment Facility	Same as above	Same as above
Portsmouth Gaseous Diffusion Plant	X-705 Decontamination Facility	Same as above	Same as above
Rocky Flats Plant	Aqueous Process Waste Treatment: Building 774	Bob Griffis	303-966-4934
Rocky Flats Plant	Mixed Residue Treatment	Dan Dustin	303-966-3809
Savannah River Site	F/H Area Effluent Treatment Facility	T. Syfert	803-557-0320
Savannah River Site	Hazardous Waste/ Mixed Waste Disposal Facility	J. Damelio	803-725-6479
Savannah River Site	M-Area Liquid Effluent Treatment Facility	J.B. Pickett	803-725-3838
Savannah River Site	SRL Ion Exchange Treatment Probe, High Activity	M. Spearman	803-725-8802
Savannah River Site	SRL Ion Exchange Treatment Probe, Low Activity	Same as above	
West Valley Demonstration Project	Integrated Radwaste Treatment System	Elizabeth Matthews	716-942-4930
West Valley Demonstration Project	Liquid Pretreatment System	Same as above	

Source: Extracted from *Conceptual Site Treatment Plan for Mixed Wastes on the U.S. DOE Oak Ridge Reservation*, prepared for DOE Office of Environmental Restoration and Waste Management by Energy Waste Management Organization, Oct. 1993, DOE/OR-1093.

APPENDIX 8: EPA CONTACTS

TABLE 8-1
EPA REGIONAL GROUND WATER AND DRINKING WATER
BRANCH CHIEFS

REGION/ADDRESS	GROUND WATER	DRINKING WATER
REGION I JFK Federal Building Boston, MA 02203	Jerome Healey 617-565-3610	Same
REGION II 26 Federal Plaza New York, NY 10278	Walter Andrews 212-264-1800	Same
REGION III 841 Chestnut St. Philadelphia, PA 19107	Virginia Thompson 215-597-2786	Stuart Kerzner 215-597-8227
REGION IV 345 Courtland St., N.E. Atlanta, GA 30365	Beverly Houston 404-347-3379	Wayne Aronson 404-347-2913
REGION V 77 West Jackson Blvd. Chicago, IL 60604	Jerri-Anne Garl 312-886-1490	Ed Watters 312-353-2650
REGION VI 1445 Ross Ave., Ste. 1200 Dallas, TX 75202	Eriece Allen 214-655-6446	Tom Love 214-655-7150
REGION VII 726 Minnesota Ave. Kansas City, KS 66101	Bob Fenemore 913-551-7033	Ralph Langemeier 913-551-7032
REGION VIII 999 18th St., Ste. 500 Denver, CO 80202-2405	James Dunn 303-294-1135	Patrick Crotty 303-293-1652
REGION IX 75 Hawthorne St. San Francisco, CA 94105	William Thurston 415-744-1817	Same
REGION X 1200 Sixth Ave. Seattle, WA 98101	Kenneth Feigner 206-553-4092	Same

APPENDIX 9: REPORT PARTICIPANTS AND OTHERS

TABLE 9-1A
REPORT PARTICIPANTS

CONTACT	TELEPHONE	DIVISION/ ORGANIZATION	COMMENTS
ENVIRONMENTAL PROTECTION AGENCY			
Auerbach, Jan	202-260-7575	Ground Water & Drinking Water	Involved in rule making for radionuclides.
Blanco, Bob	202-260-5522	Inforcement & Program Implementation	
Bonanno, Gail	202-233-9210	Air	Mill tailings regs.
Borum, Denis	202-260-8996	Human Risk Assessment	Radionuclide study
Brewer, Lawrence	202-260-8049		Works with Tim Gill, the radionuclides rule regs. manager.
Fiedler, Linda	703-308-8799		Proj. man. for <i>Cleaning Up the Nation's Waste Sites</i>
Hofthe, Barbara	202-233-9495	Radiation Programs	
Layton, Mike	301-504-2584	UMTRA	Hydrogeologist
Parott, Jack	301-504-2584	UMTRA	Hydrogeologist
Parrotta, Marc	202-260-3035	Ground Water & Drinking Water	
Puskin, Jerry	202-233-9212		
Richardson, Alan	202-233-9290	Ground Water	Regulations Researcher
Sorg, Tom	513-569-7370		
Wilheim, Ron	202-233-9379	R&D, Indoor Air Radiation	Radiation studies, soil chemist by training
DOE			
Ally, Moonis	615-576-8003	Oak Ridge, ORNL	
Brown, Don	813-545-6840	Pinellas	
Cheng, Sam	513-865-4778	Mound	
Crow, Kevin	615-574-6876	Oak Ridge, Y-12	
Estes, Lola	615-241-3098	Oak Ridge, RAPIC	
Faison, Brendlyn	615-576-0484	Oak Ridge, ORNL	
Fiedler, Elizabeth	615-435-3109	Oak Ridge, HAZRAP	
Fore, Kathy	615-435-3113	Oak Ridge, HAZRAP	
Francis, Chet	615-574-7257	Oak Ridge	
Golchert, Norbert	708-252-3912	Argonne	
Harrell, Skip	505-845-4752	Albuquerque Office	
Howard, Al	303-966-4888	Rocky Flats	
Hu, Michael	615-574-1208	Oak Ridge, ORNL	
Ingle, David	813-541-8940	Pinellas	
Johannson, Matt	509-376-9725	Hanford	

CONTACT	TELEPHONE	DIVISION/ ORGANIZATION	COMMENTS
DOE (Cont.)			
Jones, Larry	615-574-6019	Oak Ridge	Disposal/storage costs
Kent, Tim	615-576-8592	Oak Ridge	Disposal/storage costs
Mellington, Steve	702-295-0844	Nevada Test Site	
Metzler, Don	505-845-5657	Grand Junction	UMTRA site
Midcaff, Bill	505-667-7391	Los Almos	
Miltenburger	516-282-2503	Brookhaven	
Orban, Jim	505-845-4421	Albuquerque	
Otten, Jim	615-435-3137	Oak Ridge	
Paquette, Doug	516-282-7046	Brookhaven	
Robinson, Sharon	615-574-6779	Oak Ridge, ORNL	
Scanlan, Tom	615-574-4562	Oak Ridge	
Scott, Chris	615-574-7057	Oak Ridge	
Skintik, Ed	513-648-3151	Fernald	
Smith, Phillip	615-435-3472	Oak Ridge, HAZRAP	
Whitfield, Pat	202-586-6331	Washington, EM-40	
Williams, Josh	301-903-7179	Washington, WMIS	
PRIVATE INDUSTRY AND OTHER U.S. SOURCES			
Aldred, Derrek	615-581-8350	Recticel Foam	Foam costs
Anthony, Harry	512-595-5731	URI, Inc.	Uranium solution mining
Arechuk, Ken	713-796-9743	Foam Enterprises	Foam equipment costs
Blount, Jonathan	505-888-1300	Roy F. Weston	Geochemist
Bond, Michael	517-636-7305	Dow Chemical	Marketing Manager for Liquid Separations (referred by Bio-Rad's Peter Tunon)
Clifford, Dennis	713-743-4266	University of Houston	
Dagenhart, Vicci	615-483-9332	Scientific Sales	Vacuum oven, resin costs
Darnell, Ken	615-481-8002	Ogden	VP
Erickson, Steve	800-441-4369	Dow Chemical	Foam industry contacts
Fletcher, Darrell	704-553-5527	Dow Chemical	Sales rep (quantity pricing)
Forman, Forrest	615-629-6251	Culligan Commercial/ Industrial Systems	Water treatment equipment
Gibson, Jim	615-481-0222	SEG	Disposal costs
Gillen, Dan	301-492-7000	Nuclear Regulatory Commission	Geotech. engineer
Greenwell, Michael	404-639-0501	Dept. of Health & Human Services	Agency for Toxic Substances and Disease Registry
Hartman, George	505-888-1300	Gerrity & Miller	Geologist
Higgins, Erwin	615-483-7424	Tetra Tech	
Marston, Chuck	517-636-1000	Dow Chemical	Chemist, mining ion exchange applications expert

CONTACT	TELEPHONE	DIVISION/ ORGANIZATION	COMMENTS
PRIVATE INDUSTRY AND OTHER U.S. SOURCES (CONT.)			
Maynard, Dan	615-966-5430	TN Center for R&D	Databases
McGarvey, Frank	800-678-0020/609- 893-1100	Sybron Chemicals	Ion exchange
Mumford, Don	219-925-1073	Foamex	Grinder cost
Powers, Brian	713-978-3797	Dow Chemical	Resin sales
Spring, Jerry	419-289-2727	General Latex	Foam equipment costs
Tunon, Peter	800-4BIO-RAD	Technical	Large-quantity pricing
Walters, Daphne	404-639-0720	National Institute of Health	Agency for Toxic Sub- stance & Disease Registry
Wilcox, Cheryl	800-776-1314	Weapons Complex Monitor	Ed Helminski, Editor
Williams, Luke	615-481-2771	Ogden	
GERMAN			
James W. Frolich	011-49-0228- 442585/011-49- 0228-441018	Environmental & Energy Services Co., Inc.	
Dr. Wolfgang Goldammer	011-49-0221- 462196/011-49- 0221-448298	Brenk Systemplanung	
Dr. Manfred Hagen	011-49-0371-883- 669/011-49-0371- 882626	Wismut GmbH;	
Dr. Wolf-J Schmidt- Küster	011-49-0228- 441016/011-49- 0228-441018	IEAL Energie Consult GmbH	
POTENTIAL SOURCES NOT CONTACTED			
Bunger, Byron	202-233-9218	Air	Economist
Clark, Steve	202-260-3022	EPA Analytical Methods & Treatment Technology	Branch chief
Finklea, Sam	803-734-4910	NORM Committee	Chairman
Graul, Heinrich	011-49-69-2169- 247	Urangesellschaft	Referred by Harry Anthony, URI
Green, Dennis	303-234-0273	Harrison Western Environmental Services	Bio-Fix
Hardin, Charles	502-227-4543	Conference of Radiation Control Program Directors	Director

CONTACT	TELEPHONE	DIVISION/ ORGANIZATION	COMMENTS
POTENTIAL SOURCES NOT CONTACTED (CONT.)			
Johnson, Brad	202-501-9770	Bureau of Mines, Env. Tech. Div.	
Meck, Bob	Unknown	Military	Politics of cleanup standards (See Mike Webber)
Stitt, Mike	615-435-3411	HAZRAP	Back from position in Germany
Webber, Mike	301-504-1298		Works for Bob Meck
Source: KEI			

TABLE 9-2
MISCELLANEOUS GOVERNMENT OFFICES

AGENCY	ADDRESS	CITY/STATE	TELEPHONE
Bureau of Land Management, Public Affairs	Main Interior Building, Room 5600, 1849 C St. NW	Washington, DC 20240	202-208-3435
Bureau of Mines, Division of Environmental Technology	810 7th St. NW, MS 6205	Washington, DC 20241	202-501-9271
Bureau of Reclamation, Public Affairs Office Department of the Interior	1849 C St. NW	Washington, DC 20240-9000	202-208-4662
Conference of Radiation Control Program Directors	205 Capitol Ave.	Frankfurt, KY 40601	502-227-4543 (Director: Charles Hardin)
General Services Administration Safety & Environmental Management Division, Environmental Branch (PMS)	18th and F Streets NW, Room 4046	Washington, DC 20405	202-708-5236
Tennessee Valley Authority, Environmental Quality Staff	400 W. Summit Hill Dr., MS WT 8B	Knoxville, TN 37902	615-632-6578
U.S. Coast Guard, Environmental Affairs	2100 2nd St. SW	Washington, DC 20593	202-267-1587

APPENDIX 10: LIST OF REFERENCES

1. *Chemical Contaminants on DOE Lands and Selection of Contaminant Mixtures for Subsurface Science Research*, prepared by R.G. Riley and J.M. Zachara (Pacific Northwest Laboratory) and F.J. Wobber for the U.S. DOE Office of Energy Research, Subsurface Science Program, April 1992.
2. *Cleaning Up the Nation's Waste Sites: Markets and Technology Trends*, U.S. EPA, Solid Waste and Emergency Response (OS-110W), EPA 542-R-92-012, April 1993.
3. CompuServe search, "Uranium."
4. *Conceptual Site Treatment Plan for Mixed Wastes on the U.S. DOE Oak Ridge Reservation*, prepared for DOE Office of Environmental Restoration and Waste Management by Energy Waste Management Organization, Oct. 1993, DOE/OR-1093.
5. *Cost of Compliance With the Proposed Federal Drinking Water Standards for Radionuclides*, prepared by RCG/Hagler, Bailly, Inc. for the American Water Works Association, Water Industry Technical Action Panel; Oct. 10, 1991.
6. *Discussion Paper on Wastewater Treatment Issues at Wismut Properties*, Senes Consultants Ltd., March 1992
7. "Electrode Method Taps Polluted Ground Water," *Wall St. Journal*, 11/29/93.
8. *Engineering Economy*, 7th Ed., G.J. Thuesen and W.J. Fabrycky, Prentice Hall, NJ, 1989.
9. *Evaluation of Ground Water Extraction Remedies--Vol. 1 Summary Report*, U.S. EPA, Office of Emergency and Remedial Response, EPA/540/2-89/054, Sept. 1989.
10. *Federal Register*, Vol. 56, No. 138, Thursday, July 18, 1991. Proposed EPA rules changes.
11. *Fernald Site Report for 1992*, prepared for U.S. DOE by the EPA, June 1993.
12. *Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites*, U.S. EPA, Office of Environmental Engineering and Technology Demonstration, EPA/540-2-89/052, March 1989.
13. *Ground Water Handbook*, U.S. EPA, Office of R&D, Center for Environmental Research Information, ISBN 0-86587-761-0, Jan. 1989.
14. *Hawley's Condensed Chemical Dictionary*, 11th Ed., N. Irving Sax and R.J. Lewis, Sr., Van Nostrand Reinhold, NY, 1987.
15. "Indian Tree Offers Nuclear Waste Treatment," *Nature*, Vol. 365, Oct. 28, 1993.
16. *Materials Handbook 13th Ed.*, G.S. Brady and H.R. Clauser, McGraw-Hill Inc., 1991
17. *McGraw-Hill Encyclopedia of Engineering*, 2nd Ed., Sybil Parker, McGraw-Hill, New York, 1992, p.521 (Hazardous waste).
18. *McGraw-Hill Encyclopedia of Environmental Science and Engineering*, 3rd Ed., Sybil Parker and Robert Corbitt, McGraw-Hill, New York, 1993.
19. *Oak Ridge Reservation Environmental Report for 1992, Vol. 1*, F.C. Kornegay (Project director), ES/ESH-31/V1.
20. *Oak Ridge Reservation Environmental Report for 1992, Vol. 2*, F.C. Kornegay (Project director), ES/ESH-31/V2.
21. *Occurrence and Exposure Assessment for Uranium in Public Drinking Water*, prepared for the U.S. EPA, Office of Ground Water and Drinking Water, Mr. Denis Borum, by Wade Miller Associates, Contract No. 68-C0-0062.
22. *Regulatory Impact Analysis of Proposed National Primary Drinking Water Regulations for Radionuclides*, prepared by Wade Miller Associates, Inc. for the U.S. EPA Office of Drinking Water, EPA project manager: Steve Folsom, July, 1991.
23. *Risk Assessments--Environmental Impact Statement--NESHAPS for Radionuclides, Background Information Document, Vol. 2*, U.S. EPA, Office of Radiation Programs, EPA/520/1-89-006-1, Sept. 1989.

APPENDIX 10 (CONT.): LIST OF REFERENCES

24. *Sorbent Materials for Non-spill Application: Market Study*, S.A. Kaplan, C-132A, Business Communications Co., CT, April 1992.
25. *Sorbent Materials: Technical Review*, S.A. Kaplan, C-132B, Business Communications Co., CT, April 1992.
26. *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by V.J. Ciccone & Associates, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., Oct. 1985.
27. *Technology Needs Crosswalk Report*, 1st Ed., Chem-Nuclear Geotech, Inc., DOE/ID/12584-117, Jan. 1993.
28. *Technologies and Costs for the Removal of Uranium from Potable Water Supplies*, prepared by Malcolm Pirnie, Inc. for the U.S. EPA, Office of Drinking Water, Criteria and Standards Div., EPA project officer: Stephen W. Clark, Dec.30, 1986.
29. VISITT database.

REFERENCES THAT WERE NOT INCLUDED IN STUDY

30. Drury, D. Michelson, et. al., *Methods of Removing Uranium from Drinking Water*, ORNL/EIS-194, EPA-570-9-82-003, 1982.
32. Lee, S.Y. , White, S.K., et. al., *Methods of Removing Uranium from Drinking Water: II. Municipal Water Treatment and Potential Treatment Methods*, ORNL/EIS-194, EPA-570/9-82-003, 1982.
33. Malcolm Pirnie, Inc. for the U.S. EPA, *Technologies and Costs for the Treatment and Disposal of Waste By-products from Water Treatments for the Removal of Inorganic and Radioactive Contaminants*.
31. White and E.A. Bondietti, *Removing Uranium by Current Municipal Water Treatment Processes*, Journal AWWA 75(7):374-79, 1983.